Impact of Cropping Systems on the Yield of Cocoa Trees in the Daloa Department

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Abstract: ***Since 1978, Côte d'Ivoire has been the world's leading cocoa produce. However, cocoa farming today is faced with numerous constraints due to unsustainable cropping systems. Some authors advocate agroforestry as a solution. But, the relationship between agroforestry systems and cocoa productivity has not been well established. Our study aims to present the floristic richness, the cropping systems and the impact of these systems on yield. Data was collected in 60 plots of 400 m² each in which an inventory, dendrometric measurements and counting of the number of cocoa trees and pods were carried out. The study found that cocoa farms are rich in 55 species divided into 46 genera and 24 families. The analyses made it possible to define three cropping systems in the cocoa farms. These are systems without shade with the lowest yields and composed mainly of fruit species, light shade systems dominated by spontaneous species with the highest yields and dense shade systems dominated by forest species with yields between 500 kg/ha/year and 1000 kg/ha/year.***

Keywords: Agroforestry, cropping systems, Peasant preservation, Sustainable management, Daloa

1. Introduction

Côte d'Ivoire, like most African countries, inherited the role of cocoa exporter in 1912 and made it the pillar of its economic development (Duguma *et al*., 2001). It has been the world's leading producer of cocoa beans since 1978, with annual production now estimated at 43 percent of world supply (ICCO, 2017). This culture plays an important role in the economic and social development of the country. At the social level, cocoa farming occupies an agricultural population of more than one million farmers and provides many jobs in the secondary and tertiary sectors (ICCO, 2015). Economically, cocoa contributes more than 15 p.c. to the Gross Domestic Product (GDP) and provides more than 50 p.c. of export earnings (BAD, 2020). However, the development of this crop has been extensive, to the detriment of forest areas (Freud *et al.*, 2000). This has led to a shift from multi-layered agroforestry systems to crops grown under moderate shade or even full sun. Today, the sustainability of Ivorian cocoa production is threatened by several constraints, notably the ageing of orchards and the difficulties of renewing them in the face of the shortage of forest, the action of diseases and insect pests of the cocoa tree and the harmful effects of climatic disturbances (Freud *et al.,* 2000). Faced with this situation, the Ivorian government has committed to several programmes, including the international REDD+ mechanism in 2011 and the Cocoa and Forests Initiative (CFI) with some thirty companies in the cocoa and chocolate industry (ICF, 2020). These commitments to agroforestry and sustainability have led to investments in certification and the initiation of tree distribution campaigns by environmental organisations including the Rainforest Alliance (RA) and Utz (Sanial *et al*,. 2020). Agroforestry seems to be an ecologically sustainable, socially acceptable and economically profitable alternative (Agroforestry Systems, 1982 ; Jagoret *et al*., 2020). However, there are mixed views on the logic of combining trees with crops, especially after a long period of removing them from cocoa farms. On the one hand, some recent publications (Steffan-Dewenter, 2007 ; Clough *et al.*, 2011 ; Jagoret *et al*., 2020) show that the presence of trees in cocoa farms does not prevent good yields. On the other hand, cocoa agroforestry systems are criticised for having lower yields than monocultures. According to some authors, the associated trees would induce competition for light, water and mineral elements, to the detriment of the cocoa trees. Thus, reducing shading in cocoa farms entering production would have a beneficial effect on productivity (Zuidema *et al*., 2005 ; Snoeck, 2010). In Côte d'Ivoire, despite the fact that agroforestry practices are very old, direct relationships between agroforestry systems and cocoa yield have not really been established (Vroh *et al*., 2019). However, it is important to find a compromise that reconciles good yields and the longevity of cocoa farms for sustainable cocoa farm management. This article presents the floristic diversity, cropping systems and the impact of cropping systems on the yield of cocoa farms. This approach aims to highlight the best performing cropping system in terms of yield in the current context of increased drought in Côte d'Ivoire (Dufumier, 2016) and the limitation of areas suitable for cocoa production (Jagoret *et al*., 2020). Our study was carried out in the locality of Zepreguhé, located in the Haut-Sassandra region, the second largest cocoa bean production area in Côte d'Ivoire. This study took place in the locality of Zepreguhé in Daloa in the Centre-West of Côte d'Ivoire in the Haut-Sassandra region (Nguessan *et al*., 2014).

2. Materials and methods

2.1. Description of the study site

This study took place in the locality of Zepreguhé located in Daloa in the Centre-West of Côte d'Ivoire in the Haut-Sassandra region (Figure 1). This region is characterised by semi-deciduous forest vegetation with an average annual rainfall of 930.60 mm for the last 30 years (Anonyme, 2020). The temperature varies between 27.46 and 28.16 °C with an average of 26.47 °C. The relief consists largely of plateaus with numerous valleys. Hydrographically, the region is influenced by the Sassandra River and its tributaries (the Lobo and the Davo) and the Buyo dam lake (Koffié-bikpo & Kra, 2013). The soils are ferralitic of granitic origin and slightly denatured (Perraud, 1971 ; Lecomte, 1990). In addition to the ferralitic soils, this region has poorly developed soils (from alluvial and/or colluvial deposits) and hydromorphic soils. Soils with a ferralitic composition have good agricultural potential and are suitable for all types of crops.

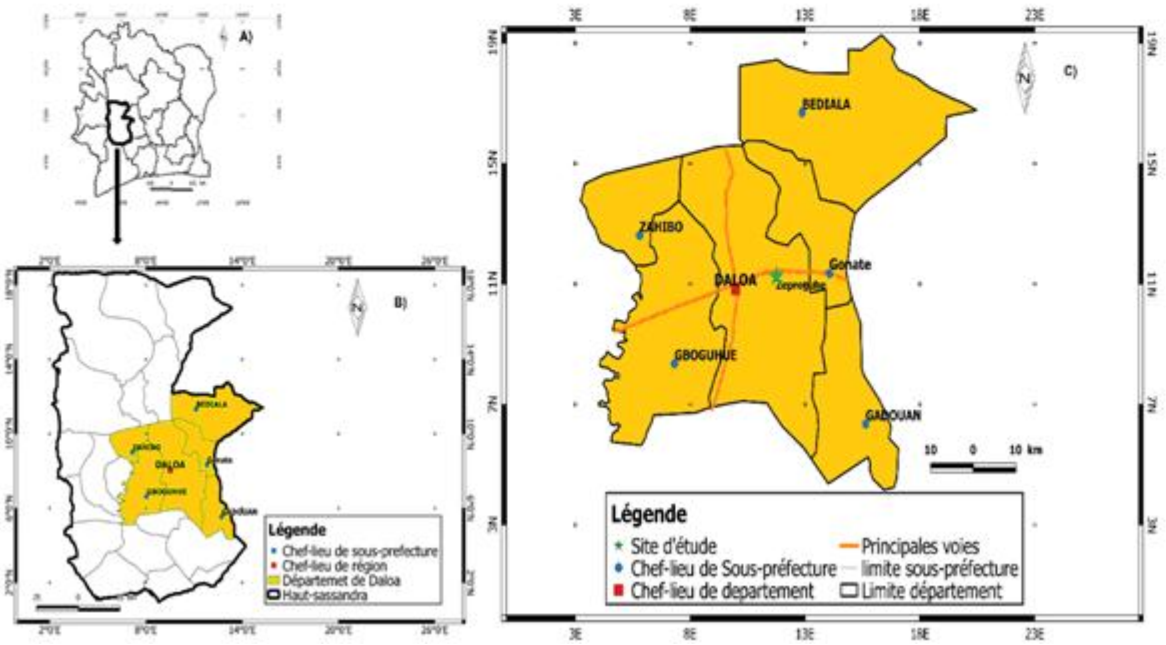

Figure 1: Location of the Haut-Sassandra region in Côte d'Ivoire (A), the department of Daloa (B) and the study site (C)

2.2. Inventory and dendrometric measurements

Floristic and structural data were collected in 60 plots of 20 m x 20 m (400 m^2) installed randomly in the most homogeneous areas of cocoa farms older than 8 years. In each delimited plot, all woody species were inventoried. Then the total height of all woody individuals other than cocoa trees, greater than or equal to 2 m and the circumference at 1.30 m from the ground were measured.

2.3. Measurement of shading and yield parameters

The shading rate was calculated for all woody individuals whose height is greater than the cocoa trees. For each individual considered, the circumference at 1.30 m above the ground, the total height, the height of the trunk and the diameter of the canopy were measured. The density of the canopy was estimated on a scale ranging from 0 to 100 per cent. Yield was assessed by counting and marking the pods with paint. The average number of pods per cocoa tree (Nbcab) was estimated from counting the number of fruits longer than ten centimetres on eight (8) cocoa trees in each 400 m² plot Bos *et al.*, 2006 as cited by Jagoret, 2011. In addition to the counting and marking of the pods, a count of all the cocoa trees was carried out.

2.4. Calculation of the recovery rate of cocoa trees

The area covered by the canopy of woody individuals associated with cocoa trees was calculated using Shademotion 4.0.3 software. The software was programmed to calculate the shade produced by the tree at noon. The cover rate of each associated woody individual (ri) was calculated from the following formula :

With ri= Cover of the woody plant percent
s= area covered by the canopy of the associated woody individual
S= plot of 400 m²

2.5. Evaluation of the potential yield of a cocoa

The potential yield of a cocoa farm (Q) depends on the average number of pods per cocoa tree and the density of the cocoa trees. It was calculated according to Lachenaud (1984) by the following mathematical relationship:

Where
Q= marketable cocoa yield (kg ha-1)
Nbcab : average number of pods per cocoa tree
0.115 : average mass of fresh beans per pod (kg)
0.35 : transformation coefficient mass of fresh beans/mass of marketable cocoa
d : number of cocoa trees ha^{-1}

2.6. Statistical analysis

To characterise the structural organisation of the woody flora of the agrosystems, a Correspondence Factorial Analysis (CFA) was carried out on the basis of the species encountered and their dimensions (diameter and height). The CFA was coupled with the Hierarchical Ascending Classification (HAC) to classify the different groups obtained. For each group, indicator species were identified

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using the IndVal method. To determine the cropping systems, a CFA was carried out based on the species encountered, their dimensions (diameter and height) and the types of cocoa tree cover. The CFA was coupled with an AHC in order to classify the different groups obtained. In order to determine the best performing cropping systems in terms of yield, a AHC was performed. All these analyses were carried out using the R 4.0.3 software.

3. Results

3.1. Floristic composition of cocoa farms

The list of species found in cocoa farms contains 55 species in 46 genera and 24 families. The most dominant families in terms of number of species are: Moraceae with 15 percent, followed by Euphorbiaceae (9 percent), Fabaceae and Rutaceae with 7 percent each, Anarcadiaceae and Apocynaceae with 6 percent and finally Bombacaceae (5 percent) see Figure 2. The species encountered during this study were of four biological types, the most dominant of which in terms of number of species were microphanerophytes with 55 percent (Figure 3).

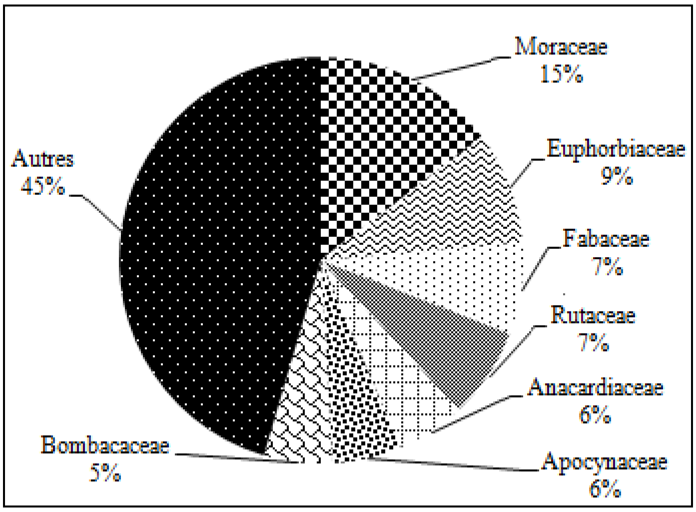

Figure 2: Spectrum of dominant families in cocoa agrosystems in the Zepreguhé zone

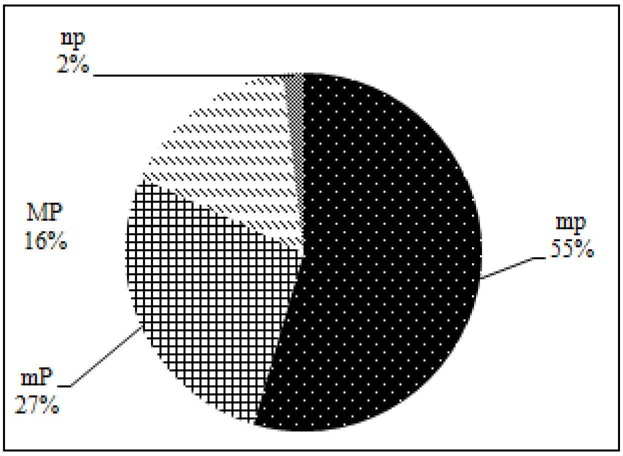

Figure 3: Spectrum of biological types of cocoa agrosystems in the Zepreguhé zone. Microphanerophyte; np: Nanophanerophyte; mP: Mesophanerophyte; MP: Megaphanerophyte

3.2. Structural organisation of woody species in cocoa farms

The study of the structural organisation of cocoa farms revealed three groups of species. Each group is characterised by an indicator species which has been revealed from the Indval method (Figure 4). Group 1 with *Coffea canephora* is characterised by species with small diameters (less than 10 cm) and small heights (less than 8 m). These species are mainly fruit trees such as: *Citrus limon*, *Annona muricata*, *Anacardium occidentale*, *Coffea canephora*, etc. Group 2 with *Sterculia tragacantha* consists of species with diameters between 10 and 30 cm and heights that vary between 8 and 12 m. This group is characterised by spontaneous species such as *Ficus exasperata*, *Morinda lucida*, *Sterculia tragacantha*, *Ficus vogelii*, etc. Group 3 with *Antiaris toxicaria* includes species with large diameters (greater than or equal to 30 cm) and heights greater than 12 m. These are mainly forest species such as *Ricinodendron heudelotii*, *Terminalia superba*, *Milicia excelsa*, *Khaya ivorensis*, *Entandrophragma angolense*, *Antiaris toxicaria*, etc.

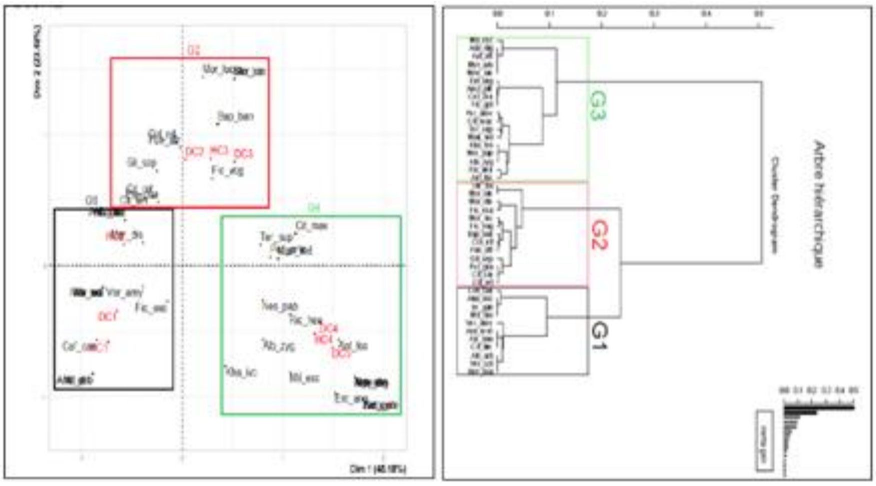

Figure 4: Graphical representation of species and dimensions along axes 1 and 2 of the CFA and HAC. DC1 : < 10 cm ; DC2 : [10 - 20 cm [; DC3 : [20 - 30 cm [; DC4 : [30 - 40 cm [and DC5 : ≥ 40
HC1: [2 - 4 m [; HC2: [4 - 8 m [; HC3: [8 - 12 m [and HC4: ≥ 12 m.

Codes	species	Groups	Codes	species	Groups
Alb_adi	*Albizia adianthifolia*	G1	Mor_ole	*Moringa oleifera*	G2
Als_boo	*Alstonia boonei*	G1	Psi_gua	*Psidium guajava*	G2
Ana_occ	*Anacardium occidentale*	G1	Ste_tra	*Sterculia tragacantha*	G2
Ann_mur	*Annona muricata*	G1	Ada_dig	*Adansonia digitata*	G3
Cit_lim	*Citrus limon*	G1	Alb_zyg	*Albizia zygia*	G3
Cof_can	*Coffea canephora*	G1	Amp_pte	*Amphimas pterocarpoides*	G3
Hev_bra	*Hevea brasiliensis*	G1	Ant_afr	*Antiaris africana*	G3
Irv_gab	*Irvingia gabonensis*	G1	Ant_tox	*Antiaris toxicaria*	G3
Mil_rho	*Millettia rhodontha*	G1	Cel_zen	*Celtis zenkeri*	G3
Ver_amy	*Vernonia amygdalina*	G1	Cit_max	*Citrus maxima*	G3
Ver_col	*Vernonia colorata*	G1	Ent_ang	*Entandrophragma angolense*	G3
Bap_ban	*Baphia bancoensis*	G2	Fic_gol	*Ficus goliath*	G3
Cit_ret	*Citrus reticulata*	G2	Kha_ivo	*Khaya ivorensis*	G3
Cit_sin	*Citrus sinensis*	G2	Man_ind	*Mangifera indica*	G3
Col_nit	*Cola nitida*	G2	Mil_exc	*Milicia excelsa*	G3
Fic_exa	*Ficus exasperata*	G2	Myr_arb	*Myrianthus arboreus*	G3
Fic_vog	*Ficus vogelii*	G2	Nes_pap	*Nesogordonia papaverifera*	G3
Fun_afr	*Funtumia africana*	G2	New_lae	*Newbouldia laevi*	G3
Gli_sep	*Gliricidia sepium*	G2	Per_ame	*Persea americana*	G3
Mar_dis	*Margaritaria discoidea*	G2	Ric_heu	*Ricinodendron heudelotii*	G3
Mor_luc	*Morinda lucida*	G2	Ter_sup	*Terminalia superba*	G3

3.3. Shade tree cover in cocoa farms

The analysis of shade tree cover shows that cocoa farms are managed according to four types of cover (Figure 5). In this locality, 20 percent of the plots studied do not combine trees with cocoa trees. Plots with trees represent 80 percent For the latter, plots under light shade are the most represented with 45 percent of the area. They are followed by medium shade plots with 22 percent of the area. Cocoa trees under strong shade are the least represented with 13 percent of the areas studied.

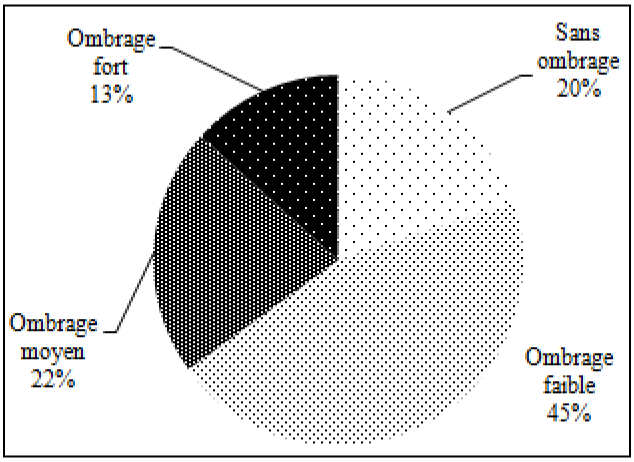

Figure 5: Proportion of shade tree cover types in cocoa agrosystems

3.4. Cropping systems encountered in cocoa farms

The characterisation of cropping systems in cocoa farms revealed three cropping systems (Figure 6). The density of each cropping system has been defined in Table I. Group 1 with *Coffea canephora* is composed of small fruit species found mainly in unshaded plots with a density of 56 (± 50,4) individuals/ha. These systems are said to be unshaded. Group 2 with *Sterculia tragacantha* consists of medium-sized spontaneous species found in plots with less than 25 percent shade and a density of 45 (± 19,61) individuals/ha. These are light shade systems. Group 3 with *Antiaris toxicaria* comprises large forest species present in plots with a shade of more than 25 percent and a density of 87 (± 39,79) individuals/ha. These are dense shade systems.

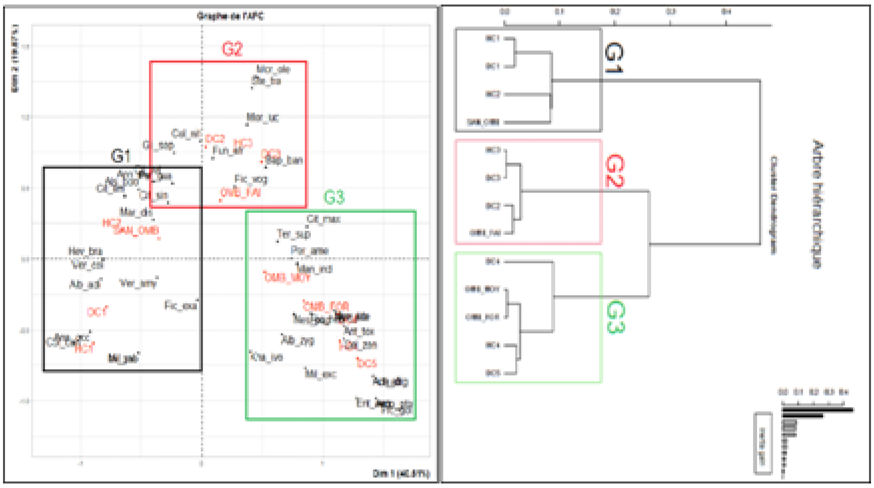

Figure 6: Graphical representation of species, height and diameter classes according to axes 1 and 2 of the CFA and HAC. DC1 : < 10 cm ; DC2 : [10 - 20 cm [; DC3 : [20 - 30 cm [; DC4 : [30 - 40 cm [and DC5 : ≥ 40
HC1: [2 - 4 m [; HC2: [4 - 8 m [; HC3: [8 - 12 m [and HC4: ≥ 12 m.
SAN_OMB=No shading, OMB_FAI=Low shading, OMB_MOY=Medium shading, OMB_FOR=High shading.

Table I: Density of cropping systems.

Cropping systems	Average number of individuals/ ha of associated species
Unshaded system	56 ± 50,4
Lightweight shading system	45 ± 19,61
Dense shade system	87 ± 39,79

Table II: Average potential yield and its components in Zepreguhé site according to the Pearson test.

Parameters	Average values
Number of pods/individual/year	35 ± 10,03
Number of cocoa trees/ha	804,01 ± 298,95
Yield Potential	1092,61 ± 450,82

3.5. Potential market cocoa yield and its components

The average potential yield of merchantable cocoa in Zepreguhé is 1092.61 (± 450,82) kg/ha/year. The average density of cocoa trees is 804.01 (± 298,95) individuals/ha with a production of 35 pods per individual over the year (Table II)

3.6. Yield of cropping systems

The performance of the cropping systems was revealed from a hierarchical ascending classification (HAC) see (Figure 7). Three groups were identified from this analysis. Group 1 associates systems without shading with potential yields below 500 kg/ha/year. Group 2 shows a correlation between dense shade systems and potential yields between 500 and 1000 kg/ha/year. Group 3 links light shade systems to potential yields of over 1000 kg/ha/year.

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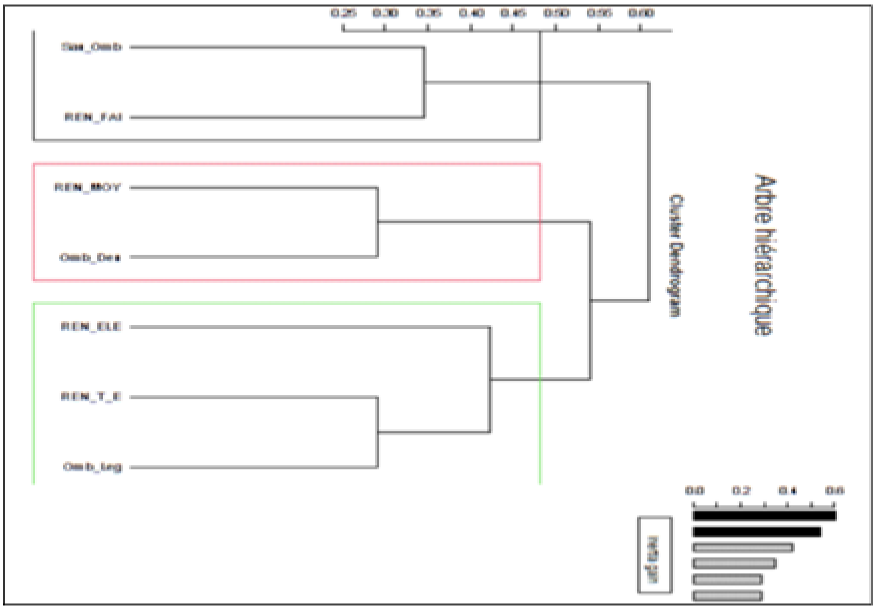

Figure 7: Graphical representation of cropping systems and cocoa yields from a HAC.
San_Omb=No shade, Omb_Leg=Light shade, Omb_Den=Dense shade.
REN_FAI=low yield, REN_MOY=average yield, REN_ELE=high yield, REN_T_EL=very high yield

4. Discussion

4.1. Floristic diversity and cropping systems

Work carried out in the locality of Zepreguhé has shown that the cocoa plantations are rich in 55 species divided into 46 genera and 24 families. These results corroborate several previous works that highlight the introduction and preservation of a significant number of species in cocoa farms in recent years (Koulibaly, 2008 ; Tondoh *et al.*, 2015). The species richness obtained in these areas is close to that found by Boko *et al.* (2020) in the cocoa farms of Doboua in the Department of Daloa (central-western Côte d'Ivoire) which was 59 species. The most dominant families are : Moraceae, Euphorbiaceae, Fabaceae, Rutaceae, Anarcadiaceae, Apocynaceae and Bombacaceae. This family sequence has also been cited as dominant in the cocoa agrosystems of Daloa in west-central Côte d'Ivoire by Boko *et al.* (2020). Moraceae and Euphorbiaceae were cited as dominant by Konan *et al.* (2011) and Apocynaceae were cited as dominant in cocoa farms in Cameroon by Temgoua *et al.* (2018). The presence of these families could be explained by the location of our study area, which is in a semi-deciduous forest zone, a favourite area for these families (Aké-Assi, 2002). In terms of biological types, microphanerophytes were the most dominant. This dominance of microphanerophytes would be due to their perennial life form including vegetative regrowth, which is the quantitatively important mode of regeneration in cocoa agrosystems as reported in the Oumé department and the Lamto reserve region (Piba *et al.*, 2011 ; Koulibaly *et al.*, 2016). The structural organisation of species associated with cocoa trees showed that the fruiting and volunteer species were shrubs. While the forest species were large trees. This organisation of species in cocoa farms is thought to be due to a farmers' preservation strategy. Indeed, according to Kouadio *et al.* (2016), when plantations are cleared, large forest trees are retained to provide shade for young cocoa trees and later for their economic value. Whereas fruiting and volunteer species appear later in the development of the plantation. Producers in the Zepreguhé locality retain and introduce shade trees into the cocoa fields in different proportions. In this locality, 20 percent of the plots are without shade and 45 per cent are under weak shade (less than 25 percent of shade). Several studies conducted on shading in Côte d'Ivoire have shown similar results. Ruf & Zadi. (1998) already estimated at that time that 66 percent of cocoa plantations throughout the country were unshaded. Another study recently conducted in the Centre-South of Côte d'Ivoire by Gala bi *et al.* (2017) showed that more than 70 percent of the plots studied were in full sun or light shade. This low level of shade in cocoa farms is thought to be due to the fact that most of these systems were established after complete felling and burning of primary forests and forest clearings (Dufumier, 2016). In the cocoa farms, three (3) cropping systems were detected. The first type is the unshaded system, which is characterised by an abundance of fruit species with diameters of less than 10 cm and heights of less than 8 m with a density of 56 individuals/ha. In this system, there is no real shading. It is the work of many research centres, including the National Agricultural Research Centre (NARC) with the selection of hybrids for the development of high-yield and disease-resistant varieties (Gnahoua *et al.*, 2012). The second type, the light shade system, is characterised by the dominance of spontaneous species with diameters of between 10 and 30 cm and heights of between 8 and 10 m. The density per hectare is 45 individuals with a cover of less than 25 percent This system is also the result of practices developed by the NARC, which, when planting crops, recommends associating young cocoa trees with legumes (*Gliricidia sepium*, *Sterculia tragacantha*, *Albizia adianthifolia*, *Albizia zygia*, etc.). The third type is the dense shade system which is characterised by the presence of a large number of forest species with diameters greater than 40 cm and heights greater than 12 m with a density of 87 individuals/ha. In this system, the coverage is greater than 25 percent This is a system where producers use empirical orchard maintenance techniques as described by Adou Yao & N'Guessan (2006) and Assiri (2007). Cocoa disease and pest control and fertiliser use are almost absent (Adou Yao, 2011).

4.2. Sustainable production of cocoa agrosystems

Despite being the world's largest cocoa producer, Côte d'Ivoire's average marketable cocoa yield is low (CCC, 2015). This performance has been declining since 2000 (FAOSTAT, 2020). In 2018, the average yield in Côte d'Ivoire was 489 kg/ha/year (FAOSTAT, 2020). However, studies carried out in the locality of Zepreguhé have made it possible to obtain an average potential cocoa yield of 1092.61 kg/ha/year. This yield is well above the average yield in Côte d'Ivoire. This result shows that cocoa yields could be improved with the application of good agricultural practices and good pest and disease management in cocoa farms. The effect of cropping systems on cocoa yield was observed in this study through a HAC. This analysis shows that the unshaded systems had the lowest potential cocoa yields. While the highest potential yields were obtained in light shade systems. These results differ from those of Gala bi *et al*. (2017) at M'Brimbo in south-central Côte d'Ivoire, which showed that the highest yields were obtained in unshaded plots. The low yields of pure cocoa in our study could be partly due to the age of the cocoa farms. Indeed, these cocoa farms had an average age of 15 years. While the M'Brimbo cocoa farms were between 5 and 10 years old. This age range corresponds to the physiological stage when yields in unshaded cocoa farms are satisfactory (Koko *et al*., 2008). However, according to Jagoret *et al*. (2014), this level of performance remains ephemeral, and may be declining after about 15 years. Our results are similar to those of Asare *et al*. (2018) who observed a doubling of yield from a full sun cocoa farm to a 30 percent shade level. It should be noted that the dense shade systems showed potential yields of 500-1000 kg/ha/year, higher than those of the unshaded systems. According to Jagoret *et al*. (2011), these systems can maintain a satisfactory level of yield without fertilize inputs. In the current context of climate change, which could lead to a reduction in areas suitable for cocoa production in West Africa (Läderach *et al*., 2013), and the scarcity of forest areas, which limits the installation of new orchards, complex agroforestry systems could be a solution for stabilising existing cocoa-growing areas, adapting to climate change, limiting deforestation and reducing the negative impact of cocoa production on the environment, while at the same time producing acceptable yields for cocoa producers.

5. Conclusion

Studies conducted in the locality of Zepreguhé show that cocoa agrosystems have a rich flora composed of fruit, volunteer and forest species. Despite the elimination of several native species during the installation of cocoa farms, we note the presence of large forest species such as *Ricinodendron heudelotii*, *Terminalia superba*, *Milicia excelsa*, *Khaya ivorensis*, *Entandrophragma angolense*, *Antiaris toxicaria*, etc... In this locality, cocoa farms are established under three types of systems dominated by light shade systems which showed the highest potential yields. The systems without shading have the lowest yields, thus confirming the limits of this practice in cocoa farms in Côte d'Ivoire. The yields obtained in the dense shade systems show that with the adoption of appropriate agroforestry techniques, cocoa farming could be conducted sustainably on the same soils with satisfactory yields. Our results shed new light on cocoa agroforestry systems in Côte d'Ivoire, the effects of which on yield were little studied until now. Far from being archaic, these systems developed by producers are, on the contrary, dynamic and allow for the sustainable production of cocoa with yield levels that are generally higher than what is commonly accepted and, above all, without mineral fertilization.

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