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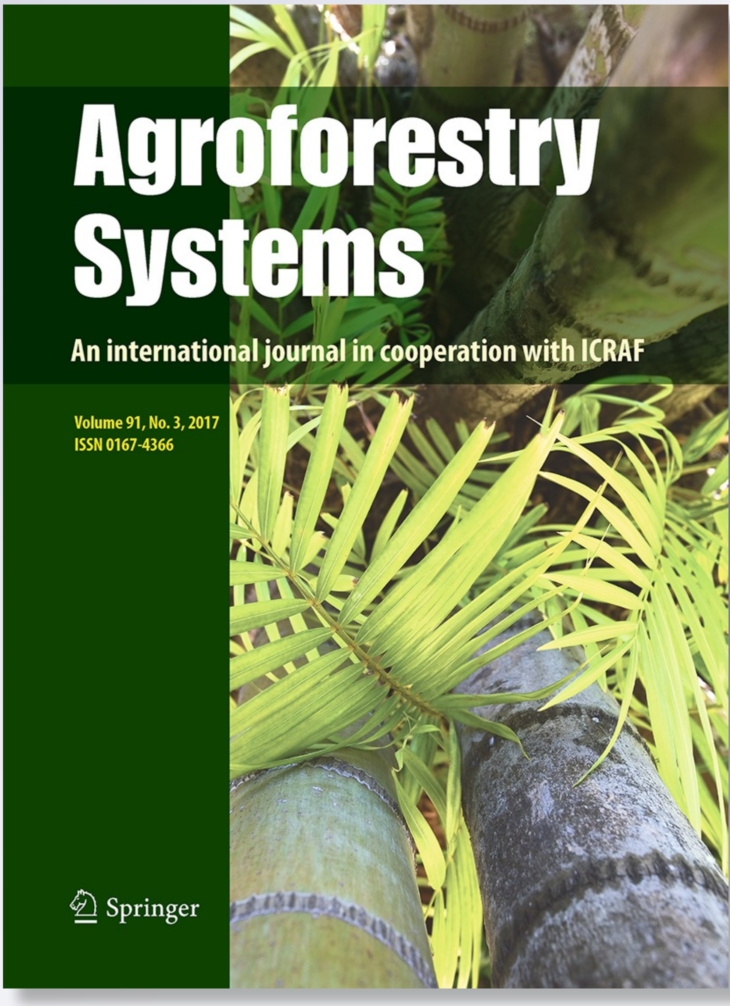

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Abstract The distribution and composition of the tree component inside cocoa agroforests plays an important role in the economic and ecological services offered by these plantations. The presence of these plant components appears to be influenced by several factors controlling the introduction and management of associated plants inside cocoa agroforests. To date, few studies have tried to evaluate the horizontal and vertical distribution of plants inside cocoa plantations in Cameroon. This study determines the structure of cocoa plantations in Southern Cameroon. Field data were collected in 60 cocoa plantations belonging to 12 villages located along a contiguous gradient of market access, population density and resource use intensity in the humid forest zone of southern Cameroon. This study area comprises (i) the sub-region of Yaoundé, (ii) the sub-region of Mbalmayo, and (iii) the sub-region of Ebolowa. Market access, population density and resource use intensity all decreased from the first to the third sub-region. For cocoa and associated plants, we quantified (1) the density (2) the individual number, the species composition and the group uses of plants (edible, timber, medicinal, etc…) distribution across strata, and (3) the basal area in the 60 cocoa plantations located in the three main sub-regions. Results are presented for each sub-region and the whole study area. The paper develops cocoa agroforest typologies and discusses possible implications of cocoa agroforest structure diversity in the achievement of economic and ecological services.

D. J. Sonwa (✉)
CIFOR (Center for International Forestry Research),
P.O. Box 2008, Messa, Yaoundé, Cameroon
e-mail: desonwa@yahoo.com;
d.sonwa@cgiar.org

D. J. Sonwa
Sustainable Tree Crops Program (STCP), International Institute of Tropical Agriculture, Humid Forest Ecoregional Center (IITA-HFC), Yaoundé, Cameroon

S. F. Weise
Biodiversity International, Rome, Italy

B. A. Nkongmeneck
Department of Plant Biology, University of Yaoundé I,
P.O. Box 812, Yaoundé, Cameroon

M. Tchatat
Institut de recherche Agricole pour le Développement (IRAD), B.P. 2067 Yaoundé, Cameroon

M. J. J. Janssens
Unit of Tropical Crops, Institute of Crop Science and Resource Conservation (INRES: Institut für Nutzpflanzenwissenschaften und Ressourcenschutz), University of Bonn, Auf-dem-Huegel 6, 53121 Bonn, Germany

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Introduction

Vegetation composition and structure of perennial tree crops in agroforestry systems, such as cocoa agroforests, determine the ecological services that they can offer. Evidence is gradually showing that a multistrata system in which cocoa is grown under trees can play an important role, in providing multiple ecological services, such as carbon sequestration, water, soil and nutrient cycling, pest and disease control, seed dispersal, pollination and biodiversity conservation. Beside the ecological services, those system offer edible products, medicinal plants, timber, etc. (Dury et al. 2000; FAO 2002; Sonwa 2004; Gockowski et al. 2004b; Jagoret et al. 2008, 2015; Smith Dumont et al. 2014; Sonwa et al. 2014).

Forest stand structure has been mainly defined, in the literature, by stand structural attributes and stand structural complexity (McElhinny et al. 2005; Zenner 2000). According to these authors, stand structural attributes include measures such as (1) abundance (e.g. density), (2) relative abundance (Dbh, diversity, basal area), (3) richness, (4) size variation (e.g. standard deviation of Dbh), (5) spatial variation (e.g. coefficient of variation of distance to nearest neighbor). Such measures can thus help in having a quantitative idea on the habitat created by combination of many components on a forest stand. These biotic elements put together, create an abiotic environment which impact positively/negatively on biotic components. In the case of cocoa agroforest, the forest structure is altered by the opening of forest stand to grow cocoa trees. The main aim of the management is to alter the forest structure in such a manner that it provides suitable conditions to the growing of cocoa. Gradually additional services, such as timber, non wood timber production, ecological and economic services are expected from the stand in which cocoa is associated with forest components. In the past, management was mainly constituted by the introduction of cocoa seedling and regular management to maintain certain amount of shade and understorey slashing to reduce competition with cocoa seedling/trees. With the recent cocoa crisis (Coulibaly et al. 2002; Sonwa et al. 2002a, 2005) characterized by the liberalization of the cocoa value chain, the constant management of associated plants include elimination of some trees and introduction of more socio-economically useful ones to provide shade but also fruits, medicinal products and timber to household (FAO 2002; Sonwa et al. 2001, 2007; Bobo et al. 2006; Zapfack et al. 2002; Gockowski et al. 2004b; Jagoret et al. 2008, 2015). The result of this management is a structurally complex system with abiotic (e.g. microclimate, humidity, low/moderate wind speed, etc.) and biotic elements (e.g. trees, vines, epiphytes, etc.) which, depending on the age and plants species composition, define a habitat structure different from the one of mono-species system such as pure cocoa orchard or cocoa with one or two associated species cultivated in an intensive manner. All these elements of the cocoa agroforest are structured vertically in the form of several layers or strata, and horizontally by the non-continuity of plants elements (or generally stratum). The vertical structural heterogeneity is combined with the horizontal discontinuity within the system, providing several patches in this multistrada and multispecies system.

The management of cocoa agroforest with constant felling of trees, non replacement of dead cocoa or associated trees results in gaps that are filled by young plants resulting from the forest seed bank or introduced seedlings. The consequence of this perturbation is the existence of several "eco-units" (Oldeman 1983b defines an eco-unit as the unit of vegetation which started its development at the same moment and at the same surface). The horizontal juxtaposition of several eco-units side by side guarantees a horizontal heterogeneity. The diverse "branching patterns" of plants composing the plantation adds to the heterogeneity created by several eco-units. These multitudes of branching pattern of plants belonging to different age and strata help to shape a horizontal discontinuity of cocoa agroforest. The result is a habitat structure where some forest ecological processes are still possible with non-negligible magnitude and where some wildlife species can find appropriate habitat for perching, foraging, breeding or nesting.

Structural requirements of species are different, but agroforest habitat structure seems to be compatible with certain flora and faunal forms (Harvey et al. 2006). Depending on the phenology, age, density, vertical and horizontal distribution of plants, cocoa agroforests are capable at different moments of the year of offering perching, foraging, breeding and nesting to animals. In Latin America, bird family richness in *cabruca* and forest are positively correlated with vegetation variables describing the height, density, cover of the herbal layer, midstory density, canopy cover, structural complexity of vegetation (Schroth et al. 2004). These agroforests can thus help in (1) Enhancing landscape connectivity, (2) Reducing edge effect and (3) improving local microclimate (Schroth et al. 2004). With these potentials, sustainable cocoa agroforest (possessing high diversity of plant and micro-habitat) can positively contribute to biodiversity conservation in the landscape (Tscharntke et al. 2011).

Plant in the forest can be easily influenced by light, water, air humidity, wind, nutrient, heat and other biotic components. Such variables are likely to be modified by the structure of the forest or agroforest. A structure with high shade intensity is known to slow the cocoa development and favors black pod disease. While with less shade, mirid attack can be a serious problem. Plant diversity can also be linked to the structure of cocoa plantation. It is generally admitted that complex cocoa agroforests are richer in biodiversity than cocoa orchards. Studying plant diversity of cocoa agroforest has revealed that land intensification, market access and population density was affecting agroforests composition (Sonwa et al. 2007). The study revealed that cocoa agroforest near the city with high population density and high intensity are constantly enriched by edible species such as plantain, banana, oil palm and avocado, to the detriment of indigenous species. Beside that, some cocoa farmers may tend to use some species while others may tend to use other species. In the same landscape, the age of the cocoa agroforest may vary and thus there might be a variation in the type of cocoa agroforestry system, passing from a rustic cocoa agroforest to another system type. The structural diversity of the cocoa agroforest of southern Cameroon is probably changing from one location to the other.

From the above review, it is evident that the structure of cocoa agroforests can help in understanding the functioning of land (e.g. its utilization and impact on the provision of ecosystem services) and can help in the management of cocoa agroforests. If stand forest structure evaluation is common in forest management, stand agroforest structure is not yet a common tool in agroforestry system management. Among these systems, homegarden remains the multi-strata and multi-species system which has been mainly described (Nair 2004). Very few description has been done on perennial base agroforests (see the work of Deheuvels et al. 2012 in cocoa Talamanca in Costa-Rica and Lopez-Gomez et al. 2008 on shade coffee in Mexico). From a management perspective, land under cocoa is gradually viewed not only as being capable of producing cocoa beans, but also as capable of providing, in a sustainable manner, timber, non-wood forest products and ecological services (e.g. biodiversity conservation, carbon sequestration, and others, as mentionned above). Several studies have already been conducted on the link between biodiversity and structure attribute parameters in Latin America. But few studies in Africa exist on the description of cocoa agroforestry systems. In the Congo Basin, few studies have tried to describe the structure of cocoa agroforests of southern Cameroon, despite the socio-economic and ecological services attributed to them. In southern Cameroon, cocoa agroforests are found in a gradient of market access, land use intensity, rural population density. These factors influence the composition of cocoa agroforests (Sonwa et al. 2005, 2007). We can thus expect also a variation of components and structure in this gradient of market access, land use intensity and rural population density. The main objective of this study is to determine the vertical and horizontal distribution of cocoa trees and associated plants and determine a typology of these cocoa plantations.

Study site and methodologies

The study was conducted in the Humid Forest Zone (HFZ) of Southern Cameroon (Thenkabail 1999; CGIAR 2000). Structure of cocoa agroforest was investigated along a gradient of market access, population density and resource use intensity in three sub-regions namely (i) the Yaoundé sub-region, (ii) the Mbalmayo sub-region and (iii) the Ebolowa sub-region. Market access, population density and resource use intensity all decreased from the first to the third sub-region (Sonwa et al. 2007; Thenkabail 1999; CGIAR 2000; Gockowski et al. 2004a). Contrary to West Africa, this is one of the area where cocoa are grown by autochthone populations with very few migrants (Sonwa et al. 2000, 2001) This study falls within the "Cameroon Gabon lowland (namely EBA 085, of The Birdlife International)" and the "North-western Congolian lowland forest (AT 0126 of the

World Wide Fund for Nature). The climax vegetation includes dense semi-deciduous forest (mainly in the Yaoundé area), dense evergreen humid Congolese forest (mainly around Ebolowa) and mixed forest around Mbalmayo (Letouzey 1979, 1985).

Tree inventory data were collected in 60 cocoa agroforests in 12 villages (4 per sub-region). For each cocoa farm the surface retained for survey was 25 % of the entire plantation. This 25 % sampling area was divided into elementary plots of 25 m × 25 m, which was randomly located in the agroforest. All trees (cocoa and non-cocoa) with a diameter at breast height (Dbh: diameter at 1.3 m) of more than 2.5 cm were recorded for all the plots. For each tree, the height was estimated and the species identified using the work of Vivien and Faure (1985, 1996), Letouzey (1982) and compared with the specimen at the National Herbarium, Yaoundé. The main uses of the tree species were also noted through interaction with key informants. The species were then grouped into one of the following use groups: edible, medicinal, timber and others. Edible products were composed of exotic plants including banana and plantain, and also edible indigenous species including oil palm (*Elaeis guinensis*). Timber species included high value (listed by the former Office National de Development des Forêts ONADEF, as exported species) and low value (used mainly locally). Each tree was also classified into one of the following height strata: 0–5 m, 5–10 m, 10–20 m and more than 20 m.

Data analysis

To characterize cocoa agroforests, we used the following stand elements (McElhinny et al. 2005): trees diameter, tree height and tree species. Those parameters allow us to describe the horizontal and vertical structure of the cocoa plantations and to calculate the eco-volume of the stand. The complexity of cocoa agroforest was expressed with the standard deviation of the tree diameter and tree height. The density of several categories of plants allows us to define a typology of cocoa agroforest of southern Cameroon.

Horizontal structure

Horizontal structure was expressed using density, Dbh, and dominance of each species. Species dominance corresponds to its basal area expressed in m^2ha^{-1} calculated as follows $G = \Sigma\ \pi D_i^2/4$ (where D_i is the diameter at breast height of the i-th species) (Sonké 1998). The basal area is known to be a good indicator (of species dominance) in several silvicultural management (Sun Hong-gang et al. 2007) and is gradually admitted as useful also in agroforestry management (Nissen and Midmore 2002). The relative dominance of the species corresponds to the ratio of the basal area of the i-th species over the total basal area of all the plants in the sampling area. The density of each species per ha was calculated for each sub-region and the entire HFZ (Humid Forest Zone, the overall study area). The density of cocoa and non-cocoa plants was calculated for each cocoa plantation. The average was calculated for each sub-region and the HFZ. For each of the parameters expressing the horizontal structure (density, Dbh and basal area), average was calculated for each sub-region and the entire HFZ.

Vertical structure

Vertical structure was expressed using tree height, height strata and distribution of plants according to diameter. For each of the height strata (0–5 m, 5–10 m, 10–20 m and more than 20 m) and each of the main uses (edible, medicinal, timber and others), the density was calculated. Species richness, basal area, density was calculated for each strata. Comparison was then made between the three sub-region of the benchmark (the HFZ). Vertical distribution of plants was also made using the Letouzey (1982) classification in forest. According to this classification, in the forest, plants with diameter below 20 cm can be classified as shrub, those with diameter ranging from 20 to 50 cm are sapling, trees comprised within 50–100 cm of diameter can be considered as average trees, and plants with diameter above 100 cm are big trees.

Cocoa agroforest complexity

Standard deviation of Dbh of each cocoa plantation was used to assess horizontal heterogeneity of agroforest stand while height standard deviation was used to evaluate vertical heterogeneity.

Eco-volume

Eco-volume is the aboveground quantifiable space or volume limited by a uniform vegetation stand and its height, within which coexist wide interactions among biotic and abiotic components (Torrico Albino 2006). This concept emphasizes the interrelationships between species living within the boundaries of a volume, and encompasses a biocenosis adapted to specific conditions in a given place (Torrico Albino 2006; Janssens 2004).

$$\text{Veco} = \text{land area} \times \text{eco} - \text{height (Janssens 2004)}$$

Eco-height Is the average height of the height canopy strata. In this case, we used the average height of tree associated components as the height of the canopy. This is in principle lower than the normal associated plants continuum strata.

Typology of cocoa agroforest

The main objective here was to determine the differences between cocoa agroforests based on their composition and the main uses of plants within the system. The age of cocoa plantations, density of each main use of non-cocoa plants (edible (e.g. exotic fruits, Musa spp, oil palm), medicinal, timber and others) and density of each sub-class diameter of cocoa tree (2.5 cm–5.41 cm; 5.42 cm–7.99 cm and more than 8.0 cm) were used to make a cluster analysis. To do this, we used Systat for the k-means clustering. For each of the cocoa agroforest types derived from the clustering analysis, the horizontal and vertical structures was also analysed. A vertical profile and horizontal crown projection of each cocoa agroforest type (deriving from the clustering analysis) were drawn in a transect of 5 m × 40 m in each transect. Each tree and his crown projection and heights were mapped. A cocoa agroforest belonging to each type was selected in the Mbalmayo sub-region to map this vertical profile and horizontal crown.

Results

Average height and diameter

Cocoa trees in Southern Cameroon have an average height of 4.1 m and a diameter of 7.2 cm (Table 1). Cocoa trees in the Yaoundé sub-region are the largest with an average diameter of 8.4 cm. Trees associated with cocoa have an average diameter of 26.7 cm and an average height of 11 m. They are shortest in Yaoundé sub-region.

Density of cocoa agroforests

A cocoa plantation in Southern Cameroon has on average 1489 trees ha^{-1} of which 22 % are trees associated with cocoa (Table 2). The average non-cocoa plant density is 298 trees ha^{-1} around Ebolowa, 358 trees ha^{-1} in Mbalmayo and 308 trees ha^{-1} in Yaoundé.

Among trees associated with cocoa, 28 % (i.e. density of 90 trees ha^{-1}) are found in the low stratum (0–5 m) range (Table 2). In this range, the Yaoundé sub-region has a tree density of 142 per ha which is more than double the density in the other sub-regions. Between 5 and 10 m and 10–20 m, more trees per ha are found around Mbalmayo. In the upper stratum, cocoa agroforests around Yaoundé have 13 trees ha^{-1} associated with cocoa and 34 and 28 trees ha^{-1} around Ebolowa and Mbalmayo respectively. More than 70 % of trees associated with cocoa dominate the cocoa canopy, thus effectively providing shade to it.

In The Humid Forest Zone (the entire study area), two-thirds of the trees found in the 0–5 m stratum provide mainly edible products. This proportion reduces to two-fifths immediately above the cocoa stratum (equivalent to the 0–5 m stratum) where the proportion of timber and minor uses tree species become important with one-fifth in each category of these groups of trees. Within the 10–20 m stratum, one-quarter of trees provide edible products, while two-fifths are timber and one-quarter are for other uses. The upper stratum is mainly occupied by timber which constitute three-fifths of the trees found in that stratum.

Within the 0–5 m stratum, edible tree species dominated (Table 3) and constitute 87, 44 and 67 % of individual plants respectively in Yaoundé, Mbalmayo and Ebolowa areas. They are followed by other trees, timber and medicinal plants. In the 5–10 m stratum (above the cocoa stratum), edible trees are proportionally less than in the lower stratum, while timber and shade trees start to gain more proportion in all the areas. This is more prominent in southern area of Mbalmayo and Ebolowa. In the stratum between 10 and 20 m, in the Yaoundé area, edible, timber and other species constitute 29, 33 and 35 % respectively of the associated plants. This proportion is 19, 44 and 28 % of plants respectively in the Mbalmayo area, and respectively 22, 44 and 25 % in the Ebolowa area. The above 20 m stratum is mainly occupied by timber

Table 1 Average height and diameter of cocoa and associated trees

Area	Cocoa		Associated trees	
	Height (m)	Diameter (cm)	Height (m)	Diameter (cm)
Ebolowa	4.4	6.9b	13a	27.3
Mbalmayo	4.0	6.2b	12a	27.1
Yaoundé	4.0	8.4a	9b	25.6
HFZ	4.1	7.2	11	26.7
P	0.1122	0.0003	0.000	0.7671

Means not sharing a common letter in a column are significantly different at 0.05 probability

P probability, *LSD* least significant difference, *HFZ* Humid forest zone

Table 2 Tree density of cocoa agroforests of Southern Cameroon (tress ha^{-1})

Zone	Cocoa	Trees associated with cocoa					Total
		Strata				Sub total associated trees	
	Cocoa tree ha^{-1}	0–5 m	5–10 m	10–20 m	>20 m	Tree ha^{-1}	Total Tree ha^{-1}
Ebolowa	1048	67b	59b	138b	34a	298	1346b
Mbalmayo	1283	60b	108a	161a	28a	358	1641a
Yaoundé	1173	142a	64b	89b	13b	308	1481ab
HFZ	1168	90	77	129	25	321	1489
P	0.20	0.00	0.02	0.00	0.00	0.33	0.08

Means not sharing a common letter in a column are significantly different at 0.05 probability

P probability, *LSD* least significant difference, *HFZ* Humid forest zone

plants with density of 20 trees ha^{-1} in Ebolowa and Mbalmayo area, against 10 in cocoa agroforest around Yaoundé. As we move from the more forested sub-region of Ebolowa to the more degraded one of Yaoundé, edible plants are more maintained in the cocoa stratum and the stratum above cocoa. Only few timbers are kept generally above cocoa but with low density compared to the more forested sub-region.

Height class of species

Within the cocoa canopy (0–5 m), *Musa* species, *Elaeis guinnensis*, *Grewia brevis, Dacryodes edulis* together make up 62 trees ha^{-1} among the 90 found on average in this stratum (Table 4). In Yaoundé, *Musa* and oil palm constitute around 80 % of plants within the cocoa canopy.

The strata above cocoa are mainly dominated by *Dacryodes edulis* with a density from 4 around Ebolowa to 14 trees ha^{-1} in cocoa agroforest of Yaoundé. *Rauwolfia vomitoria* (a medicinal pioneering plant) is mainly found in the cocoa agroforest of Mbalmayo area. Although not present around the top ten of the strata in the Mbalmayo, *Persea americana* is found with density around 5 and 9 trees ha^{-1} in Ebolowa and Yaoundé. Some *Musa* and oil palm plants can be found in this stratum. In Yaoundé, *Mangifera indica* is well represented in these strata with 7 trees ha^{-1}.

Within the 10–20 m stratum, *Persea americana, Funtumia elastica, Albizia adianthifolia* were the most common species found. *Albizia glaberima, Ficus exasperata, Persea americana* and *Hallea stipulosa* were found most in this stratum in Ebolowa, while *Funtumia elastica, Albizia adianthifolia* have high density compared to other species at Mbalmayo. Idem for *Pesea americana* which were the species commonly found in 10–20 m strata around Yaoundé.

Above 20 m, *Terminalia superba* was generally found and mainly associated with *Ficus exasperata,*

Table 3 Density of non-cocoa trees in cocoa plantations by height strata and dominant use in the Forest Margin benchmark area of southern Cameroon (number of trees per hectare)

Canopy stratum	Zone	Main utilization				
		Edible	Medicinal	Timber	Others	Total
0–5 m	Ebolowa area	45.7	1.1	9.7	10.7	67.2
	Mbalmayo area	26.8	6.3	7.8	19.5	60.4
	Yaoundé area	123.7	4.0	2.7	11.7	142.0
	HFZ	65	3.8	6.7	13.9	90
5–10 m	Ebolowa area	23.3	5.9	12.9	16.7	58.8
	Mbalmayo area	31.1	19.7	29.4	28.2	108.2
	Yaoundé area	42.9	6.2	6.7	8.0	63.9
	HFZ	32.4	10.6	16.3	17.6	77
10–20 m	Ebolowa area	30.7	11.0	61.5	34.9	138.1
	Mbalmayo area	32.1	11.3	71.3	46.4	161.0
	Yaoundé area	26.1	1.6	29.5	31.9	89.1
	HFZ	29.6	7.9	54.1	32.7	129
>20 m	Ebolowa area	4.7	1.7	19.2	8.7	34.3
	Mbalmayo area	2.4	0.5	21.2	4.0	28.1
	Yaoundé area	0.0	0.4	9.5	3.2	13.1
	HFZ	2.36	0.86	16.63	5.3	25

HFZ Humid forest zone

Pycnanthus angolensis, Albizia adianthifolia, Margaritaria discoida, Ficus mucuso and *triplochiton scleroxylon* around Ebolowa; associated with *Chlorophora excelsa* and *Albizia glaberima* in Mbalmayo area. Other species found generally had 1 or less than one trees ha^{-1}.

As we move from Ebolowa to Yaoundé, *Musa* and oil palm individuals become more important in the cocoa stratum. *Dacryodes edulis, Persea Americana* and *Mangifera indica* become more important immediately above cocoa (Although not too much important in Mbalmayo). In the 10–20 m stratum, the density of *Albizia and Ficus* reduces while *Persea americana* maintains/increases its density. Above the 20 m stratum, the density of *Terminalia superba* and other species generally found in the forested area of the south reduces as we move towards north to Yaoundé.

Among the plants associated with cocoa, only one-thrid reached the upper stratum (Table 5), half reached their maximum height within the 10–20 m stratum while 13 % will not go further than 5–10 m stratum and 5 % did not cross the cocoa stratum (Table 5). 11 species in the cocoa agroforest of Yaoundé have their maximum height in the cocoa stratum again 8 and 5 in Mbalmayo and Ebolowa respectively. The number of species that reached the above 20 m strata in Mbalmayo and Yaoundé are three quarters and half respectively of what we have in the cocoa agroforest of the Ebolowa area.

Basal area

The average basal area of cocoa agroforest is 36 m^2 ha^{-1} (Table 6). The plants associated with cocoa account for 85 %. Cocoa tree basal area is significantly more important around Yaoundé than in the other areas.

Across strata, only 2.6 % of the total basal area of plants associated with cocoa (Table 6) were found in the 0–5 m strata (i.e. cocoa tree strata). The rest were over 5 m. Of the total basal area of plants associated with cocoa, 45 and 43.9 % respectively fall within 10–20 and >20 m strata.

The top ten species present nearly half of the entire basal area of plants associated with cocoa (Table 7). Each of these dominant plants in the entire area or within the sub-region accounts for more than 2.5 % of the total basal area. *Ceiba pentandra* and *Terminalia superba* each account for 7 % of the total basal area of the HFZ. *Ceiba pentandra* and *Pycnanthus angolensi* with 2.78 and 2.98 m^2 ha^{-1} respectively are the dominant species in the Ebolowa area. Each accounts for 9 % of the total basal area of the region. *Terminalia superba* with 2.60 and 2.41 m^2 ha^{-1} around Mbalmayo

Table 4 Main species per strata and cocoa area in the humid forest zone of southern Cameroon

HFZ	DST/Ha	%	EBWA	DST/Ha	%
0–5 m					
Elaeis guineensis	25	29	*Elaeis guineensis*	17	25
Musa paradisiaca	25	29	*Musa sapientum*	11	17
Musa sapientum	5	5	*Musa paradisiaca*	10	16
Grewia brevis	4	4	*Ficus exasperata*	4	6
Dacryodes edulis	3	3	*Funtumia elastica*	4	6
Funtumia elastica	2	2	*Persea americana*	2	2
Ficus exasperata	2	2	*Terminalia superba*	2	2
Rauvolfia vomitoria	2	2	*Carpolobia alba*	1	2
Carpolobia alba	2	2	*Petersianthus macrocarpus*	1	2
Persea americana	1	1	*Vernonia conferta*	1	2
Grand total	87	100	Grand total	67	100
5–10 m					
Dacryodes edulis	10	12	*Persea americana*	5	8
Rauvolfia vomitoria	5	7	*Ficus exasperata*	5	8
Persea americana	5	6	*Fernandoa adolfi-friderici*	5	7
Musa paradisiaca	4	5	*Dacryodes edulis*	4	7
Elaeis guineensis	4	5	*Funtumia elastica*	4	6
Ficus exasperata	3	4	*Elaeis guineensis*	3	5
Mangifera indica	3	4	*Musa paradisiaca*	3	5
Funtumia elastica	3	4	*Mangifera indica*	2	3
Ficus mucuso	2	3	*Citrus sinensis*	2	3
Myrianthus arboreus	2	2	*Tetrorchidium didymostemon*	2	2
Grand total	80	100	Grand total	62	100
10–20 m					
Persea americana	7	6	Albizia glaberrima	9	7
Funtumia elastica	6	5	Ficus exasperata	8	6
Albizia adianthifolia	6	5	Persea americana	7	6
Ficus exasperata	6	5	*Hallea stipulosa*	7	6
Margaritaria discoidea	5	4	*Margaritaria discoidea*	5	4
Spathodea campanulata	5	4	*Petersianthus macrocarpus*	5	4
Albizia glaberrima	5	4	*Funtumia elastica*	4	3
Ficus mucuso	4	3	*Spathodea campanulata*	4	3
Dacryodes edulis	3	3	*Fernandoa adolfi-friderici*	4	3
Petersianthus macrocarpus	3	2	*Markhamia lutea*	4	3
Grand total	129	100	Grand total	128	100
>20 m					
Terminalia superba	3	11	*Ficus exasperata*	4	11
Ficus exasperata	2	6	*Terminalia superba*	3	9
Albizia adianthifolia	1	6	*Pycnanthus angolensis*	2	5
Ficus mucuso	1	5	*Albizia adianthifolia*	2	5
Chlorophora excelsa	1	5	*Margaritaria discoidea*	2	4
Pycnanthus angolensis	1	5	*Ficus mucuso*	2	4
Albizia glaberrima	1	4	*Triplochiton scleroxylon*	2	4
Dacryodes buettneri	1	3	*Dacryodes buettneri*	1	3
Triplochiton scleroxylon	1	3	Tricalysia sp.	1	3
Trilepisium madagascariense	1	3	*Pterocarpus soyauxii*	1	3
Grand total	26	100	Grand total	36	100

Table 4 continued

MBYO	DST/Ha	%	YDE	DST/Ha	%
Elaeis guineensis	10	18	*Musa paradisiaca*	64	44
Grewia brevis	7	13	*Elaeis guineensis*	52	36
Musa paradisiaca	6	11	*Grewia brevis*	4	3
Dacryodes edulis	4	6	*Dacryodes edulis*	4	2
Rauvolfia vomitoria	4	6	*Citrus reticula*	3	2
Funtumia elastica	2	4	*Voacanga africana*	3	2
Massularia acuminata	2	3	*Carpolobia alba*	2	1
Carpolobia alba	1	2	*Persea americana*	2	1
Tabernaemontana crassa	1	2	*Musa sapientum*	1	1
Cola acuminata	1	2	*Rauvolfia vomitoria*	1	1
Grand total	56	100	Grand total	146	100
5–10 m					
Rauvolfia vomitoria	13	12	*Dacryodes edulis*	14	20
Dacryodes edulis	12	11	*Musa paradisiaca*	9	13
Elaeis guineensis	6	5	*Persea americana*	7	11
Funtumia elastica	5	5	*Mangifera indica*	7	11
Myrianthus arboreus	4	4	*Voacanga africana*	3	5
Ficus exasperata	4	3	*Ficus mucuso*	3	4
Ficus mucuso	4	3	*Rauvolfia vomitoria*	3	4
Dacryodes buettneri	3	3	*Elaeis guineensis*	2	3
Lovoa trichilioides	3	3	*Psidium guajava*	1	2
Chlorophora excelsa	3	3	*Terminalia superba*	1	2
Grand total	110	100	Grand total	68	100
10–20 m					
Funtumia elastica	14	9	*Persea americana*	9	11
Albizia adianthifolia	10	6	*Spathodea campanulata*	5	6
Margaritaria discoidea	7	4	*Albizia adianthifolia*	5	6
Spathodea campanulata	6	4	*Ficus exasperata*	5	6
Ficus mucuso	6	4	*Dacryodes edulis*	5	5
Ficus exasperata	5	3	*Terminalia superba*	4	5
Chlorophora excelsa	5	3	*Mangifera indica*	3	4
Persea americana	5	3	*Chlorophora excelsa*	3	4
Dacryodes buettneri	5	3	*Margaritaria discoidea*	3	4
Albizia glaberrima	5	3	*Albizia zygia*	3	3
Grand total	166	100	Grand total	87	100
>20 m					
Terminalia superba	3	11	*Terminalia superba*	2	15
Chlorophora excelsa	2	7	*Albizia adianthifolia*	1	9
Albizia glaberrima	2	7	*Ficus mucuso*	1	9
Albizia adianthifolia	1	5	*Trilepisium madagascariense*	1	9
Ficus mucuso	1	5	*Ceiba pentandra*	1	9
Dacryodes buettneri	1	5	*Chlorophora excelsa*	1	6
Trilepisium madagascariense	1	5	*Albizia zygia*	1	6
Pycnanthus angolensis	1	4	*Pycnanthus angolensis*	1	6
Pentaclethra macrophylla	1	4	*Petersianthus macrocarpus*	0	3
Triplochiton scleroxylon	1	4	*Morinda lucida*	0	3
Grand total	26	100	Grand total	12	100

Table 5 Number of species according to the maximum strata reached in cocoa agroforest

Strata	Ebolowa		Mbalmayo		Yaoundé		HFZ	
	No. of spp.	%	No. of spp.	%	No. of spp.	%	No. of spp.	%
0–5 m	5	4	8	6	11	11	10	5
5–10 m	18	14	20	14	16	16	26	13
10–20 m	59	47	76	55	56	55	111	53
>20 m	43	34	34	25	19	19	61	29

HFZ Humid forest zone

Table 6 Total basal area of cocoa agroforests (m^2 ha^{-1})

Zone	Cocoa	Plants associated with cocoa					Total (cocoa and plants associated to cocoa)
		Canopy stratum				Sub total associated plants	
	Cocoa m^2 ha^{-1}	0–5 m	5–10 m	10–20 m	>20 m	Tree m^2 ha^{-1}	Total plant m^2 ha^{-1}
Ebolowa	4b	0.9	1.5b	11.9	17.0	31.2	36
Mbalmayo	5b	0.4	3.1a	14.3	12.8	30.7	35
Yaoundé	7a	1.1	2.5ab	15.8	10.3	29.7	36
HFZ	5	0.8	2.4	14.0	13.4	30.5	36
P	0.00	0.24	0.06	0.17	0.44	0.95	0.97

Means not sharing a common letter in a column are significantly different at 0.05 probability

P probability, *LSD* least significant difference, *HFZ* Humid forest zone

and Yaoundé respectively accounts for 9 % of the total basal area in each of the two zones.

Distribution of plants associated with cocoa according to diameter

The total structure of plants associated with cocoa is dominated by plants in the lower diameter classes (Table 8). Generally, more than half of the plants are found within the first two diameter ranges. Taking into consideration Letouzey (1982) diameter classification of forest, 56 % of the plants associated with cocoa are shrubs (meaning that they are below 20 cm of diameter), 33 % are sapling (belonging to 20–50 cm of diameter), 9 % are average trees (50–100 cm of diameter) and 2 % can be classified as big trees (diameter above 100 cm). 59, 56 and 52 % of plants associated to cocoa are shrubs in cocoa agroforest around Yaoundé, Mbalmayo and Ebolowa respectively. For these respective sub-region (i.e. Yaoundé, Mbalmayo and Ebolowa) 30, 34 and 36 % of trees are sapling (20–50 cm diameter).

Ecovolume of cocoa agroforest

Each cocoa agroforest build on average an ecovolume of 110,000 m3 ha^{-1} (Table 9). This ecovolume in Yaoundé is only three quarters of what is found in the more forested sub-region of Mbalmayo and Ebolowa. Of these ecovolume, 40,000 m3 ha^{-1} are occupied by the cocoa stratum.

Complexity of cocoa agroforest

In each cocoa agroforest, the standard deviation of the tree diameter is 23 cm, while the standard deviation of tree height is 6 m (Table 10). The standard deviation seems to be similar in the different sub-regions.

Difference in structure between cocoa agroforests: typology

The cluster analysis according to the age of plantations and the density of cocoa and other trees (including *Musa* species and oil palms) showed three types of cocoa plantations. Types A and C have low cocoa

Table 7 The 10 most dominant plant species associated with cocoa (basal area in m^2 ha^{-1}) in each sub-region

	Species	Ebolowa %	Mbalmayo %	Yaoundé %	HFZ %
1	*Ceiba pentandra*	2.78 (8.91)	1.30 (4.24)	2.10 (7.08)	2.06 (6.75)
2	*Terminalia superba*	1.02 (3.25)	2.60 (8.49)	2.41 (8.11)	2.01 (6.58)
3	*Ficus mucuso*		1.72 (5.60)	2.19 (7.40)	1.58 (5.16)
4	*Pycnanthus angolensis*	2.98 (9.53)			1.52 (4.98)
5	*Elaeis guineensis*	2.01 (6.44)	1.75 (5.70)		1.52 (4.98)
6	*Albizia adianthifolia*	1.01 (3.24)	1.32 (4.29)	2.19 (7.38)	1.51 (4.93)
7	*Triplochiton scleroxylon*	2.76 (8.84)			1.32 (4.32)
8	*Alstonia boonei*	0.92 (2.95)	1.49 (4.84)		1.11 (3.63)
9	*Pentaclethra macrophylla*		1.65 (5.38)		0.89 (2.91)
10	*Spathodea campanulata*			1.33 (4.49)	0.79 (2.60)
12	*Pterocarpus soyauxii*	1.02 (3.25)			
13	*Albizia glaberrima*	1.00 (3.21)	0.98 (3.19)		
14	*Margaritaria discoidea*	0.93 (2.98)			
15	*Pentaclethra macrophylla*				
16	*Milicia excelsa*		0.95 (3.11)	0.92 (3.10)	
17	*Funtumia elastica*		0.87 (2.84)		
18	*Mangifera indica*			1.27 (4.27)	
19	*Persea americana*			1.10 (3.71)	
20	*Albizia zygia*			1.00 (3.37)	
21	*Ficus exasperate*			0.92 (3.11)	
	Percentage basal area of the top 10 plants	52.61	47.68	52.02	46.85
	Basal area of the top 10 plants	16.44	14.62	15.43	14.30
	Total basal area	31	31	30	31

HFZ Humid forest zone

densities of 918 and 1060 plants ha^{-1} respectively, against 1757 for Type B. In contrast, Type A plantations have a high density of *Musa* spp. and oil palms, while Type C contains more high-value timber and indigenous fruit trees (Table 11; Figs. 1, 2, 3). Total tree density is the highest in Type B plantations.

Discussion

Horizontal structure of cocoa agroforest

There was no difference in cocoa density or associated plants as we moved from Ebolowa to Yaoundé. The cocoa density was between 1040 and 1283 plants ha^{-1}. Similarly Bobo et al. (2006) found a cocoa density of 1111 cocoa trees ha^{-1} in the more remote area of Korup region in the South West of Cameroon. Jagoret et al. (2012) found a density of 1315 trees ha^{-1} in forest savannah transition zone. Recommendation to plant cocoa in Cameroon had been generally 3 m × 3 m (this gives a density of 1111 cocoa trees ha^{-1}) and/or 2.5 m × 2.5 m (giving the density of 1600 cocoa trees ha^{-1}). But generally, when the extension services are not constanly present, farmers can increase this density. On the other hand, reduction of cocoa density is a result of cocoa trees destroyed during the felling of big associated trees, cocoa trees which died due to pest and disease (mainly root rot attack and mirideae infestation), or non replacement of dead trees with the intention of managing more associated plants in the cocoa plantation. Stan village in the Yaoundé sub-region presents those characteristics: the cocoa density was reduced to 495 cocoa trees ha^{-1} with high management of exotic fruits tree (Gockowski and Dury 1999). There was no significant difference between Ebolowa, Mbalmayo and Yaoundé regarding the density of associated plants. Putting the cocoa and associated plants together, the plantations of Mbalmayo area (the transitional area between

Table 8 Density of associated trees according to diameter (trees ha^{-1})

Diameter class (cm)	Density of associated plants (tree ha^{-1})			
	Ebolowa	Mbalmayo	Yaoundé	HFZ
2,5–10	83	99	110	97
10–20	73	99	72	82
20–30	55	66	44	55
30–40	32	37	26	32
40–50	20	20	21	20
50–60	11	10	12	11
60–70	7	6	7	7
70–80	3	7	3	4
80–90	6	4	2	4
90–100	2	4	3	3
100<	6	5	10	7
Total	298	358	308	321

HFZ Humid forest zone

Table 9 Ecovolume (m^3 ha^{-1}) defined by cocoa agroforest in southern Cameroon

Zone	Eco-volume in the cocoa stratum	Eco-volume above the cocoa stratum	Total ecolvolume
Ebolowa	44,000	86,000	130,000
Mbalmayo	40,000	80,000	120,000
Yaoundé	40,000	50,000	90,000
HFZ	41,000	69,000	110,000

HFZ Humid forest zone

Table 10 Standard deviation of tree diameter and tree height in cocoa agroforest of southern Cameroon

Zone	Standard deviation of tree diameter	Standard deviation of tree height
Ebolowa		
Average	23.3	6.3
Max	54.8	8.9
Min	4.8	2.2
Mbalmayo		
Average	22.6	5.7
Max	38.3	7.5
Min	8.8	3.7
Yaoundé		
Average	24.9	5.9
Max	47.2	8.7
Min	11.3	4.2
HFZ		
Average	23.6	5.9
Max	54.8	8.9
Min	4.8	2.2

HFZ Humid forest zone

Ebolowa and Yaoundé) are denser than those of the forested area. This density of associated plants is lower compared to the one of the primary and secondary forest in Cameroon (Ibrahima et al. 2002; Bobo et al. 2006). Unsurprisingly, this shows that cocoa growing under forest reduces the density of forest plants in favour of the cocoa trees. The total density of 1489 plants ha^{-1} is not far from the 1560 obtained by Zapfack et al. (2002) in cocoa agroforests in Cameroon. The average cocoa tree density of 1168 trees ha^{-1} is within the range of 1028 and 1212 of the shaded plantations around Daloa and Gagnoa in Côte d'Ivoire (N'goran 2003). The density of associated plants, 321 plants ha^{-1}, is five times the value of 16–56 plants ha^{-1} at Daloa and Gagnoa in Côte d'Ivoire, and is also far above the 10–15 trees ha^{-1} advised in Ghana (Padi and Owusu 2003). Cocoa agroforest of Southern Cameroon are thus denser in terms of associated plants than those of West Africa. But the cocoa density seems to be the same. A well organised research network has played a key role in producing advice on how the cocoa should be managed in West and Central Africa.

Table 11 Age and density of cocoa and other trees (including *Musa* spp. and oil palms) in three types of cocoa plantations in the forest margin benchmark area of Southern Cameroon (trees ha^{-1})

	Type A	Type B	Type C	P	LSD 5 %
Age of cocoa plantation establishment (years)	37a	30ab	24b	0.02	11
Cocoa (trees ha^{-1})	918c	1756a	1060b	0.00	160
Musa spp. (trees ha^{-1})	53a	21ab	11b	0.09	48
Oil palm (trees ha^{-1})	46a	18b	23b	0.02	25
High value timber (trees ha^{-1})	27b	49a	61a	0.00	19
Indigenous fruit trees (trees ha^{-1})	31b	41ab	62a	0.01	23
Exotic fruit trees (trees ha^{-1})	23	20	25	0.81	16
Other trees (trees ha^{-1})	121b	131b	212a	0.00	68
Total (trees ha-1	1218c	2036a	1453b	0.00	177
Number of cocoa field	28	15	17		

Means not sharing a common letter in a row are significantly different at 0.05 probability

P probability, *LSD* least significant difference, *Type A* cocoa agroforest with high density of Musa spp and oil palm plants, *Type B* cocoa agroforest with high density of cocoa; *Type C* cocoa agroforest with high density of timber and non-timber tree species

For the associated plants, lesser efforts were put on the proper density they should have. Main recommendation was generally that the density should be kept at a level that will provide enough shade for cocoa development. For certain cocoa orchard, recommendation was toward zero-shade in West Africa (mainly Cote d'Ivoire and Ghana) (Ruf 2011, 2014).

The basal area of 36 m^2 ha^{-1} obtained in this study is greater than the 30 m^{2}ha^{-1} noticed by Zapfack et al. (2002) in cocoa agroforests of Cameroon. This basal area is within the range of 9.5–46.7 m^2 ha^{-1} noticed by Bisseleua and Vidal (2008) in Cameroon. The value obtained here is near the double of what is obtained in dense cocoa agroforests of Nigeria (Oke and Olatiilu 2011). In Southern Cameroon, Zapfack et al. (2002) have obtained tree basal area of 44.9, 39.2 and 0.07 m^2 ha^{-1} respectively in secondary forest, primary forest, and farmlands of Southern Cameroon. Bobo et al. (2006) obtained tree basal area of 48.7, 40.0, 32.7 and 4.9 respectively in near-primary forest, secondary forest, agroforestry system (cocoa/coffee) and annual culture in the Korup area in the South West of Cameroon. In another forest in South Cameroon, Guedje (2002) obtained 35.68 m^2 ha^{-1} in a forest stand containing *Garcinia lucida*. The cocoa agroforest basal area value is thus generally somewhere between those of forest and the one of annual culture, and more specifically closer to a forest basal area value. This implies that this cocoa agroforest properly covered land and may prevent erosion as forest does.

Despite their lower density, the upper stratum trees (>20 m) contributed far more than 40 %of the basal area of all associated plants. By their large canopy, they contribute to build an agroforest habitat suitable for other life form such as bird, vine, epiphytes, etc. In this line, cocoa habitat of Ebolowa, with 17 m^2 ha^{-1} provided by tree above 20 m may be more shaded than the Yaoundé ones. Canopy closure is known to be an important variable for bird diversity. At the landscape level, most of the cocoa agroforests form a continuous and complex mosaic of ecosystems, Sometimes disrupted by other land uses -, that help satisfy the many needs of the inhabitants of the forest zone. They constitute part of the forest corridor observed by Thenkabail (1999) in Southern Cameroon and therefore deserve to be studied in relation to other land use systems.

Vertical structure of the cocoa agroforest

The average height of 11 m for plants associated with cocoa is not far from the 12 m of one of the cocoa agroforests (of more than 45 years old) evaluated by ASB (2000) but less than 18 m for cocoa groves, younger than 30 years old, from the same study. The more degraded the area surrounding the cocoa plantations (as it is the case in the Yaoundé landscape), the lower the height of plants associated with cocoa and the higher the diameter of cocoa (Table 1). This suggests a higher availability of light to plants which do not need

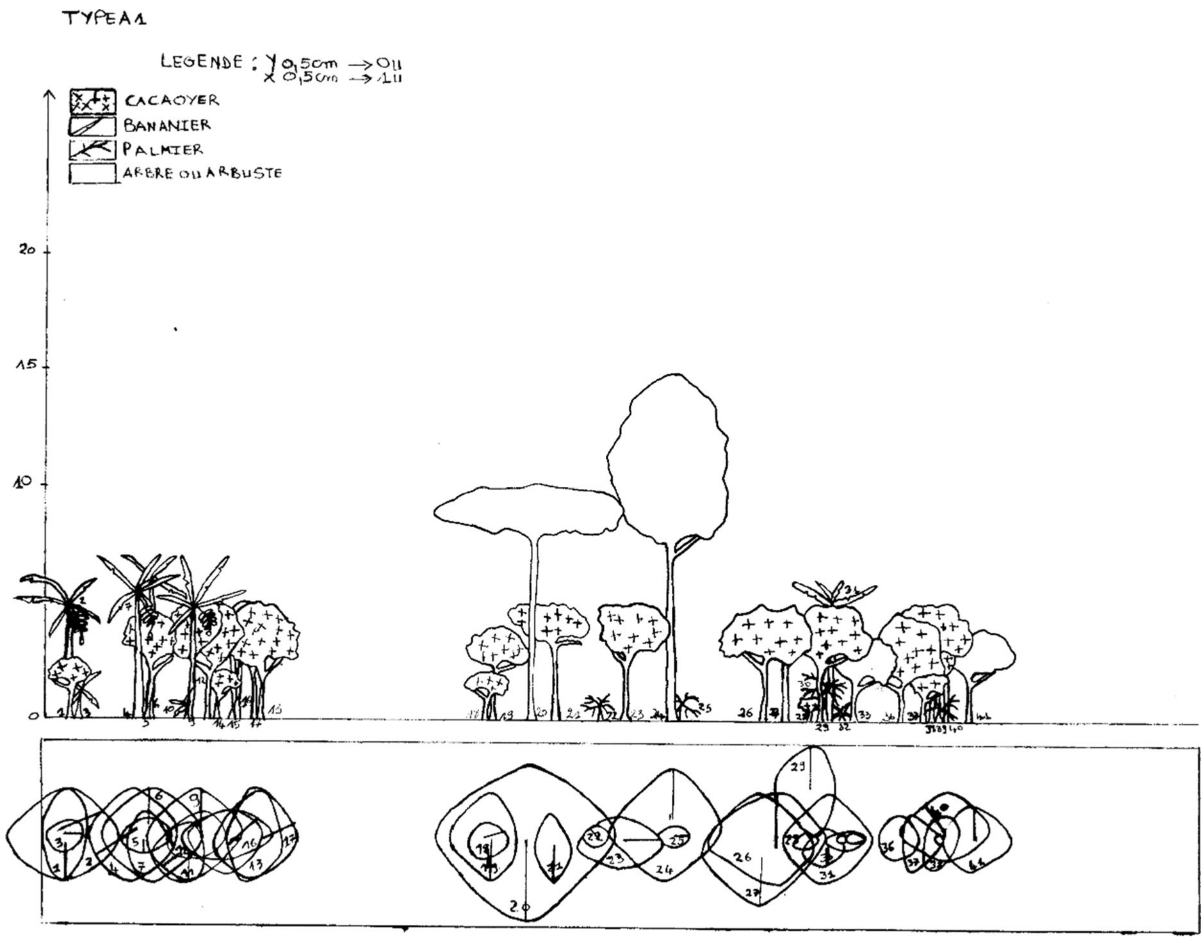

Fig. 1 Horizontal and vertical view of Type A cocoa agroforest (low cocoa densities, high density of *Musa* spp. and oil palms) in the Mbalmayo area. Nrs *1*, *5*, *11*, *12*, *13*, *14*, *15*, *16*, *17*, *18*, *19*, *21*, *23*, *26*, *27*, *28*, *29*, *34*, *36*, *37*, *38*, *40 Theoboroma cacao*; Nrs *2*, *3*, *4*, *6*, *7*, *8*, *9*, *10*, *31*, *32 Musa paradisiaca*; Nr 20 *Dacryodes edulis*; Nrs *22*, *25*, *30*, *35*, *39 Elaeis guineensis*; nr *24* Unknown tree; No *33 Carpolobia alba*; Nr *41 Vernonia amygdalina*

to search for it by increasing their heights as is the case in more forested area. In addition, intensive light allows good vegetative development of the cocoa tree and leads to higher diameter of cocoa trees.

More than 70 % of plants associated with cocoa dominate the cocoa canopy, thus effectively providing shade to it. Only 8 % is more than 20 m tall. This upper stratum contains few plants per ha in the Yaoundé area. The number of trees above 20 m in Yaoundé is 50 and 40 %of the amount of trees associated with cocoa in these stratum respectively in Mbalmayo and Ebolowa (Table 2). The amount of trees in the cocoa stratum (0–5 m) of Yaoundé is double what is found in the cocoa agroforest of Ebolowa and Mbalmayo. Edible species were found to be more abundant in the enrichment of the cocoa stratum around Yaoundé. Edible plants in Yaoundé are a third and more than half of what is found in Mbalmayo and Ebolowa area respectively (Table 3). Oil palm and banana were found to be highly present in this stratum contrary to timber which was more abundant in the upper strata. As we moved from Ebolowa to Yaoundé, the density of the upper stratum is reduced in favour of the cocoa stratum.

Taking the class diameter in consideration (Table 8), it is evident that only 7 trees ha^{-1} are big trees found in cocoa agroforest. This is low compared to 24 and 16 trees ha^{-1} in this class diameter respectively in primary and secondary forests found by Zapfack et al. (2002) in the benchmark of southern

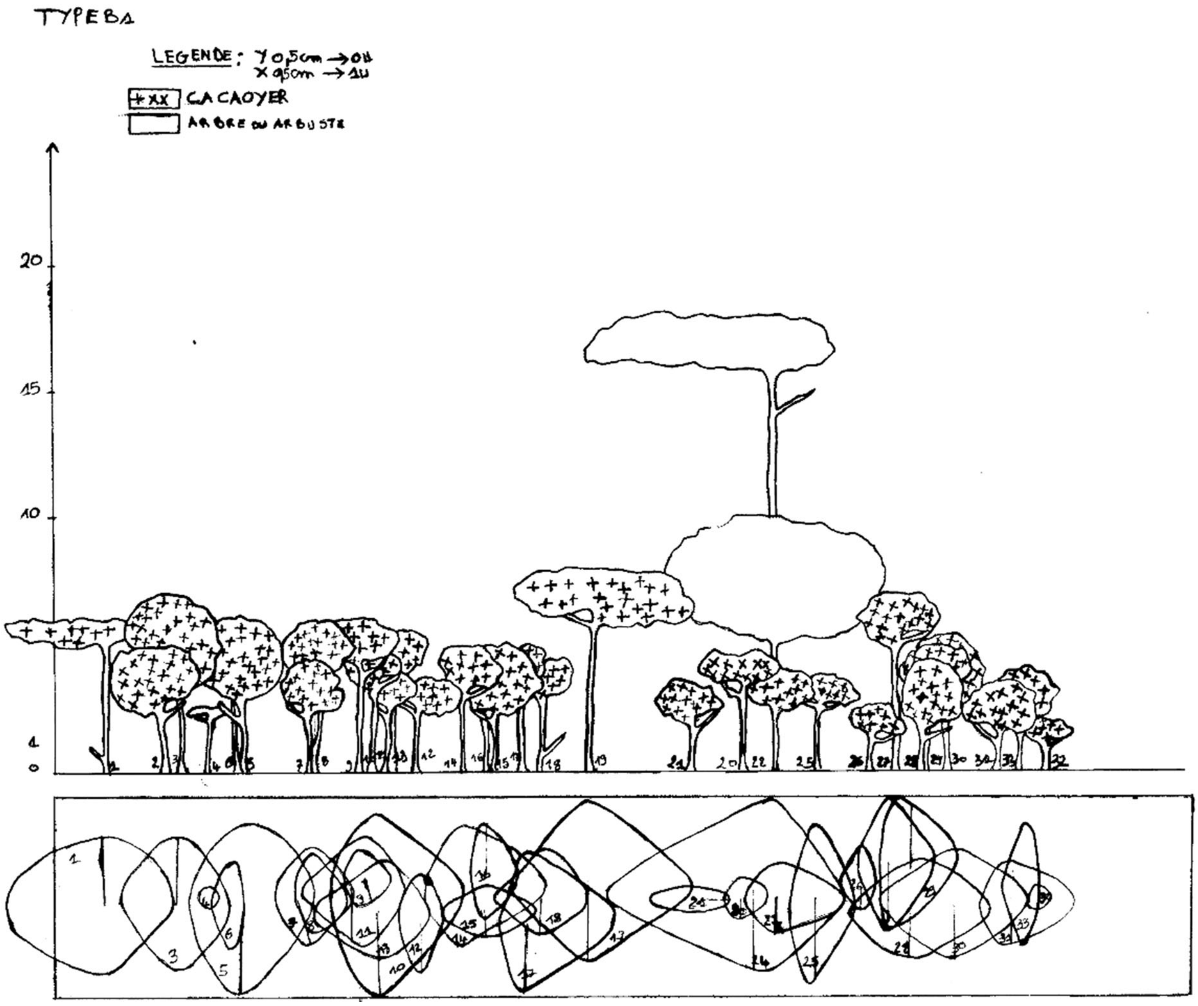

Fig. 2 Horizontal and vertical view of Type B cocoa agroforest (high density of cocoa trees) in the Mbalmayo area. Nrs *1*, *2*, *3*, *5*, *6*, *7*, *8*, *9*, *10*, *11*, *12*, *13*, *14*, *15*, *16*, *17*, *18*, *19*, *20*, *21*, *22*, *25*, *26*, *27*, *28*, *29*, *30*, *31*, *32*, *33*, *34* *Theoboroma cacao*; Nr *4* *Carpolobia alba*; No *23* *Rauvolfia vomitoria*; No *24* *Pentaclethra macrophylla*

Cameroon. In the South West province of Cameroon, Bobo et al. (2006) found that cocoa plantations have 15 big trees ha^{-1} (diameter > 100 cm) against 6 and 11 trees ha^{-1} respectively in primary and secondary forests. This suggests an increase in diameter of trees as we moved from close to open multistrata structures. This is the case as we moved from Ebolowa to Yaoundé (moving from 5 to 10 big trees ha$^{-1)}$. This does not necessarily mean an increase in height of associated plants. In the current study, increase of tree diameter as we moved from Ebolowa to Yaoundé was paralleled to a reduction in height, suggesting less competition between trees in search of light in the more open landscape of Yaoundé.

The structure of plants associated with cocoa shows that, all species taken globally, there are many small class diameter trees (Table 8). This corresponds to an inverse J shape structure. But since previous study in the semi deciduous forest of Cameroon had shown that there is very weak link between age and tree diameter, and between age and height (Worbes et al. 2003), it is difficult to say if there are enough younger plants to replace the older ones when they disappear. In the study area, in general 5, 15, 50 and 30 % of species reached their maximum height development in the 0–5 m, 5–10 m, 10–20 m and >20 m strata respectively (Table 5). The fact that many of the plants will not

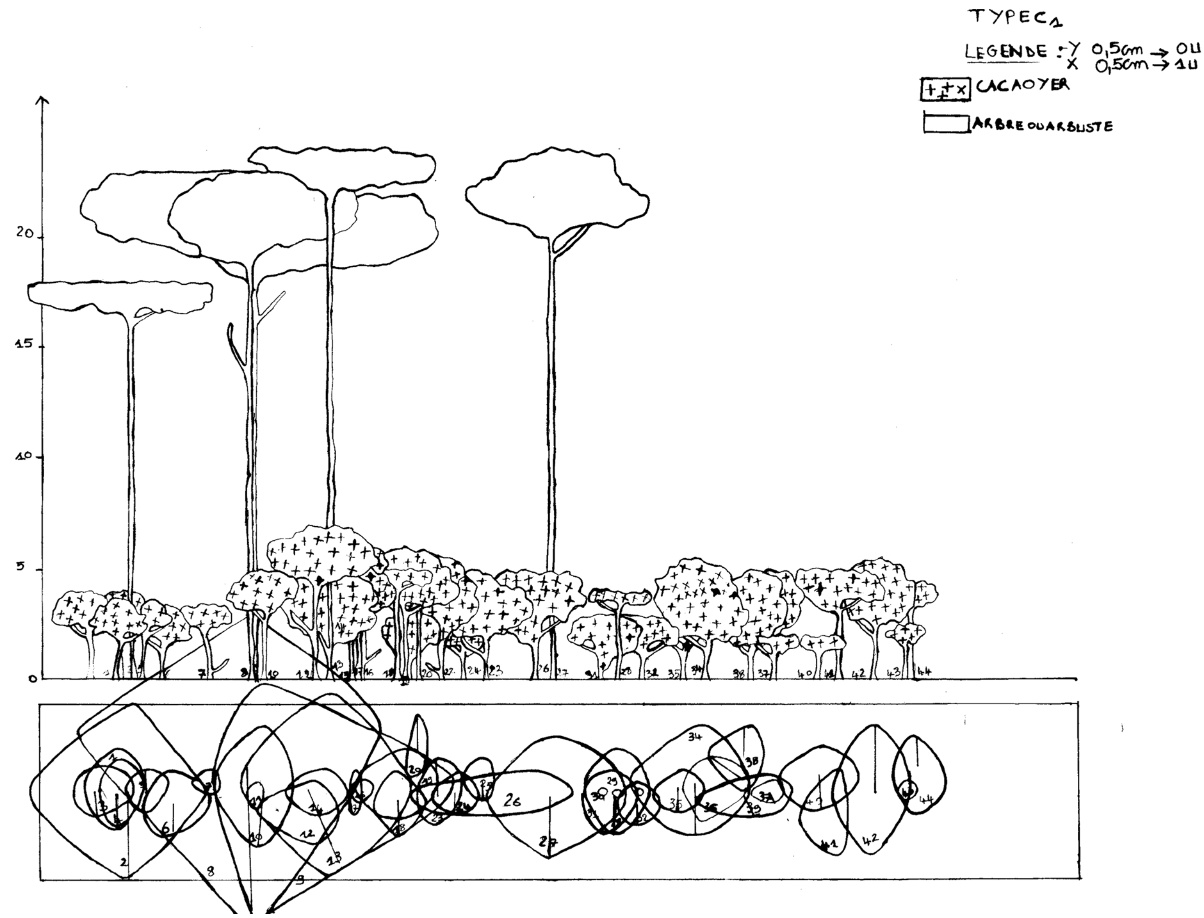

Fig. 3 Horizontal and vertical view of Type C cocoa agroforest (low cocoa densities and high-value timber and indigenous fruit trees) in the Mbalmayo area. Nrs *1*, *3*, *4*, *5*, *6*, *7*, *10*, *11*, *12*, *14*, *15*, *16*, *17*, *18*, *19*, *20*, *21*, *22*, *23*, *24*, *25*, *26*, *28*, *30*, *31*, *32*, *33*, *34*, *35*, *36*, *37*, *38*, *39*, *40*, *41*, *42*, *43*, *44*, *45 Theoboroma cacao*; No 2, *13 Alstonia boonei*; Nr *8 Margaritaria discoidea*; No *9 Ficus mucuso*; No *27 Spathodea campanulata*; No *29 Carpolobia alba*

probably reach the upper canopy implied that each species needs its own management plan.

From the above discussion, it appears that agroforests in the southern part of the study area (Mbalmayo and Ebolowa) (i) may present a more continuous upper stratum and (ii) mimic primary or secondary forest more than those of Yaoundé. In this last zone (.e.i. Yaounde), the discontinuity of the upper stratum may affect plant and animal species that usually live in the upper forest canopy. Rice and Greenberg (2000) noticed that even in the case of extensive cocoa growing, the canopy of the associated plants is dramatically altered. Management methods for biodiversity conservation should pay enough attention to the maintenance of a continuous upper stratum inside the cocoa agroforest. The under storey habitat may be more tied under cocoa in Yaoundé, while the above cocoa canopy is more open. In the other sub-regions the storey under cocoa are less thick while the above cocoa seems to be more complex. Wildlife movement under cocoa may be more difficult under cocoa of Yaoundé than those of the more forested ones of the Mbalmayo and Ebolowa. As cocoa agroforest is the land use most similar to the forest in the Yaoundé areas, the most degraded sub-region, they constitute a good compromise between production goals (generally common in this landscape) and biodiversity conservation.

Eco-volume

The more the cocoa agroforest is closer to the forest, the more important the ecovolume. By combining cocoa with associated plants, agroforest provides an important habitat in which biotic and abiotic components can interact. This offers an important space for living organisms for nesting, development, etc. In the more urbanized landscape, the eco-volume is paradoxically low, while this is where we need an important forest-like habitat to host remnant forest species. The ecovolume is important in terms of diversity if they present a more complex situation. This is not the case in the Yaoundé landscape where complexity seem to be very low, the high proportion of plants being constantly found in the cocoa strata only. The integrative indicator, eco-volume, enables us to better discriminate between vegetation types and farming systems. Eco-volume contributes to supplementary precipitations of ecological origin. It is an inter-connecting parameter helping in the validation of more complex hydrological models. This suggests that higher eco-volume as well as biomass per unit of land, is likely to ensure a closer and stable water cycle, susceptible to maintain rain at the landscape level. In this perspective, the Yaoundé Ecovolume needs to be properly increased.

Different types of cocoa agroforest and complexity of cocoa agroforest

The existence of different types of cocoa agroforests may imply different degrees of exposure to pest attack. Type A, with more *Musa* spp and palm oil, may be more susceptible to capsid attack, while type B, with high cocoa density and type C, with high non wood forest products (NWFP) and timber may be more prone to black pod disease. Wind damage may cause more problems in type C, which has more timber trees and NWFP. The negative impact of black pod disease on type B was noticed during this study (Sonwa 2004). A study on the linkage between structure and production in the Talamanca (Costa-Rica) reveals that the nature of structure affect cocoa production as a consequence of spatial distribution more than botanical composition (Deheuvels et al. 2012). Distributed forest trees contrary to aggregated or random one reduced disease (Frosty pod rot) (Gidoin et al. 2014). This difference offers several management options for pest and other environmental concerns likely to be considered by cocoa producers (see Sonwa et al. 2005).

Different types of cocoa agroforest also revealed options of diversification within the cocoa agrorest landscape. Each cocoa farm is generally managed by a household which has its own characteristics. ASB (2000) had previously observed that in southern Cameroon, several model cocoa agroforest exist as a result of different intensity of inputs management and different access to the market. Each cocoa farm managed "homogeneously in its entire area" could constitute an "Eco-Unit" as described by Oldeman (1983a, b cited by Vester 1997). This could have been the case since, apart from the wild trees left on the land at establishment, cocoa and associated plants start their development together when the cocoa plantation is settled and coexist till the end of the cocoa plantation "cycle". But natural events (e.g. felling of trees, occurrence of pest and disaster, etc.) and management interventions (e.g. replacement of old cocoa trees, killing of some associated plants, etc.) generally create a gap inside the cocoa agroforest. The development of a generation of plants in these gaps constitutes a small eco-unit. The result of this dynamic inside a cocoa agroforest, link to non homogeneous distribution of biotic components inside the plantation, is several patchiness inside the cocoa agroforest. Each cocoa agroforest within itself is an uneven-aged agroforest stand consisting of plants of various ages, with varied crown canopy and irregular stand in the vertical and horizontal dimension. Such systems are quite common in forestry management (Peng 2000). At the landscape level, variations inside and among agroforests provide a complex continuum of cocoa agroforests with complex structure horizontally and vertically.

In terms of biodiversity conservation perspective, it is generally admitted that an ecosystem with stand presenting a multitude of structural components is susceptible to having a variety of resources and species that utilise these habitat (McElhinny et al. 2005). This diversity of species can also mean diversity of pest and diseases, germs or vectors which can play a role in the infestation of biotic components (Schroth et al. 2000; Krauss 2004). Sonwa et al. (2005) had already mentioned the link between cocoa pest and tree management and underline the need of an integrated approach in the management of production constraints inside the cocoa agroforest. It is well established that structure with too much shade create black pod diseases, while a less shaded environment is favourable to mirid attack. Farmers in southern Cameroon recently reported the link between plant species composition, structure of the farm and pest and diseases development, and cocoa production (Bidzanga 2005). The current dominance of shade in plantation around Ebolowa may suggest a high risk of black pod disease compared to cocoa plantations around Yaoundé, where the open structure may lead to mirid attacks.

Conclusion

This study illustrates the structural and compositional diversity of cocoa agroforests of southern Cameroon. These vary based on management factors and productive use priorities of farmers. In the zone where resource intensification is higher, population is greater and markets are more accessible, cocoa agroforests on average are less high, have fewer tress in the higher strata but more in the lower strata. The lower strata of these systems also contain more edible species linked to household food and market opportunities (e.g. *Musa* spp. and oil palm). On the other hand, the cocoa agroforests in the lower resource use intensity and market access areas tend to contain more timber species and indigenous fruit trees, indicating the retention of more of the trees from the original forest before cocoa was planted through partial clearing. Thus management practices of the farmers, as driven by their specific circumstances, have an important and rational impact on the vertical and horizontal structure of the cocoa agroforests, even if the respective total basal areas are largely similar. While we have tried to indicate possible impact of the structural differences of the agroforests on ecological services, we need more targeted studies to elucidate this. What are the implications of a more open or closed cocoa stratum? More or less dense mid- or high strata? Differences in species composition? With such information, we can start developing a more integrated picture of the value, beyond solely economic, of different cocoa agroforests. This study shows that the diverse systems in Southern Cameroon lend themselves for such an integrated analysis.

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