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Typology of cocoa-based agroforestry systems in a forest-savannah transition zone: case study of Kokumbo (Centre, Côte d'Ivoire)

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Abstract

The introduction of hybrid varieties cocoa has led to the progressive disappearance of the complex agroforestry systems in Côte d'Ivoire. However in forests-savannah transition area, these systems seem to persist in despite the high frequency of bushfires, low rainfalls and the change of cocoa trees varieties. To understand the farming practices in that zone, data were collected in 68 cocoa farms located in three major cocoa producing in the sub-prefecture of Kokumbo. We used 105 plots of 0.0625 ha (25 m X 25 m) to characterize the botanical composition, structure, biophysical variation and management practices. In the 6.56 ha cocoa farm surveyed 2,149 stems belonging to 86 species and 36 families were encountered. The average species richness varied from 4 species to 6.4 per 625 m^2 plot. The global density of associated plants was 227.3 trees/ha for a basal area of 24.1 m^2 / ha. Results also showed significant differences in farmers' practices which enabled us to distinguish three main cocoa agroforestry Systems (AFS): Simple AFS with open canopy and high density of plantain trees, characterized by the hybrid varieties; young complex AFS with high species diversity and opened canopy; and complex AFS with dense and closed canopy characterized Amelonado variety. These results highlight the strategy adopted by the farmers in the management of cocoa plantations in the zone of transition forest-savannah. Additional analyses must be done to assess their yield and the biomass.

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Introduction

About 1.4 billion people in the world work in agriculture. Among them, 96% lives in Southern countries where familial farming, based on slash-and-burn system, was viewed, for long, as the major cause of unsustainable agriculture. Indeed, this practice is considered as one of the main causes of deforestation which induced global warming (Ferraton and Touzard, 2009). In West and central Africa particularly, introduction of the cash crops such as coffee and cocoa has increased this forest depletion. Adoption and the monopolization of the lands by these cropping systems have led to a decrease in fallow length in traditional systems due to their life cycle varying between 30 and 50 years (Blanc Pamard, 1978). However, all these practices do not mean loss of the biodiversity. Many studies showed that the traditional agroforestry systems (AFS) would participate in the conservation of the local diversity, and in the fight against the global warming (Rice and Greenberg, 2000, Bhagwat *et al.*, 2008). These agroforestry systems can bring in some economic and ecological benefits according to their highly diverse structural and compositional complexity (Ruf and Schroth, 2004, Deheuvels *et al.,* 2012). They offer a diverse types of habitat on which depend directly the main crop, the associated ones and the populations for they survived.

In Côte d'Ivoire, characterization of cocoa cropping systems is mainly based on the varieties of cocoa trees. The "Amelonado" variety generally called "Français» is very often associated with systems having complex structure and with high trees diversity. At the opposite, the hybrid varieties are identified by systems with simple structure and low diversity (Ruf and Schroth, 2004). The introduction of the hybrid varieties of cocoa from 1950 was so considered as the beginning of the disappearance of the complex agroforestry systems in the first cropping areas (Ruf, 1991).

In the forest-savannah transition zone, where low rainfalls and high frequency of bushfires made difficult a good practice of the cocoa farming, multistratified systems have been the main way to introduce this cash crop in the region since 1930 (Blanc-Pamard, 1978, Chauveau, 1979). These systems seem to persist in despite of the change of cocoa trees varieties. Sometimes, as it is the case in the Sub-prefecture of Kokumbo, theses practices favor several generations of cocoa trees in the same farm and provide different products which are essential in the daily life and play an important role in local economy (Herzog, 1994). In the transition zone, few studies about the farming management practices have been done in Kokumbo area. The environmental and human factors as well as theirs interactions that could impact associated species diversity, structural and compositional complexity of the cocoa-based AFS are not enough analyzed.

The objective of the present study was to understand the cocoa-based AFS in the forest-savannah transition zone. Especially, we intended to assess the diversity and structure of cocoa farms, to analyze the possible interactions between the various biophysical factors and the vegetation features of plantations, and to establish the typology of the various agroforestry systems in this ecological transition area.

Material and methods

Site of study

The sub-prefecture of Kokumbo (Center, Côte d'Ivoire) is located within the western side of the "V Baoulé" between the latitude 6°19 ' 43.3 " and 6°41 ' 20.7 " North and 5°04 ' 44.35 " and 5°21 ' 06.5 " longitude West. It belongs to the department of Toumodi and the region of the "Bélier". The populations are mainly made up of native "Baoulé", came after various waves of migrations (Chauveau, 1979) and several non-native groups. The climate of the region, an equatorial type of transition (Eldin, 1971) is characterized by annual rainfalls that vary between 1106 mm and 1300 mm. The annual temperatures vary between 26.5°C and 28°C. The vegetation belongs to the mesophilous sector of the Guinean domain (Guillaumet and Adjanohoun, 1971). It is made up of a mosaic of Guinean savannahs and semi-deciduous evergreen forest with characteristic species like *Celtis* spp (Cannabaceae) and *Triplochiton scleroxylon* K. Schum. (Sterculiaceae). Within the study zone, savannah areas increase while moving away from the Bandama River (Hiernaux, 1975). The soils lay on vast granitic substratum, metamorphic and shale rocks (Perraud, 1971). In terms of topography, the study area belongs to the "Chaîne Baoulé" with an elevation between 100 m. The highest peak, mount "Kokumbo-Boka" rises 505 m.

Choice of sites and data collection

The choice of the study sites took was based on various preexisting vegetation covers (Hiernaux, 1975). Three sites were chosen: Langossou, with close contact to savannahs zones where forest and the savannahs seem to have equivalent proportions; Niamkey-Konankro, located in mountainous area dominated by semi-deciduous forests, and Kimoukro characterized by forest in contact with the border of the river Bandama (Fig.1.).

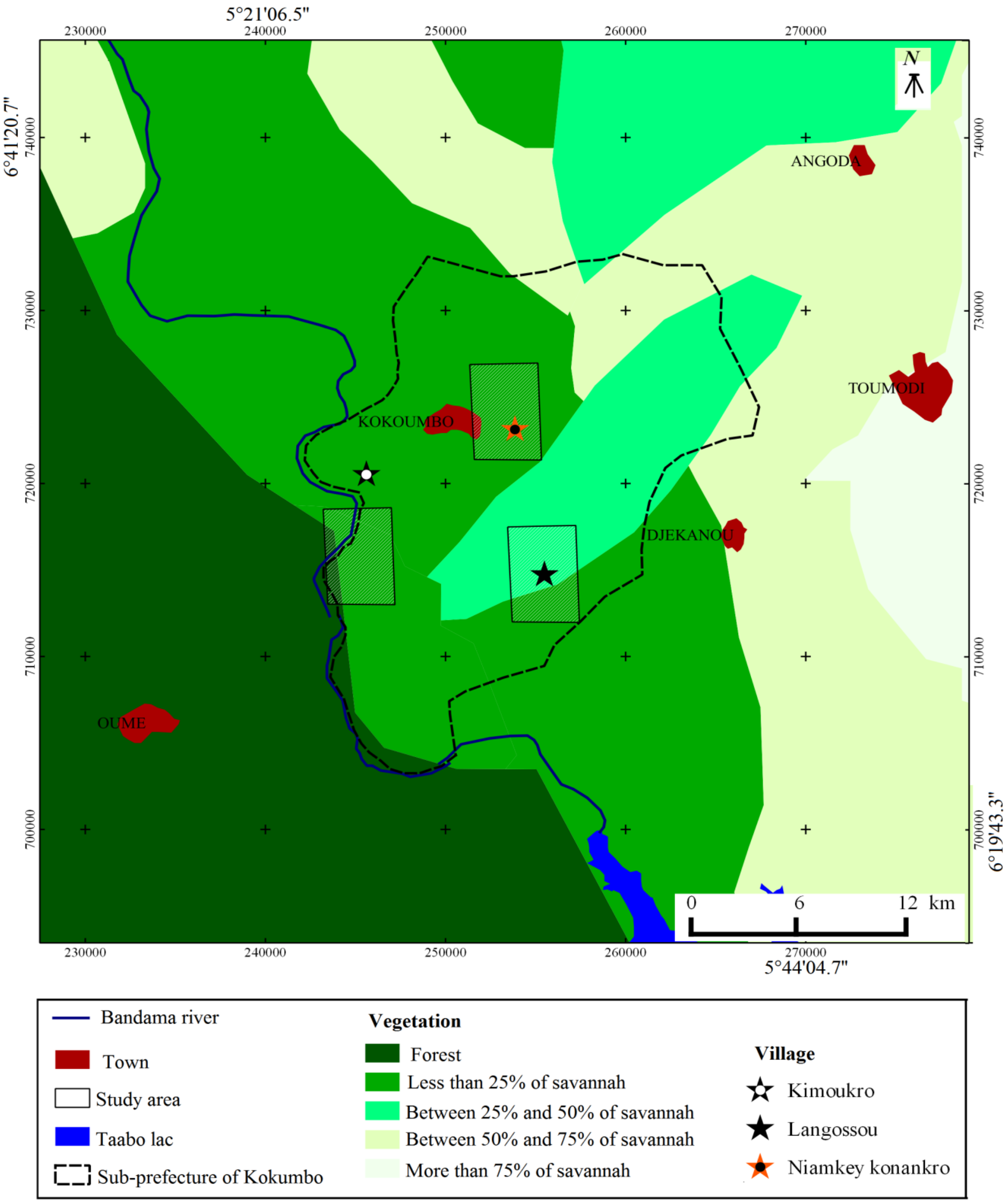

Fig. 1. Sample areas location in « V Baoulé » forest Savannah mosaic sectors (Source: modified by Hiernaux, 1975).

In each of these sites, a survey was undertaken with farmers to identify cocoa AFS and the factors that could guide the choices of their associated management practices. The certified farms and the uncertified ones were distinguished during the interviews. In each of the visited plots, we recorded the type of the cocoa cultivated in the AFS, the former agriculture practices, the age of the farms, the possible benefits they gained from the farms. Then, in some selected farms, plots 625 m² (25 m x 25 m) were installed so as to avoid border effects. In each plot, all plant species, with dbh 2.5 cm or over, were recorded and counted to determine their richness and composition. The total heights of plant species were also measured. The data allowed us to assess the diversity and structural parameters of each cocoa-based AFS.

In this work, the ground cover stratum (herbaceous stratum) was not taken into account because this part was regularly cut during the weeding of the farms.

Analytical methods

Plant species richness, composition, and diversity

The Cronquist (1981) classification was adopted in this manuscript and the names of plants were corrected according to Lebrun and Stork (1997). The plant species of each plot was listed. The compilation of all the lists provided the cocoa-based AFS associated plant species richness and composition. Diversity was assessed by the calculation of the Shannon (1948), Pielou's evenness (1966) and Simpson (1949) indexes which formulas are recorded in Table 1.

Table 1. Mathematical formulas of calculated floral and structural indices.

Indices	Equations
Index of Shannon (H)	$H' = - \Sigma (ni/N) \ln (ni/N)$
Index of Pielou (E)	$E = H'/\ln S$
Index of Simpson (D')	$D' = 1 - \sum(((n\_i * (n\_i - 1)) / (N(N-1))$
Density of individuals (d) indv/ha	$d = N / s$
Basal area (A) en m²/ha	$A = D^2 \times \pi / 4$

ni : Individuals number of a species i ; N : Total individuals number ; S : Total species number from a biotope ; D : Individuals diameter ; s : surface in hectare.

The life forms of each associated species were determined according to o Aké-Assi (2001, 2002): plantain trees (Geophytes) and Phanerophytes. The phytogeographical zone and chorological affinities were used to assess the type of species kept by farmers in their plantation. Five categories were distinguished: introduce or exotic (i), Guineo-Congolian (GC) and Guineo-Congolian fruit trees (GC_f), Guineo-Congolian/Soudanian (GC-SZ), and Guineo-Congolian/Soudanian fruit trees (GC-SZ_f) and coffee trees.

Structural parameters (densities and basal areas) were computed for associated species. Four classes of height were defined to assess the vertical structure of the cocoa farms (Table 2). For cocoa trees, only the average height was calculated.

Table 2. Classes of heights retained in biotopes vertical structure study.

Classes of heights	Denominations
2 - 4 m	Lower stratum
4 - 8 m	Medium stratum
8 -16 m	Upper stratum
> 16 m	Emergent stratum

Determination of cocoa production system

Both qualitative and quantitative variables were measured and used to describe each plot. The quantitative are represented by different group of variables which explain flora diversity, Biological types, Chorological affinity, Structural parameters of cocoa and associated plants and altitude. The qualitative parameters included the topographic position, the sample zone (locality), the cocoa cultivated variety, the former cultural system, farm certification and farmers supervision.

A Multiple Factorial Analysis (MFA) was performed on each group of variables (Pagès, 2002). This analysis is recommended to estimate the relationship between several cases of contingency having equivalent lines constituted of plots from plants survey (Bouxin, 2011). Afterward, a Cluster analysis, based on the Euclidian distance and the method of aggregation of Ward, was performed on plots' coordinates on the first twenty two dimension of MFA explained 90% of the variation. A clustering performed on the first principal components issues from MFA allows to create a clustering balancing the influence of each group of variables. This combination of MFA and cluster analysis is recommended to the creation of typologies (Kristensen, 2003, Avelino *et al.,* 2006, Deheuvels *et al.,* 2012).

Chi-square and Fisher tests were respectively performed on qualitative and quantitative variables to identify those which discriminate well the groups of plots. Mean comparisons of and assignment to clusters were made using the hypergeometric test (v test) at $p < 0.5$, using FactoMineR package of R (Bécue-Bertaut and Pagès, 2008).

Results

Richness, diversity and botanical composition

A total number of 2,149 stems were recorded in the cocoa-based agroforestry systems. These stems belonged to 86 species, 74 genera, and 36 families. The richest families were Moraceae (9 species) and Sterculiaceae (8 species). Most species were inventoried in Niamkey-Konankro the richest AFS, the average species richness varied from 4 species to 6.4 per 625 m² plot. The Shannon's index was low in all sites (1.16) and varied from 0.9 (Kimoukro) to 1.3 (Niamkey-Konankro). Pielou evenness index varied also from 0.7 in Kimoukro to 0.8 in Langossou. Simpson index varied from 0.5 (Kimoukro) to 0.6 (Niamkey-Konankro). In the entire study area, plantain trees were the most represented with 36.1% of tree (table 3). In total, the different parameters of richness, diversity, and composition varied from one site to another (Table 3).

Table 3. Floristic characteristics of sample plantations in the three sites.

	Floristic characteristics	Locations			
		Kimoukro	Langossou	Niamkey-Konankro	Overall means
Richness	Total species record	22	40	73	86
	Average species per plot (625 m²)	4	4,1	6,4	5,2
Diversity	Shannon Index	0,9	1,1	1,3	1,1
	Pielou Index	0,7	0,8	0,7	0,7
	Simpson Index	0,5	0,6	0,6	0,5
Biological type	Plantains trees (%)	32,6	44,6	31,0	36,1
	Nanophanerophyte (%)	0	0,3	0,2	0,2
	Microphanerophtye (%)	23,3	22,3	18,6	20,6
	Mesophanerophyte (%)	30,2	26,9	42,8	35,3
	Megaphanerophyte (%)	13,8	5,7	7,2	7,7
Chorological affinties	Coffee (%)	4,1	7,1	5,6	5,9
	Exotic species (%)	49,8	57,3	41,5	48,3
	GC (%)	21,6	12,4	14,2	14,7
	GC_f (%)	15,2	20,4	29,3	24,1
	GC-SZ (%)	9,1	2,3	9	6,6
	GC-SZ_f (%)	0	0,3	0,2	0,2

Phytogeographic zone : GC : Guineo-Congolian ; GC_f : Guineo-Congolian fruiterers ; GC-SZ : Guineo-Congolian/Soudanian ; GC-SZ _f : Guineo-Congolian/Soudanin Fruiterer.

The Nanophanerophytes plants were less represented (0.02%) while the exotic species (i) had the most dominant individuals in all the sites. The Guineo-congolian species (GC and GC-f) were represented by 38.7% of all individuals. Coffee trees were less represented in the cocoa-based AFS with only 5.9% of trees.

Densities and basal areas of the plant species

The global density was 227.3 trees/ha for a basal area of 24.1 m²/ha. The lowest density of plant species associated with cocoa trees was recorded in Kimoukro (133 trees/ha). The highest density was recorded in Langossou (347.3 trees /ha). The biggest mean basal area of the species, is recorded in the farms of Niamkey-Konankro (31.4 m²/ha) and the lowest in Kimoukro (13.6 m²/ha).

In the lower stratum of the study zone 31.8% of the species associated with cocoa trees were recorded in average. This proportion of individuals varied from 15.5% (Kimoukro) to 37.8% (Niamkey-Konankro). In the medium stratum of the entire study area, 37.2% of the associated species were censued. They varied from 36.2% (Kimoukro) to 44.1% (Langossou). The number of associated in the upper stratum varied between from 12.6% (Niamkey-Konankro) to 21.5% (Langossou) with an average of 16.6%. In the emergent stratum, the listed species varied from 3.8% (Langossou) to 29.9% (Kimoukro). The average density of cocoa varied from 2023 trees/ha (Kimoukro) to 2473.2 trees/ha (Niamkey-Konankro). The average basal area of cocoa-trees was 23.56 m²/ha, it varied from 12.1 m²/ha (Langossou) to 34.3 m²/ha (Niamkey-Konankro). The average height is 5.7 m for all the plantations.

Typology of the cocoa-based agroforestry systems

The multivariate analysis grouped the sampled cocoa farms into three clusters (Fig. 2.). Among the 32 variables used in the analysis, 24 allowed the discrimination of these various clusters (Table 5 and Table 6).

Table 4. Values of plantations structural parameters.

Structural parameters		Kimoukro	Langossou	Niamkey-Konankro	Overall means
Associated species	Density (trees/ha)	133	347,3	172	227,5
	Basal area (m²/ha)	13,6	18,2	31,4	23,1
	Lower stratum (%)	15,5	30,4	37,8	31,8
	Medium stratum (%)	36,2	44,1	32,5	37,2
	Upper stratum (%)	18,2	21,5	12,6	16,6
	Emergent stratum (%)	29,9	3,8	16,5	14,1
Cacao trees	Density (trees/ha)	2023	2181,1	2473,2	2301,7
	Basal area (m²/ha)	15	12,1	34,3	23,5
	Average height of cacao trees	5,8	5,6	5,8	5,77

Table 5. floristic and structural characteristics of groups from AHC.

Variables group	Variables	G1(38)	G2(28)	G3(39)	Overall means	Fischer value
Diversity	Species richness	4[a]	7,6[c]	4,7[b]	5,2	0,2***
	Shannon Index	0,8[a]	1,4[c]	1,2[b]	1,1	0,2***
	Pielou Index	0,7[a]	0,7[a]	0,8[b]	0,7	0,1**
	Simpson Index	0,4[a]	0,6[b]	0,6[b]	0,5	0,2***
Biological types	Plantain trees (%)	57,8[c]	43,5[b]	9,5[a]	36,1	0,40***
	Nanophanerophyte (%)	0	0,7	0	0,2	NS
	Microphanerophyte (%)	22,9	21,6	17,66	20,6	NS
	Mesophanerophyte (%)	15,7[a]	32,1[b]	56,6[c]	35,3	0,4***
	Megaphanerophyte (%)	3,3[a]	1,8[a]	16,1[b]	7,7	0,2***
Chorological affinity	exotic trees (%)	73,5[c]	54,3[b]	19,4[a]	48,3	0,5***
	Coffee (%)	6,6	9,6	2,5	5,9	NS
	GC (%)	7,8[a]	6,08[a]	27,63[b]	14,7	0,3***

Variables group	Variables	G1(38)	G2(28)	G3(39)	Overall means	Fischer value
Structural parameters	GC_f (%)	10,7^a	26,5^b	35,2^c	24,1	0,2***
	GC-SZ (%)	1,1^a	2,9^b	14,8^c	6,6	0,2***
	GC-SZ_f (%)	0	0,4	0,3	0,2	NS
	Density (trees/ha)	352,4^c	210,2^b	118,9^a	227,8	0,1**
	Basal area (m²/ha)	13,5^a	18,1^b	38,6^c	24,1	0,2***
	Lower stratum (%)	34,4^b	57,4	10,9^a	31,8	0,3***
	Medium stratum (%)	45,2	31,6	33,4	37,2	NS
	Upper stratum (%)	17,5^b	7,9^a	22^b	16,6	0,1*
	Emergent stratum (%)	2,7^a	2,9^a	33,1^b	14,1	0,3***
Cacao trees	Age (year)	22,4^a	22,9^a	52,9^b	33,8	0,3***
	Average height (m)	5,6^b	4,8^a	6,5^c	5,7	0,1***
	Density (trees/ha)	2089,6	2328,5	2489	2301,7	NS
	Basal area (m²/ha)	10,4	8,9	46,8	23,5	NS
Topographic position	Altitude (m)	206,7^a	366,7^c	287,4^b	279,4	0,4***

NS : variable that does not participate to AHC classes creation ; for each row, values followed by the same letter are not significantly at 5% level; tests of Fisher significance levels : * < 0,05, **<0,01, ***<0,001.

Phytogeographic zone : GC : Guineo-Congolian ; GC_f : Guineo-Congolian fruiterers ; GC-SZ : Guineo-Congolian/Soudanian ; GC-SZ _f : Guineo-Congolian/Soudanian Fruiterer.

Table 6. Biophysical and human variables characteristics of different plantations groups**.**

Category	Variables	G1 (38)	G2 (28)	G3 (39)	Overall means	Khi-deux value
Sample zone	Kimoukro	26,3	0	15,4	15,2	53,9***
	Konankro	5,3	92,9	61,5	49,5	
	Langossou	68,4	7,1	23,1	35,2	
Cocoa variety	Français (%)	5,3	7,1	53,8	23,8	43,4***
	Ghana (%)	47,4	50	33,3	42,9	
	Français/Ghana (%)	15,8	28,6	10,3	17,1	
	Français/Mercedes (%)	5,3	0	0	1,9	
	Ghana/Mercedes (%)	23,7	7,1	0	10,5	
	Français/Ghana/Mercedes (%)	2,6	7,1	2,6	3,8	
Former agricultural practice	Forest (%)	21,1	42,9	66,7	43,8	20,6***
	Fallow (%)	21,1	10,7	2,6	11,4	
	Plantation (%)	55,3	46,4	25,6	41,9	
	Savannah (%)	2,6	0	5,1	2,9	
Topographic position	Bottom of slope (%)	21,1	21,4	28,2	23,8	27***
	Above of slope (%)	13,2	17,9	15,4	15,2	
	Plateau (%)	60,5	10,7	28,2	35,2	
	Apex of slope (%)	5,3	25	17,9	15,2	
	Valley (%)	0	25	10,3	10,5	
Farmers supervision	Non supervised (%)	63,2	82,1	59	66,7	NS
	Supervised (%)	36,8	17,9	41	33,3	
Farm certification	Non certified (%)	13,2	67,9	15,4	28,6	28,9***
	certified (%)	86,8	32,1	84,6	71,4	

Variety : "Français" : Amelonado, "Ghana" : Forasteros High-Amazonian and hybrids ; Mercedes : Forasteros High-Amazonian Hybrid and Amelonado and Trinitario mixture.

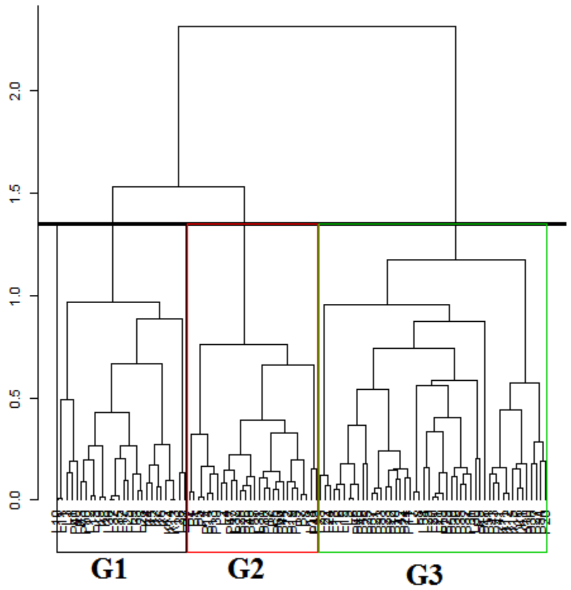

Fig. 2. Hierarchical clustering; the individuals are sorted according to their coordinate on the first principal component.

Description of cocoa-based AFS types

AFS type G1

The plots that make up the cluster G1 were observed in all sites but mainly in Langossou and Kimoukro (Table 6). There were farms which age varied from 2 to 70 years (22.4 years in average). They are located on plateaus (62.2%), with the lowest altitude (206.7 m), including the highest rate of mixed cocoa hybrid (23.7%) named "Ghana" and "Mercedes" by farmers. They were mainly settled on old cocoa farms (55.3%) and farm certified (86.7%). In this cluster, the species richness was the lowest (Table 5). Life forms were dominated by exotic species (73.6%) mainly represented by plantain trees (57.8%) and Microphanerophytes (22.9%). Low rate of Mesophanerophytes (15.8%), Megaphanereophytes (3.3%) and local species (GC, GC_f and GC-SZ), were recorded in this cluster (table 6). The cluster was characterized by the lowest proportion of emergent stratum species (2.7%) and the highest density of associated species (352.4 trees/ha) corresponding to the lowest basal area (13.5 m^2/ha).

AFS type G2

This cluster of AFS type G2 was exclusively represented by plots from Niamkey-Konankro and Langossou. They were located at 366.7 m a.s.l. (average age of 22.9 years). Here, was recorded the lowest rate of Amelonado variety (Table 6). This cluster had the highest species richness (7.6 species/plot) and Shannon index of diversity (1.4). The proportion of exotic species (54.3%) dominated by plantain trees (43.5%) was lower than the cluster G1. The indigenous fruit species individuals were most important in this group compare to the cluster G2 (table 5). The density and the basal area of the associated species were significantly lower than those of cluster G1 but remained higher than those from cluster G3. The vegetation structure was represented by the highest proportion of individuals in the lower stratum (59.4%) and the lowest rate of individuals in the upper and emergent strata. The average height of the cocoa trees (4.8 m) in this cluster was the lowest (Table 5) in compare with other clusters.

AFS type G3

The plots belonging to this cluster G3 were observed in Niamkey-Konankro cocoa farms (61.5%). Their average age, 52.9 years, was higher than those of the previous two clusters. Farms were mainly settled up by clearing natural forests (66.7%). They were located at 287.4 m a.s.l. in average and the Amelonado was the most cultivated variety. In this cluster plots, the values of Pielou index were the highest (table 5). Contrary to clusters G1 and G2, the indigenous species were high (34.1%) and they were dominated by the fruit species. The highest proportions of Mesophanerophytes (56.6%) and Megaphanerophytes (16.1%) were recorded. Density of the associated species (118.9 trees/ha) was low while their basal area (38.6 m^2 / ha) was the highest. They were also characterized by a large proportion of individuals in the highest stratum (33.1%). The average height of the cocoa trees (6.5 m) in this cluster was the higher (Table 5) in compare with other clusters.

Discussions

In this study, we characterized cocoa based agroforestry systems (AFS) of Kokoumbo area and we assessed the diversity of associated tree species of these AFS. The plant species inventory a high diversity in this forest-savannah transition zone. A total of 86 species were recorded in the plots of AFS. This associated flora was made of indigenous and exotic trees and shrubs. Concerning the structure, a large density of species individuals was recorded, which distribution varied according to the strata. All these parameters confirmed that these cocoa farms around Kokumbo can be qualified as agroforestry systems as Herzog (1994) suggested it.

Identification of cocoa production systems

Cocoa farms vegetation and structural characteristics varied significantly according to most of the biophysical factors. Three groups of plots were identified. Every group represented an agroforestry system (AFS) type according to its features. Usually, the name of the AFS leaned on two types the cocoa production systems (Somarriba and Lachenaud, 2013). The first type of classification was based on the crop combination and the structure of the vegetation (John, 1999, Moguel and Toledo, 1999, Rice and Greenberg, 2000). Five main types of cocoa plantations were described: full sun cultivation, specialized shade, commercial shade, mixed shade and rustic systems. Compared to the present study area, the AFS identified presented a large diversity of native, exotic and/or plant species with commercial value. These factors allowed keeping, in this transition zone, only farms with mixed shade, and rustic systems. The distinction between these two systems was generally made by the cocoa variety and the vegetation structure. Indeed, Ruf and Schroth, 2004 described plantations under mixed shade as being linked to the introduction of the hybrid varieties of cocoa. Their implementation of system consisted at first, in cutting down almost the local species in order to keep only the useful species which will accompany cocoa trees when growing. It resulted in a low density of big trees in farms. Then, farmers introduce edible or exotic species to preserve shade and diversify of their source of incomes (Koko *et al.,* 2013). This description corresponded to those from the first two groups (G1 and G2) observed in this study. The rustic systems were on the contrary, characterized by the presence of non hybrid varieties as Amelonado (Ruf and Schroth, 2004). This type of production system was set up after cutting the small trees and destroying some trees considered as harmful. This was shown by a high density of big trees which gives, to AFS, a progressive structure and source of confusion with a secondary forest (Sonwa *et al.,* 2007, Jagoret *et al.,* 2009). In the present study, the farms of G3 corresponded to this description. This first classification of the type of production systems did not however allow us to differentiate the two groups G1 and G2 identified. For numerous authors such as Deheuvels *et al.* (2012), it was beyond the questions of complexity and variability. Indeed, Somarriba and Beer (2011) indicated that the vegetation characteristics of cocoa farms could vary at the same time inside regions, farms, and even inside plots. A second classification was thus used by these authors to define the level of complexity from descriptive variables of the vegetation composition, floristic diversity, structure, and dominant variables (Deheuvels *et al.*, 2012). We thus distinguished, very simple systems, monospecific with a unique and complex stratum through species diversity and/or vegetation structure (Somarriba and Lachenaud, 2013). In our case, considering first of all, the diversity of the associated species, the most complex AFS were those from group G2 which richness and calculated diversities were the highest compare to farms of groups G3 and G1. Looking at species composition, the variables which allowed us to appreciate better the complexity of farms were trees (Megaphanerophytes and Mesophanerophytes). They were generally represented by indigenous species. These types of species, by their large proportion in a cocoa farm could predict a dense canopy over time. At the opposite, a large proportion of exotic species result either in the presence of full sun cocoa system or the one of young plantations (Jagoret *et al.,* 2009). The complex systems were thus the farms of groups G2 and G3. In group G1 where small proportions of indigenous species were recorded, the plots had less dense and opened canopy. Concerning the complexity of structure, it was defined by the density of the individuals in both strata of cocoa trees and above this Group G3, with 50% of the individuals of species listed in these strata have a dense and closed canopy. Group G1 and G2 were distinguished by a more opened canopy. In the group G2, the rate of tall individuals in the lower stratum and the weak mean height of cocoa trees could be linked to the large proportion of young farms in this group. Finally, the variables which characterized better the groups were: the density of exotic species, especially plantain trees (G1); the high diversity (G2); and the dense and closed canopy (G3). On the basis of these criteria, the identified groups could be qualified as agroforestry systems: simple with open canopy and high density of plantain trees (G1); young complex with open canopy, and high diversified (G2); complex with dense and closed canopy (G3). Deheuvels *et al.* (2012) by using a similar method of analysis identified four agroforestry systems in Costa Rica. One of the AFS described by these authors, qualified as complex and dense canopy could correspond to the group G3. However, the differences of variables used did not allow correspondences with the rest of the AFS described by this author.

Biophysical and human factors influencing the choice of the agroforestry systems

Environmental factors

Topography and height of cocoa trees were the environmental factors identified as influencing the choice of the AFS. The analyses showed the simple AFS were encountered at the plateaus (G1). The complex AFS were more observed in mountainous areas. These results were understandable by the fact that the landscape affected the availability of grounds and the sufficient water for implementation and development of cocoa trees (Perraud, 1971, Koko *et al.,* 2009). Farmers maintained a large density of indigenous species in the mountainous zones to fight against soil erosion. That explained the presence of complex AFS in Niamkey-Konankro where the landscape was the most uneven. On the contrary, in less uneven zones, grounds being rather deep, the major concern of the farmer was linked to the management of water in the farm. Very few species were thus associated to cocoa trees when the environment was rather wet. That was the case in Kimoukro where farms were close to the river Bandama, which explained the dominance of simple systems. In Langossou, the abundance of simple systems would rather be linked to the large proportion of savannah. Indeed, humidity being low, big trees were replaced by a high density of exotic species to avoid competitions with cocoa trees (Blanc-Pamard, 1978).

Variety and the previous crop systems

Analyses showed that the simple agroforestry systems (G1) were correlated to the hybrid varieties ("Ghana" and "Mercedes") in the old farms as the previous crop system. In complex systems however, proportions of non improved varieties (Amelonado) and plantations created by clearing the forests were important. These results demonstrated that the cultivated varieties and the previous systems required the choice of cocoa cultivation under shade or full sun. Indeed, each of the cultivated varieties was linked to a type of farming practice. The variety Amelonado, named "Français" by farmers, was present under a closed canopy because the crop required the preservation of the shade during all the life cycle of the plantation (Ruf and Schroth, 2004). Its introduction in the area was made around 1930 (Chauveau, 1979) under bright period of the forest. It explained the presence in the oldest cocoa plantations and those created by forest clearing. The complex structure of cocoa plantations with “Amelonado” variety was also revealed in the west central region of Cote d’Ivoire and in Cameroon by numerous authors (Ruf and Schroth, 2004, Sonwa *et al.,* 2007, Jagoret *et al.*, 2009). The variety named "Ghana" by farmers corresponded to the Upper Forastero Amazonian and its hybrids introduced in Ghana around 1950 (Ruf, 1991) then popularized after 1970. The simultaneous presence of these hybrids in the three agroforestry systems was understandable by the fact that the first introduced varieties would be fewer hybrids and bearing more shade than those distributed by the structures of farmers’ supervision (Ruf, 1991). This distinction was made by the farmers under the name of “old Ghana” for the first varieties and “new Ghana" for those distributed by supervisors. The variety named collectively "Mercedes" is a relatively new hybrid in Côte d'Ivoire. It was associated with the rehabilitation of the old cocoa farms. It arised from the continuous mixing of Forastero High Amazonian, Amelonados and Trinitarios (Pokou *et al.,* 2009). It did not tolerate the excessive shade, which explains its predominance in Kimoukro and Langossou where the simple AFS dominated. The adoption of this new variety by the farmers was guided by its capacity to produce continuously every month while the first ones produced only two or three times in a year. Its presence in the complex systems could explain their progressive abandonment but also a distrust of the farmers towards the latter that they considered as fragile.

Human impact

This factor allowed characterizing the level of training of farmers and their origins. Numerous authors showed that cocoa plantations devoided of big trees belonged to the foreign populations (non-native and immigrant) in a given area. At the opposite, the plantations of natives were more supplied in local species (Ruf and Schroth, 2004, Adou Yao and N' Guessan, 2006). These observations are confirmed in the study zone although all the visited plantations belonged to farmers of the same ethnic group (Baoulé). Indeed, populations belonging to the first waves of migrations of this ethnic group and founders of the city of Kokumbo settled down around the Mount Kokumbo for gold mining (Chauveau, 1979). It was the case of Niamkey-Konankro where prevailed complex AFS even if plantations are young (G2). Preservation of complex systems met the need of assuring supply in non-timber forest products (NTFPs). Farmers of Kimoukro and Langossou considered themselves, generally, as immigrant. They were mainly the second wave of migration of baoulés people in this area (Chauveau, 1979). Lands were lent to them for the production of food to feed the workers of the mines of Kokumbo. For these "foreign" populations, the implementation of systems capable of assuring a good cocoa production was the priority whence the presence of simple agroforestry systems in these sites.

Conclusion

The inventory of cocoa plantations of the sub-prefecture of Kokumbo allowed listing 86 plant species preserved by farmers. Beyond the plant diversity, this study underlined the existence of varied vegetation composition and structure of cocoa farms in a set of environmental and human factors. The cultivated variety alone did not allow characterizing the systems of cocoa farms production. It was also necessary to take into account the landscape, the previous crop cultivation system and the social context. The analysis of the incidence of these factors on the farmers' practices ended in the identification of three main clusters of agroforestry systems (AFS). The simple AFS with open canopy and high density of plantain trees, located on plateaus were characterized by the hybrid varieties. The young complex systems with high diversity and open canopy were observed in the mountainous areas. The complex systems with dense and closed canopy were made up of old cocoa farms where the "Amelonado" variety was dominant. The study allowed highlighting the typology of the cocoa production systems in the forest-savanna transition zone of Côte d'Ivoire. An assessment of the economic benefits of these systems as well as their ecological values remained useful in proposing definitive choices for farmers.

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