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Typology of cocoa-based agroforestry systems of the semi-deciduous forest zone in Togo (West Africa)

Oyetounde DJIWA^{1,2*}, Hodabalo PEREKI² and Kudzo Atsu GUELLY²

¹Food and Agriculture Organization of the United Nations (FAO) 01 BP. 4388, Lomé, Togo.

²Department of Botany, Laboratory of Botany and Plant Ecology, University of Lomé, 01 BP 1515, Lomé, Togo.

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In the tropical zone, cocoa-based agroforest systems (CAFS) are considered as a mean to maintain and conserve biodiversity. In the sub-humid zone of Togo (West Africa), agroforest plant species are key components of the landscape and agricultural lands. Cocoa and coffee agroforest systems contribute directly and indirectly to the livelihoods of an estimated one million people in Togo. Despite this fact, there is only few informations regarding their structure, and typology. The current study assessed the typology, tree structure and diversity of cocoa-based agroforest systems. 213 random plots across the study area were sampled using variable areas (25 × 25 m², 50 × 50 m² and 100 × 100 m²) for the survey. 4766 non-cocoa trees belonging to 195 plant species, 140 genera and 47 families were identified. Only woody trees were recorded during this study. The estimated average tree density was 159.21 ± 97.58 trees/ha, whereas the basal area was 54.19 m²/ha. Based on the Importance Value Index (IVI), the floristic composition, and the frequency of species, six groups (from G1 to G6) were discriminated. Each group was a particular type of CAFS. These results are similar to those obtained in the CAFS of West, Central Africa and other tropical zones, confirming CAFS key role in forest trees diversity conservation.

Key words: Cocoa-based agroforest system, typology, sub-humid, forest tree diversity, Togo.

INTRODUCTION

Agroforests are qualified as agricultural lands of forest zone covered by more than 10% of woody trees (Zomer et al., 2009). In humid tropical areas, they are complex multispecies cropping systems whose value for farmers is often hard to assess (Jagoret et al., 2014). According to Correia et al. (2009), their multi-strata structure is shaped by a diversity of biological form and habitat (seedlings,

woody trees, lianas and herbaceous) in order to make their ecological functions similar to that of natural forests (de Foresta et al., 2000).

The important role of agroforest systems in general and of cocoa-based agroforest systems (hereafter referred to as "CAFS") in particular is well known over the world.

Agroforestry trees may enhance vegetable intake by

*Corresponding author. E-mail: Oyetounde.Djiwa@fao.org, oyedjiwa@hotmail.fr. Tel: +228 22210411, 90093551.

providing vegetables in the form of leaves and fruit from trees, but possibly also through the ecosystem services provided within agroforest systems likely support availability of wild and cultivated vegetables by providing the microclimates needed for vegetables to grow and other ecosystem services. Many studies demonstrated the direct link between CAFS and *in situ* biodiversity conservation in humid forest zones (Sonwa *et al.*, 2007; Jagoret *et al.*, 2008; Dumont *et al.*, 2014; Wartenberg *et al.*, 2017). CAFS are rich and diversified in terms of forest tree species (Sonwa *et al.*, 2007; Sonwa *et al.*, 2014). They control key ecological functions such as carbon storage, water and air regulation, soil protection and fertility maintenance, micro-climate regulation and shading. From smart agriculture perspective, it is widely accepted nowadays that CAFS in general could serve as useful and practical models to mitigate climate change issues in tropical zones, by reconciling productivity increase of lands, biodiversity conservation and use of forest biodiversity (Schroth *et al.*, 2016). From food safety, nutritional and rural livelihood perspectives, the potential of agroforestry products to contribute to incomes, and value for domestic consumption is well-recognized (Cerda *et al.*, 2014). Data on local flora of CAFS contribution in nutrition, human well-being and household incomes were published for different agroforestry products such as cocoa, timber, fruits, and other food crops (Akinnifesi *et al.*, 2008; Cerda *et al.*, 2014).

In Togo CAFS are found in the sub-humid zone of the country, and play key important socioeconomic and ecological roles (Adden, 2017). Despite their importance, only few studies assessed their typology, structure and floristic diversity. Most of existing studies did not consider tree diversity and species richness even if some of them recognized the conservation value provided by CAFS and qualified them as potential biodiversity conservation areas (Wembou *et al.*, 2017; Sodjinou *et al.*, 2019). Their assessment is often discussed in terms of productivity, yields and soil properties (Adden *et al.*, 2016) and cocoa diseases (Oro *et al.*, 2012) without qualitative and quantitative data on multi-species which shape CAFS multi-strata. Past studies in the sub-humid zone in Togo were focused on forest investigation (Akpagana, 1989; Adjossou, 2009; Issa, 2018) with less emphasis on CAFS. Up to now, research on biodiversity in agroforest systems are related to coffee based agroforest systems (Koudjega and Djekpor, 1997; Koda *et al.*, 2019).

Consequently, knowledge about CAFS relationships with biodiversity is still scarce compared to those in West Africa and other tropical cultivation zones. This gap causes a lack of information in the management of CAFS, which contrasts with their ecological and socio-economic potential.

To meet both productivity needs, pest and disease management, Koudjega and Tossah (2009) and Wegbe and Agbodzavu (2013) recommended to associate cocoa

trees with particular forest tree species such as *Albizia* spp., *Erythrophleum guineensis*, *Eleais guineensis*, *Citrus* spp., *Cola nitida*, *Khaya* spp., *Milicia excelsa*, *Samanea saman*, *Terminalia* spp., in Togo. This introduction of trees species needs to be based on a good understanding of the current species composition and typology of CAFS. The objective of this study is to analyze the tree diversity within and among CAFS in Togo and to determine their structure and typology as related to sustainable management practices.

MATERIALS AND METHODS

Study area

This study was carried out in the sub-humid and mountainous zone in Togo, located at the south-western part of the country and bordering Ghana. It extends between 6°57' and 7°35' latitude North and 0°30' and 1°08' longitude East (Figure 1). This zone belongs to ecological zone IV (Ern, 1979) and is characterized by a transitional subequatorial climate. However, this type of climate is more Sudanian in the north of the study area because of harmattan and Foehn effect. It is the wettest area of the country, with mean annual rainfall comprising between 1,250 and 1,500 mm and temperatures varying between 22.5 and 26°C. The long rainy season period is about eight (8) months and extends from March to October.

Geologically, the study area is part of the Atakorian mountains and the main structural unit is composed of epimetamorphic rocks. The dominant soils are ferruginous tropical soils, ferrallitic soils and hydromorphic soils, according to the French classification system (CPCS, 1967). The vegetation is dominated by a mosaic of relics of dense forests, savannahs, fallows and agroforests (Adjossou, 2004). Cocoa and coffee agroforests mainly dominate these agroforests. Riparian forests and remnant semi-deciduous forests of the study area are still the biodiversity hot-spot in Togo (Kokou *et al.*, 2008; Issa, 2018; Sodjinou *et al.*, 2019).

Agriculture is the main activities in the area due to soil fertility and moist climate conditions. This favours cash crops, food crops, fruit plantation and gardening (Adden, 2017; Koglo *et al.*, 2018). However, the area is facing agronomic and environmental issues, which are soil degradation and crop yield decrease (Koglo *et al.*, 2018). Illegal wood logging of forest trees species (*Milicia excelsa*, *Khaya grandifoliola*, *Terminalia superba*, *Triplochiton scleroxylon*, *Antiaris toxicaria*, etc.), and charcoal production are some factors of forest lands degradation (Kedjei *et al.*, 2013). The area is part of the Region Plateaux (the highest producer of cash crops such as coffee, cocoa, cotton as well as vegetables), which is also one of the regions where there is intensive use of chemical pesticides for agricultural production enhancement in Togo (Kolani *et al.*, 2017).

Data collection

Vegetation data such as names of woody plant species, trees height and diameter were collected across eight (8) Prefectures in 62 villages; approximately three representative cocoa agroforests are selected randomly in each village. 213 random plots across the study area were sampled using a variable area method (25 × 25 m², 50 × 50 m², 100 × 100 m²). The variable sampling method was used as basis of woody species inventory in CAFS in Côte d'Ivoire (Vroh *et al.*, 2015). According to the author, this method has the advantage of analyzing results independently to the sampling size. According to DSID (2019), in the sub-humid zone of Togo, the size of CAFS varies from 0.125 ha to 5.5 ha. For the current study, in CAFS with size less than 1 ha we surveyed 39 plots of 25 × 25 m²,

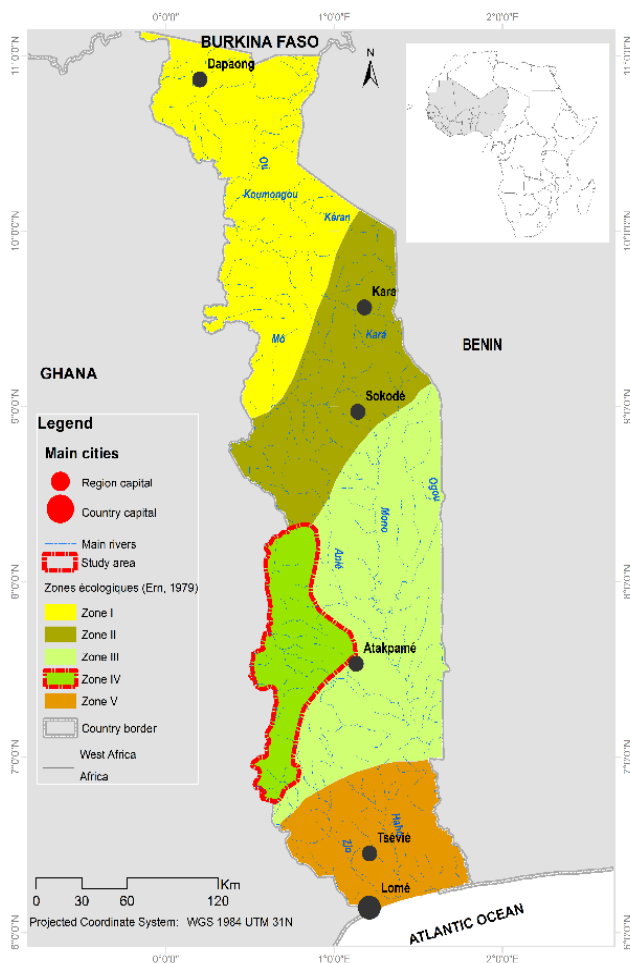
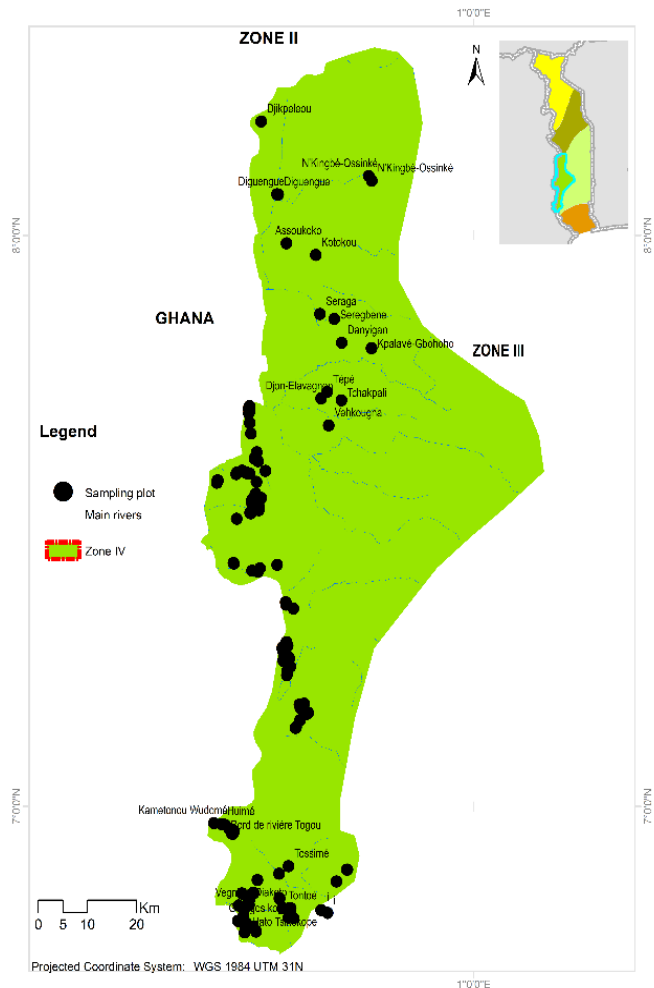


Figure 1. Study area showing sampling plots in CAFS.

while 41 plots of $50 \times 50 \text{ m}^2$ were sampled in CAFS with 1 to 2 ha size. In CAFS with size higher than 2 ha, 134 plots of $100 \times 100 \text{ m}^2$ were sampled. The total surveyed area was 157.81 ha. For practical purposes, when the farm's size exceeded 2 ha, the sample area was divided into elementary plots of $25 \times 25 \text{ m}^2$, which were randomly located in the agroforests, according to Sonwa et al. (2014) and Vroh et al. (2015).

In each elementary plot, trees (excluding cocoa trees and including exotic fruit trees) with a diameter at breast height (dbh) ≥ 10 cm were recorded. Cocoa trees were also measured for their dendrometric characteristics assessment and their basal area calculation by considering a dbh ≥ 5 cm within sub-plots of $10 \text{ m} \times 10 \text{ m}$ (100 m^2) inside $25 \times 25 \text{ m}^2$ plots. Such a sub-plot size is adopted to take advantage of different ages of cocoa trees as focus species of this study.

The total height of recorded trees was estimated with a clinometer while the diameter was recorded using a diameter measuring tape. The nomenclature for plant species identification was based on Brunel et al. (1984)'s *Flora of Togo*, and Akoègninou et al. (2006)'s *Flora of Benin*, and in the same way by comparing collected samples with some specimens at the National Herbarium (University of Lomé). Only woody trees were recorded during inventories. The prospected sites were geolocated by a GPS Garmin 64S.



Data analysis

Plant species richness, occurrence, and α -diversity

The plant species list recorded in the CAFS was compiled and stored in the Comma delimited (CSV) format. Plant species richness (S), occurrence, frequencies (Fr) according to Mori et al. (1983), number of species per family and specific abundance were analysed through pivot table "plant species" versus "plot" in Excel®.

The α -diversity was evaluated by computing the Shannon-Wiener index (I_{sh}), the Pielou's evenness (Eq) and the species pool (S) (Hill, 1973 ; Kent and Coker, 1992 ; Magurran, 2004). Frequent and rare plant species in CAFS were determined by computing the Rarity Index (Ra) (Géhu and Géhu, 1980). Following Adomou (2005), species were considered rare when the Ra is lower than 80% and frequent when the Ra is higher than 80%.

Biological forms, life forms and phytogeographic spectra

The plant species were classified into their life forms and chorological affinities according to White (1983). The biological and phytogeographical spectra were computed. Table 1 summarizes

Table 1. α -diversity calculation formulas.

Indices	Equation
Species richness (S)	S
Relative frequency (Fr) in%	$\frac{n_i}{n} \times 100$
Shannon-Wiener index (I_{sh}) in bits	$-\sum_{i=1}^s \left(\frac{n_i}{n}\right) \log_2 \left(\frac{n_i}{n}\right)$
Pielou's evenness (Eq)	$\frac{I_{sh}}{\log_2 s}$

Where S is number of plant species recorded, n_i is number of plots where plant species i is present, and n is total number of sampled plots.

Table 2. Structural parameter calculation formulas.

Parameter	Equation
Density of trees (D) in trees/ha	$\frac{N}{A}$
Basal area (G_i) in m^2/ha	$\frac{\pi}{4} \times dbh^2 \times 0.0001$
Importance value index (IVI) in %	Fr + Der + Dor
Relative density (Der) in %	$\frac{N_i}{N} \times 100$
Relative dominance (Dor) in %	$\frac{G_i}{\sum_{i=1}^n G_i}$
Rarety index (Ra) in %	100 – Fr

where N is total number of individuals (trees) recorded, A is area (ha), dbh is diameter at breast height (cm), N_i is number of individuals (trees) of plant species i and Fr is relative frequency, Der is -----, and Dor is -----.

formulas used for the α -diversity calculation.

Structural parameters

The main structural parameters considered are density (D) and basal area (G_i). The importance value index (IVI) for each tree species was then calculated according to Curtis and McIntosh (1950). Table 2 summarizes formulas use for structural parameters calculation. Horizontal and vertical distributions were obtained by grouping individuals into height and diameter class sizes by considering a pitch of 2 m and 5 cm, respectively, using Minitab (2000) and Excel. The distributions were adjusted with the Weibull theoretical function because of its relevance in structural parameter prognosis (Miguel et al., 2010). The 3-parameter Weibull theoretical density function was computed as follows:

$$f(x) = \frac{c}{b} \left(\frac{x-a}{b}\right)^{c-1} e^{-\left(\frac{x-a}{b}\right)^c}$$

where x is tree diameter or height, a is location parameter, b is scale parameter and c is shape parameter of the structure.

Analysis of the typology of CAFS

A Gradient Analysis Method of direct Canonical Correspondence

Analysis (CCA) in Canoco® 4.51 was performed on the “plant species” versus “plot” binary table. The Ward method was applied and focused on inter-species distances (Ter Braak and Smilauer, 2002), and analysis based on Whittaker's Index of Association (WIA) was used to adjust results with Community Analysis Package (CAP®) (Pisces Conservation, 2002; Legendre et al., 2005). The inter-species distance approach offered more flexibility, allowing easy visual analysis of patterns in ordination biplots for response data. The WIA is expressed as the fraction of the total number of individuals in the sample to measure similarity distance and is computed as follows:

$$WIA = \frac{1}{2} \sum_{i=1}^n \left| \frac{P_{i1}}{\sum_{i=1}^{i=n} P_{i1}} - \frac{P_{i2}}{\sum_{i=1}^{i=n} P_{i2}} \right|$$

where i is the number of plots holding species i and P is the total number of plots.

RESULTS

Richness, floristic diversity and species frequency of CAFS

In total, 4766 non-cocoa trees were recorded within

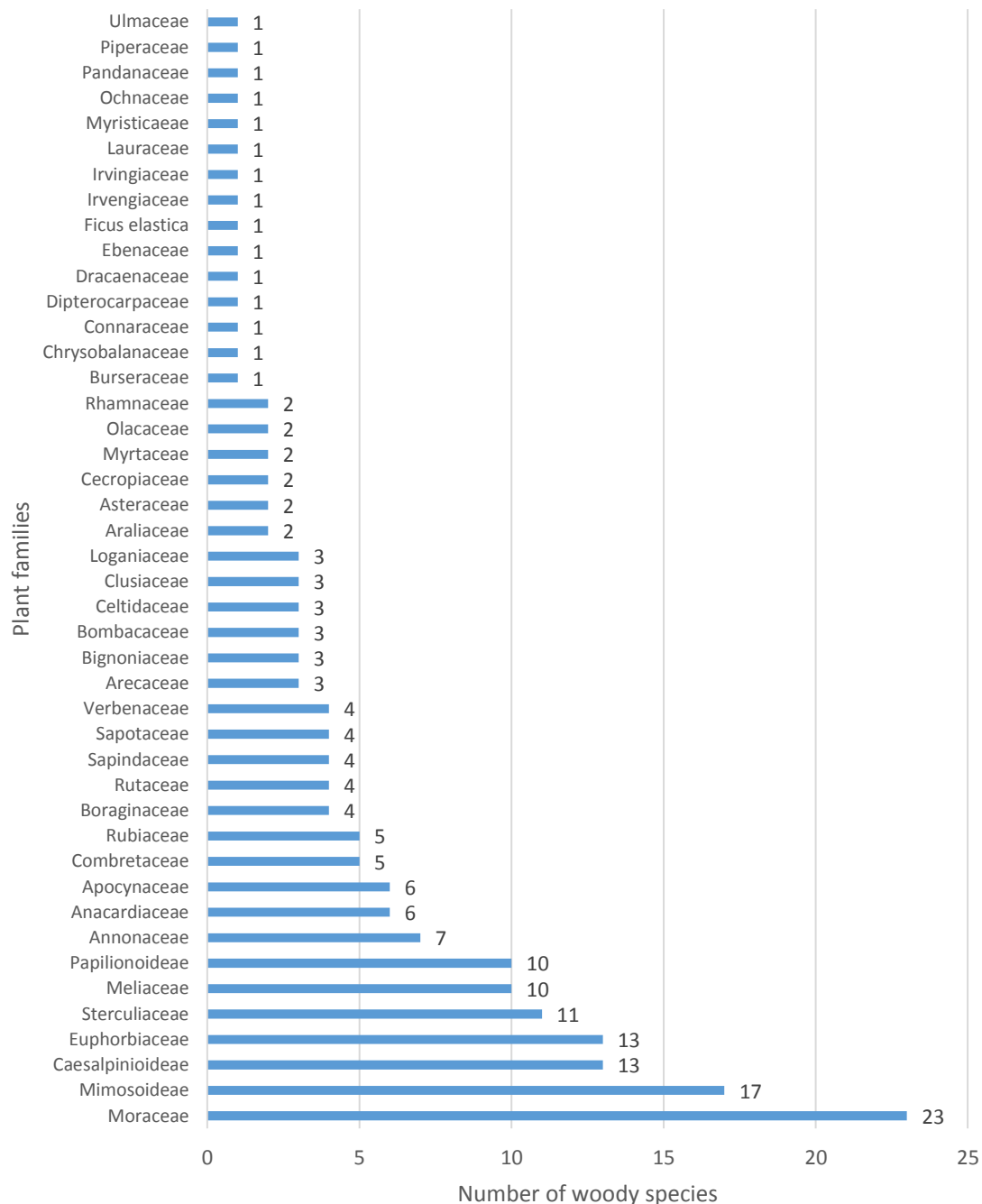


Figure 2. Relative frequency distribution of plant families.

157.81 ha of CAFS. They belonged to 195 plant species, 140 genera, and 47 families. The ten most represented plant families, all together, recorded 56.85% of trees with an average of 12 plant species. These plant families were Moraceae (23 plant species), Mimosoideae (18 plant species), Caesalpinoideae (13 plant species), Euphorbiaceae (13 plant species), Sterculiaceae (12 plant species), Meliaceae (10 plant species), Papilionoideae (10 plant species), Annonaceae (7 plant

species), and Anacardiaceae (6 plant species) (Figure 2).

The most represented plant species were *Milicia excelsa* (43.66 %), *Persea americana* (43.35 %), *Cola nitida* (42.25 %), *Terminalia superba* (37.08 %), *Cola gigantea* (33.33 %), and *Ficus mucuso* (30.51%) (Figure 3). The Important Value Index (IVI) revealed that *Persea americana* (284.93%), *Milicia excelsa* (281.31%), *Terminalia superba* (233.25%), *Bombax costatum* (215.72%), *Ficus mucuso* (208.08%), *Cola nitida*

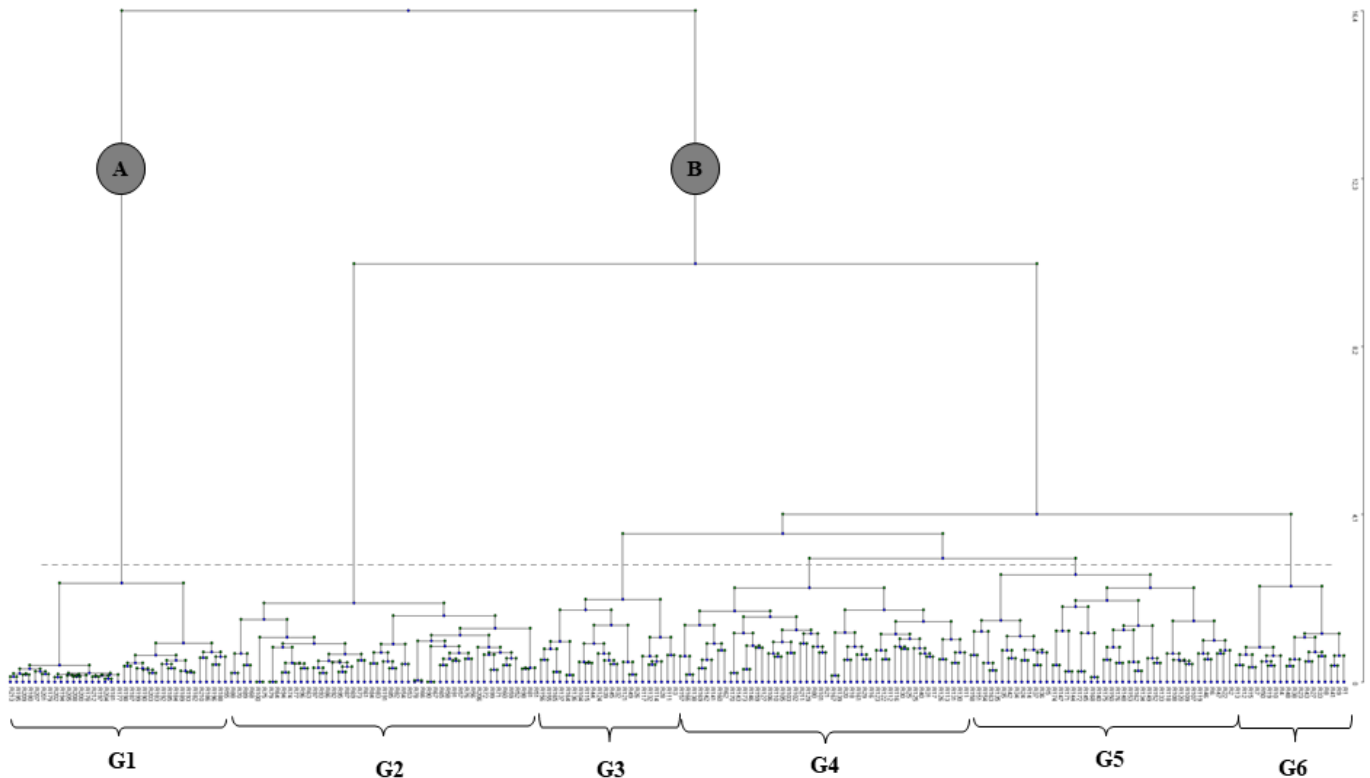


Figure 3. Hierarchical Clustering Analysis Classification of plots (Agglomerative. Ward's Whitaker distance) showing six clusters G1 to G6.

(181.66%), *Ceiba pentandra* (180.04%), *Cola excelsa* (167.12%), *Alstonia boonei* (151.65%), *Albizia zygia* (124.09%) and *A. toxicaria* (119.99%) were the 10 most important woody species of CAFS. The Shannon-Wiener index and the Pielou evenness index were respectively 6.41 bits and 0.84 for the whole CAFS. The estimated average tree density was 159.21 ± 97.58 trees/ha, whereas the basal area was $14.26 \text{ m}^2/\text{ha}$. Tables 3 and 4 provide the summary of frequent woody species and the structural parameters of the CAFS identified in this study.

Typology and characteristics of CAFS

Based on the hierarchical Clustering Analysis and applying agglomerative method of Ward, the 213 sampling plots were discriminated into six groups of plots at the threshold of 3.0 Whitaker distances. The categorization of each group was also based on the Importance Value Index (IVI) and the structural parameters of the CAFS (Figure 3).

CAFS with *M. excelsa* and *P. americana* (G1)

This group is composed of 33 plots. The CAFS is mainly

shaped by *M. excelsa* (IVI = 52.59%) and *P. americana* (IVI = 50.03%) as important species. The species richness was 89 plant species. The Shannon-Wiener index and Pielou's evenness index were 5.69 and 0.87, respectively. The density of associated species was 253.62 trees/ha, whereas the basal area was $52.60 \text{ m}^2/\text{ha}$. This group is characterized by the dominance of Guineo-Congolian (57.30 %), Afro-Tropical (12.35 %) and Exotic (12.35 %) plant species. The most represented life forms were Microphanerophytes (51.68 %) and Mesophanerophytes (26.96%) (Figure 4).

CAFS with *F. mucoso* and *Ceiba pentandra* (G2)

The total number of plots of this group is 49. The type of CAFS is dominated by *F. mucoso* (IVI = 139.71 %) and *Ceiba pentandra* (IVI = 83.60 %). In terms of diversity, the species richness of this CAFS type is 75 plant species; and the Shannon-Wiener index and Pielou's evenness were 5.31 and 0.85 bits, respectively. The computed structural parameters showed 226 trees/ha as tree density, and the basal area was $32.45 \text{ m}^2/\text{ha}$. Considering phytogeographical affinities, the Guineo-Congolian species (52%) were the most frequent. Microphanerophytes and mesophanerophytes were represented by 45.33 and 37.33 %, respectively (Figure 5).

Table 3. Frequent woody species in inventoried CAFS.

Woody species	Family	Chorology	Life form	Rarety index (%)
<i>Persea americana</i>	Lauraceae	I	mp	51.18
<i>Milicia excelsa</i>	Moraceae	GC	MP	55.92
<i>Cola nitida</i>	Sterculiaceae *Malvaceae	GC	mP	57.82
<i>Terminalia superba</i>	Combretaceae	GC	MP	62.56
<i>Cola gigantea</i>	Sterculiaceae *Malvaceae	GC	mP	66.35
<i>Ficus mucoso</i>	Moraceae	GC	mP	69.19
<i>Ceiba pentandra</i>	Bombacaceae *Malvaceae	Pan	MP	70.14
<i>Albizia adianthifolia</i>	Mimosoideae	GC	mP	72.51
<i>Alstonia boonei</i>	Apocynaceae	GC	MP	72.99
<i>Antiaris toxicaria</i>	Moraceae	GC	mP	75.83

MP = Megaphanerophytes. Mp = Mesophanerophytes. mp = Microphanerophytes; GC = Guineo-Congolian. I = Exotic species. Pan = Pantropical, * refers to the Angiosperm Phylogeny Group IV classification (Chase et al., 2016).

Table 4. Calculated parameters for cocoa trees.

Parameter	Value
Density (stems/ha)	1425
Basal area (m ² /ha)	12.78
Mean diameter (m)	13.87 ± 8.2
Mean height (m)	7.04 ± 4.7
Surveyed area (ha)	13.31

CAFS with *C. nitida* and *A. adianthifolia* (G3)

This group is composed of 22 plots. CAFS were shaped by *C. nitida* (IVI = 90.90 %) and *A. adianthifolia* (IVI = 40.90 %). The species richness was 56 plant species. Shannon-Wiener index and Pielou's evenness were 5.33 and 0.91 bits, respectively. The tree density was estimated at 53.48 trees/ha; whereas the basal area was evaluated to 6.48 m²/ha. Guineo-Congolian species were the most represented (37.5%). Microphanerophytes (51.78 %) were the predominant life forms (Figure 4).

CAFS with *Albizia* spp. and *M. excelsa* (G4)

This CAFS type is composed of 46 plots. The group is characterized by *Albizia* spp. (IVI = 62.42%) and *M. excelsa* (IVI = 50.48 %) as important plant species. 110 plant species were recorded. Shannon-Wiener index and Pielou's evenness were 6.06 and 0.89 bits, respectively. The density was 285.75 trees/ha and a basal area of 6.21 m²/ha. The Guineo-Congolian (GC) and Sudano-Zambezian (SZ) were the most represented with 45.45 and 12.72% of the individuals. Microphanerophytes (50

%) followed by mesophanerophytes (31.81 %) were the most represented life forms (Figure 4).

CAFS with *P. americana* and *T. superba* (G5)

This CAFS type is composed of 43 plots. The group is characterized by *P. americana* (IVI = 79.88 %) and *T. superba* (IVI = 79.11 %) as important plant species. The highest plant richness was recorded in this group and was 122 plant species. The Shannon-Wiener index and Pielou's evenness were 6.44 and 0.93 bits, respectively. The density was 58 trees/ha and the basal area was 24.12 m²/ha. Considering phytogeographical affinities, Guineo-Congolian (GC) and exotics (I) were the most represented. Their values are 33.60 and 21.31%, respectively. Microphanerophytes (57.37 %) followed by mesophanerophytes (24.59%) were the most represented life forms (Figure 4).

CAFS with *C. pentandra* and *M. excelsa* (G6)

This cluster is the smallest with 18 plots. The most

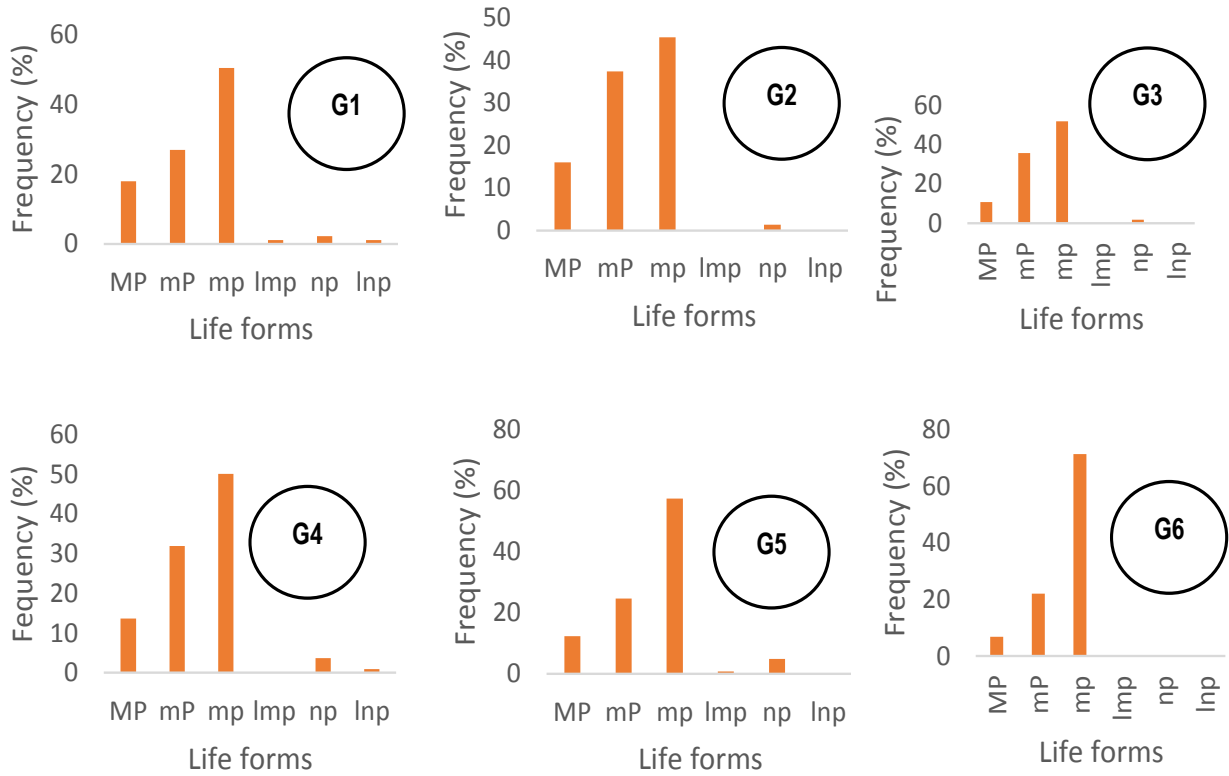


Figure 4. Spectrum of life forms. MP = Megaphanerophytes, Mp = Mesophanerophytes, mp = Microphanerophytes, np = Nanophanerophytes, and l = Liana

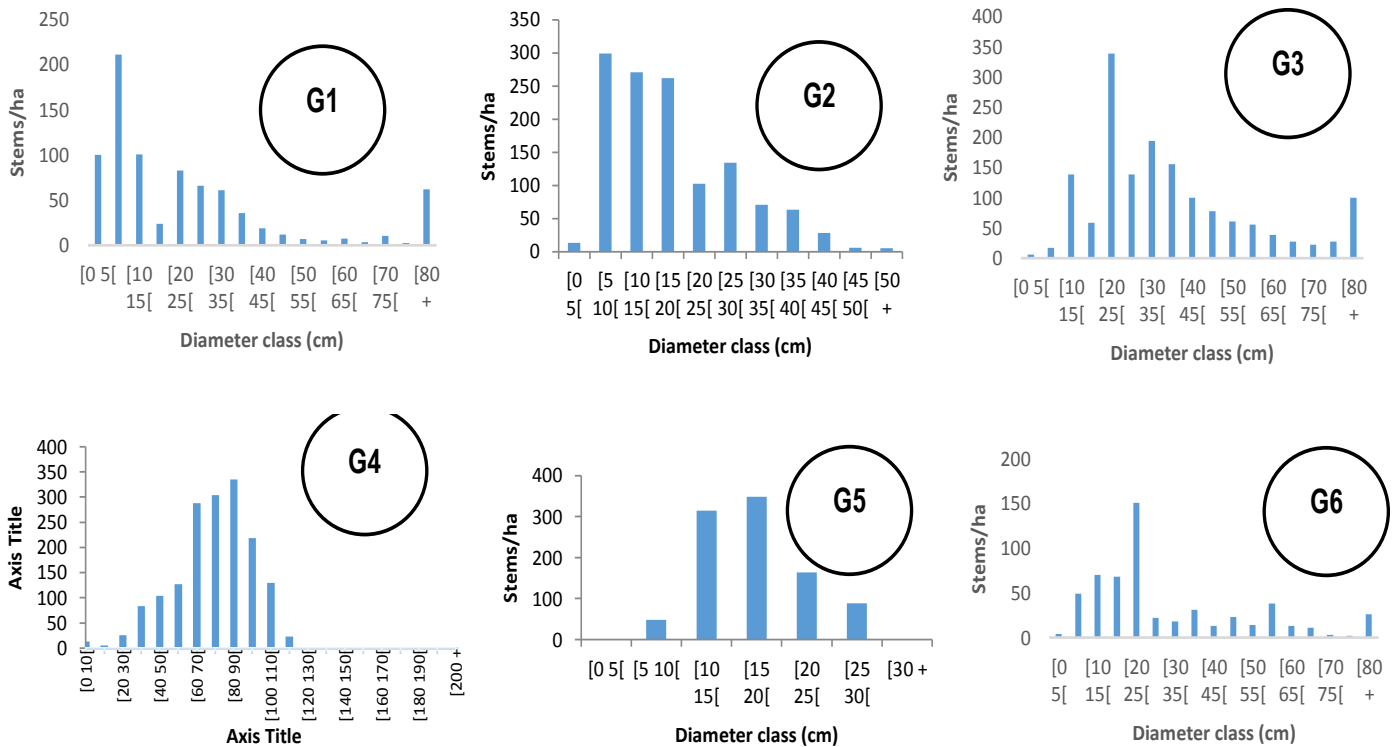


Figure 5. Diameter class distribution of the six types of CAFS.

Table 5. Importance Value Indices of discrimated sub-systems.

CAFS sub-systems	Woody species	Fr (%)	Der (%)	Dor (%)	IVI (%)
G1	<i>Persea americana</i>	48.48	2.48	1.62	52.59
	<i>Milicia excelsa</i>	42.42	1.49	6.11	50.03
G2	<i>Ficus mucuso</i>	75.51	0.12	64.07	139.71
	<i>Ceiba pentandra</i>	71.42	0.13	12.03	83.6
G3	<i>Cola nitida</i>	90.90	22.88	13.88	127.67
	<i>Albizia adianthifolia</i>	40.90	10.49	5.52	59.09
G4	<i>Albizia adianthifolia</i>	56.52	0.30	5.59	62.42
	<i>Milicia excelsa</i>	47.82	0.28	2.37	50.48
G5	<i>Terminalia superba</i>	53.48	17.23	8.39	79.11
	<i>Cola nitida</i>	37.20	1.67	2.923	41.80
G6	<i>Ceiba pentandra</i>	83.33	13.99	60.15	157.49
	<i>Milicia excelsa</i>	66.66	9.63	10.15	86.45

Fr = Relative frequency; Der = Relative density; Dor = Relative dominance; IVI = Importance Value Index.

Table 6. Descriptive characteristics of each sub-systems.

Sub-system characteristics	G1	G2	G3	G4	G5	G6
S	89	75	56	110	122	32
I _{sh} (bits)	5.69	5.31	5.33	6.06	6.44	4.36
Eq	0.87	0.85	0.91	0.89	0.93	0.87
D (Stem/ha)	253.62	226	53	285.75	58	79.53
Gi (m ² /ha)	52.61	32.45	6.48	6.21	24.12	11.67
Aam (%)	0	1.33	0	0	0	0
AT (%)	12.36	10.67	0	0	0	0.91
GC (%)	57.30	52.00	37.50	45.45	37.27	10.91
I (%)	12.36	14.67	21.43	19.09	23.64	10.00
Pan (%)	2.25	1.33	3.57	1.82	1.82	0.91
S (%)	2.25	2.67	1.79	3.64	5.45	0
SG (%)	3.37	2.67	1.79	1.82	3.64	1.82
SZ (%)	10.11	14.67	17.86	12.73	19.09	5.45

Aam = Afro-american, AT =Afro-Tropical, GC = Guineo-Congolian, I = Exotic species, Pan = Pantropical, S = Sudanian base element. SG = Sudano-Guinean, and SZ = Sudano-Zambeian.

important plant species encountered were *C. pentandra* (IVI = 157.49%) and *M. excelsa* (IVI = 86.45 %). 110 plant species were recorded. The Shannon-Wiener index and Pielou's evenness were 4.36 and 0.87 bits, respectively. The density was 79.53 trees/ha and a basal area of 11.67 m²/ha. The Guineo-Congolian (GC) and Sudano-Zambeian (SZ) were the most represented with 45.45 and 12.72% of the individuals. Microphynerophytes (50%) followed by mesophanerophytes (31.81 %) are the most represented life forms (Figure 4). The Importance

Value Indices and the descriptive characteristics of each sub-system are summarized, respectively, in Tables 5 and 6.

Structures of CAFS

Diameter class distribution

The distribution of CAFS trees by diameter class-size

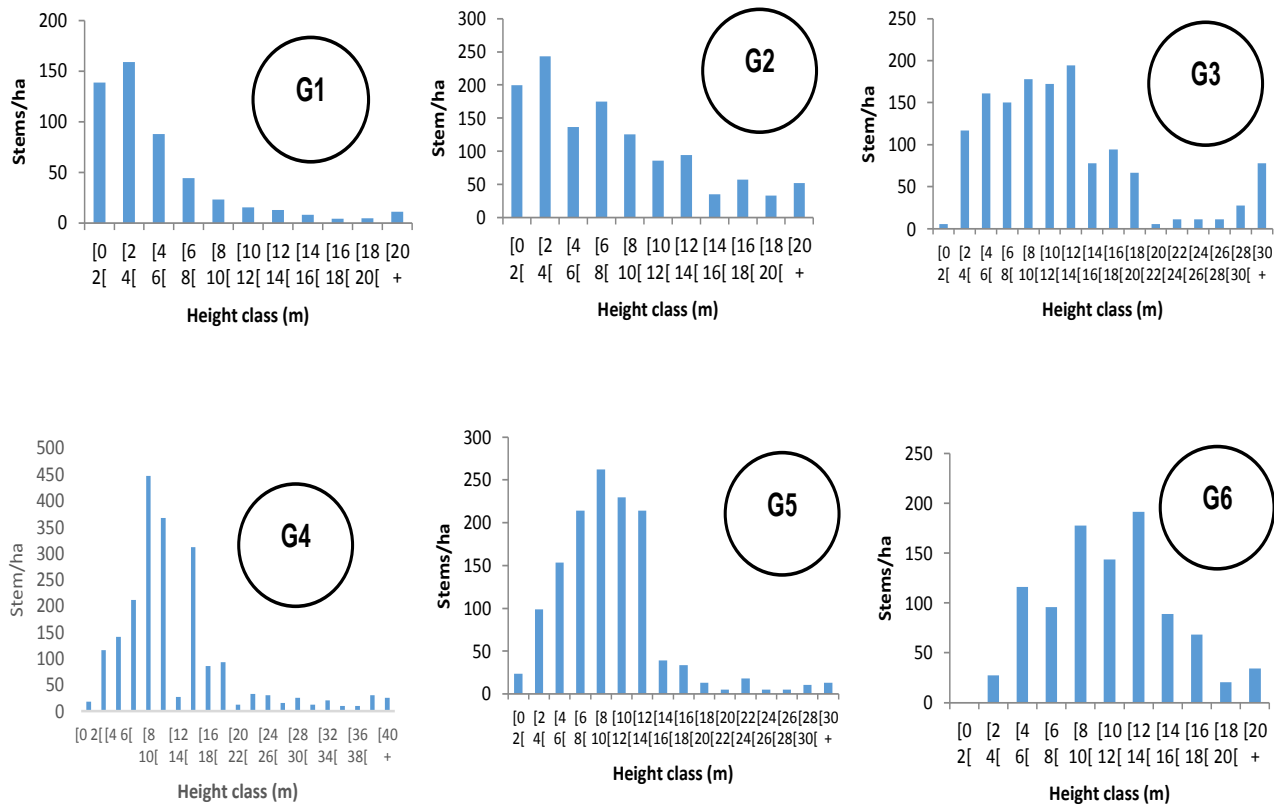


Figure 6. Height class distribution of the six types of CAFS.

follows an "L"-shaped or "bell"-shaped curve (Figure 5). The "L"-shaped distribution is mainly observed in G1 and G2; and is characterized by high density of trees of small diameter size (5 to 20 cm). The predominance of medium diameter size trees, between 20 to 50 cm diameter, was observed in the CAFS with large tree species such as *Albizia* spp., *Ficus mucoso*, *M. excelsa* and *A. toxicaria*. Large tree diameter size (up to 50 cm) is less represented (e.g., *Adansonia digitata*, *C. pentandra*, *Cola gigantean*, etc.). The calculated mean diameters of each of the six groups are in the following order: 42.36 ± 17.21 cm, 39.54 ± 23.45 cm, 31.54 ± 21.07 cm, 29.66 ± 11.54 cm, 28.32 ± 12.38 cm and 43.55 ± 19.23 cm.

Height class distribution

The distribution of CAFS trees by height class-size follow an "L"-shaped or "bell"-shaped curve (Figure 6). This structure reflected the dominance of trees with small (less than 6 m) and medium height (6 to 12 m). The small heights are mainly found in CAFS type 1 and 2. The height class from 6 to 12 m is the most represented from G2 to G6. In general, heights greater than 20 m are less represented except in the CAFS dominated by *C. nitida* and *A. adianthifolia* (G3 and G6). In each of the six CAFS

types the mean height is in order 9.67 ± 2.22 m, 17.78 ± 7.53 , 18.63 ± 5.04 , 17.11 ± 6.21 , 14.13 ± 6.24 and 16.29 ± 5.69 m.

DISCUSSION

Floristic composition and species frequency

In this study conducted in the sub-humid zone of Togo, 195 plant species were recorded as non-cocoa trees in CAFS. Issa (2018), in their findings on distribution sites of *Khaya* spp. (Meliaceae), reported 117 plant species in 12 plots in cocoa and coffee agroforests of the sub-humid zone. Compared to coffee-based agroforestry systems, that were first inventoried by Koda et al. (2016) there were only 19 woody species. These authors emphasized that CAFS are dominated by *P. americana* and *Citrus* spp. However an updated inventory from Koda et al. (2019) showed 138 woody species from coffee plantations in the whole study area.

In this study, the Shannon-Weiner index calculated was 4.36 and 6.44 bits, showing that CAFS were diversified in terms of woody species. These findings are similar to those of West Africa agroforests (Osei-Bonsu et al., 2003; Wade et al., 2010; Sonwa et al., 2014). For

instance, the Shannon-Weiner index reported from cocoa agroforests in Ghana varied between 4.69 and 4.76 bits (Anglaaere et al., 2011). In the semi-deciduous forest zone of centre Côte d'Ivoire, the diversity was low.

The Shannon-Wiener index varied between 1.5 and 4.2 bits and the plant specific richness ranged from 56 to 97 plant species (Vroh et al., 2015). The number of species in this study is comparable to the reference values found in Nigeria. Bobo et al. (2006) and Zapfack et al. (2002) located the specific richness between 116 and 206 woody species. Osei-Bonsu et al. (2003) and Anglaaere et al. (2011) inventoried less woody species in sub-humid zone of Ghana comparable to our study. Their values were 116 and 82 woody species, respectively.

Togolese cocoa agroforests were characterized by the predominance of Moraceae, Mimosoideae and Caesalpinioideae. This is consistent with that of Vroh et al. (2015) in cocoa agroforests in Côte d'Ivoire. There was also a great similarity between species composition. Some species such as *P. americana*, *C. nitida*, *Irvingia gabonensis*, *Margaritaria discoidea*, *Spondias monbin* etc. were well represented in cocoa agroforests in Togo as well as in Ghana (Anglaaere et al., 2011).

Typology of cocoa-based agroforestry systems

Six types of CAFS were discriminated based on importance value indices, species richness, and structural parameters of species. However, some other ecological parameters such as temperature, hygrometry, topology, soils etc., were under the control of this typology (Bongers et al., 2004). The drying-out from south to the north on sub-humid forest in the zone might also have had an influence (Akpagana, 1989) on the species composition, and the density of the defined groups. To avoid such drying-out on cocoa productivity, farmers maintained in their CAFS some native trees or introduced new exotic or native trees. CAFS with *M. excelsa* and *P. americana* (G1) and CAFS with *C. nitida* and *A. adianthifolia* (G3) were mainly shaped by multipurpose trees. Specialy, *P. americana*, *C. nitida* and other fruits trees found in the CAFS were not only present as shading species, but also for commercial purpose and for economic benefits. It is widely accepted that trees in CAFS had important value for farmers and were used as medicinal, nutritional plants, or as a source of indirect cash from the agroforests (Akinnifesi et al., 2008; Koda et al., 2016). This added value of plant species may also explain the predominance of exotic plant species in some discriminated CAFS. Our findings were similar to those obtained by Vroh et al. (2015). These authors also remarked about this co-dominance of exotic and plant species in old agroforests in Côte d'Ivoire. Besides fruits species, some CAFS, such as sub-systems with *P. americana* and *T. superba* (G5) were mainly characterized by timber-tree species.

Indeed, some species such as *T. superba* and *Khaya* spp. were recommended to be included in some density rate by agroforestry technical services during their training, awareness and sensitization. Some tree species were completely avoided due to the fact that they were hosts of diseases or infection vectors (Oro et al., 2012). At the same time, some species such as *C. gigantea* were avoided in some CAFS, because they could be shelter for rodents that are a serious threat to cocoa production.

Structure of CAFS

The density of non-cocoa trees in CAFS is relatively low and the distribution of diameter class-size revealed the predominance of individuals with small diameters. This might be explained by the fact that trees are removed progressively for use (house-construction, fuelwood, timber, etc.), to regulate shadow for cocoa trees or avoid windthrow that can damage cocoa trees. One of the consequences of illegal logging in CAFS could be drought severity leading to high death rate of young cocoa trees, especilay during the dry season. Sonwa et al. (2014), in this perspective, demonstrated that human interventions such as frequent use of fire, intensive use of fertilizers and pesticides, and lack of tree cover are expected to cause negative effects on cocoa farms. According to famers, to prevent low cocoa productivitiy, or to avoid pest and diseases in cocoa trees, some species such *C. gigantea*, *C. pentandra*, *M. excelsa*, *Cola nitida*, etc. are removed from CAFS. These practices may explain the low density and the rarity of some woody species in some groups.

Conclusion

The species richness in cocoa agroforest systems in Togo was 195 plant species. Based on the Importance Value Index (IVI), six types of CAFS were identified. They were sub-systems (from G1 to G6) shaped, respectively, by *M. excelsa* and *P. americana* trees (G1), *F. mucoso* and *C. pentandra* (G2), *C. nitida* and *A. adianthifolia* (G3), *Albizia* spp. and *M. excelsa* (G4), *P. americana* and *Terminalia superba* (G5), and *C. pentandra* and *M. excelsa* (G6). Tree species richness and diversity were high in the CAFS associated with *P. americana* and *Terminalia superba* (G5) (species richness = 122, Shannon-Wiener index = 6.44 bits); but much lower than in any other CAFS for the case of CAFS associated with *C. pentandra* and *M. excelsa* (G6) (Species richness = 32, Shannon-Wiener index = 4.36 bits). The highest (52.60 m²/ha) and lowest (11.67 m²/ha) basal areas were recorded, respectively, in CAFS dominated by *M. excelsa* and *P. americana* (G1) and CAFS associated with *C. pentandra* and *M. excelsa* (G6). These findings, and those of other published work referenced here provide

useful information that could contribute to improved CAFS's management.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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