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Potential reconstitution of semi-deciduous forests from weeds of cocoa and rubber farms in eastern Ivory Coast

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Abstract:

Background: *The conversion of forest into perennial crops, particulary cocoa and rubber farms, is a phenomenon that is increasingly affecting protected areas in Ivory Coast. This situation reveal the contrast, which threatens the survival of biodiversity, this study examines the possibility of reconstituting these ecosystems from the floristic potential that is expressed in the cocoa and rubber farms.*

Materials and Methods*: For this, 108 plots of 400 m² each were first laid out in 54 selected cocoa farms and 54 selected rubber farms in the Indénié-Djuablin region. Then, the weed species present in these plots were inventoried taking into account their abundance-dominance. Finally, an ascending hierarchical classification (AHC), a non-parametric Non-metric Multidimensional Scaling (NMDS) analysis and quantitative and qualitative analyses of the species' life histories were performed on the collected data.*

Results: *The data revealed that the weed flora of cocoa and rubber farms contains a high diversity of species, considering the development stage of the crops. Moreover, this flora, characterised by tree species, is more than 60% similar to of the old secondary forests flora present in the study area.*

Conclusion: *Therefore, it would be possible to see a reconstitution of forest flora after crop abandonment from the weed flora. However, this dynamic would be more effective if farmers spared or introduced a diversity of trees into their cocoa and rubber farms.*

Key Word*: Natural regeneration, Weeds, Cocoa and rubber farms.*

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I. Introduction

The eastern regions of Ivory Coast, particularly Indénié-Djuablin, have been an important cocoa bean producers for years. As a result, almost all (90%) of the original forest cover in this region has been lost to agriculture dominated by cocoa and rubber farms[1]. This deforestation level even extends beyond the limits of the rural domain to protected areas and especially to classified forests. However, it is widely recognised that these forest ecosystems are excellent providers of services beneficial to humans. These include the provision of basic necessities, climate regulation, soil erosion control, the maintenance of soil fertility and the conservation of cultural practices[2]. In addition, from an ecological point of view, these ecosystems are a refuge for an important diversity of fauna and flora species, which to a lesser extent limits the spread of certain zoonosis.

There is therefore a need to take measures to correct the negative effects of deforestation and forest ecosystem degradation in such areas. One such measure is to preserve what remains and facilitate the resilience of degraded ecosystems[3]. Such an option implies the fencing off of all agricultural plots that have been illegally installed in these protected sites in order to restore the flora and ecological services of these biotopes[4,5,6]. However, this requires a thorough knowledge of the floristic potential that is expressed in the farms, as the quality and speed of the post-cultural reconstitution process depends on it. In this subject, many studies on the dynamic of floristic diversity under the influence of land use in Ivory Coast has been published. Most of these studies are generally focused on post-cultural successions[7,8,9,10]. On the other way, they generally deal with the impacts of cropping practices on floristic diversity[11,12,13]. More rarely, the floristic reconstitution potential of farms has been analysed. However, this analysis allows us to assess the possibility of natural reconstitution of degraded forest ecosystems, before any possible management[14].

In order to contribute to the provision of data set on the capacity of farms to restore floristic diversity, the general objective of this study was to characterise the weed flora of cocoa and rubber farms in the Indénié-Djuablin region. Specifically, the aim was first to (i) determine the specific diversity of the flora expressed in the undergrowth of cocoa and rubber farms, (ii) analyse the variability of this flora according to the stage of development of the crops and finally (iii) examine the biological characteristics that constitute this flora.

II. Material and Methods

Data collection

Data collection was carried out in the Indénié-Djuablin region, located in eastern of Ivory Coast, between latitudes 5°53' and 7°10' North and longitudes 3°10' and 3°4' West. It consisted of carrying out a floristic inventory in 108 farms of different ages, including 54 cocoa plots and 54 rubber plots. For this, plot of 400 m^2 (20 m × 20 m) were first laid out within each farms. Then, all plant species present in the undergrowth, with the exception of cultivated plants, were inventoried and their abundance-dominance was estimated according to the Braun-Blanquet scale[15] modified by Van der Maarel[16] (**Table n°1**). Finally, an itinerant inventory was carried out from one plot to another. This consisted of inventorying the species not encountered during the surface surveys in order to establish an exhaustive list of the flora of the area.

Table n°1 : Braun-Blanquet coefficient and correspondence according to the Van der Maarel scale. r. the estimated cover rate as a percentage of the survey area. AD represents the Braun-Blanquet coefficient, AD^a represents the Braun-Blanquet coefficient modified by Van der Maarel and AD^b represents the Van Der Maarel coefficient.

AD	Definitions	AD^a	AD^b	Definitions	Average recovery (%)
i	1 individual	rare	1	1 individual	1
+	r. insignificant	+	2	2 insignificant	2
1	r ≤ 5 %	1	3	r ≤ 5 %	3.5
2	5 < r. ≤ 25 %	2m	4	5 < r ≤ 10 %	7.5
		2a	5	10 < r ≤ 15 %	12.5
		2b	6	15 < r ≤ 25 %	20
3	25 < r. ≤ 50 %	3	7	25 < r ≤ 50 %	37.5
4	50 < r. ≤ 75 %	4	8	50 < r ≤ 75 %	62.5
5	75 < r. ≤ 100 %	5	9	r > 75 %	87.5

Data analysis

Determination of the specific richness of the adventive flora of cocoa and rubber farms

The floristic inventory carried out in the undergrowth of the cocoa and rubber farms made it allowed to draw up an exhaustive list of the weeds found in each type of agrosystem, . Then, the species of each floristic lists were divided into genus and family. This made it helped to determine the most represented botanical families through a spectrum of families and to calculate the ratio number of species per genus (E/G). This ratio allowed us to evaluate the diversity of the habitats[17].

Analysis of the variability of the floristic composition of the weeds according to the stage of development of the crops

This analysis is based on the assumption that a factor is likely to influence the distribution of the flora of a given environment when it best contributes to the dispersion of the flora of that environment. For this purpose, the developmental stages of the crops were first determined. Then, their influence on the floristic composition of the weeds was evaluated.

Determination of the stages of development of the crops

The data were first arranged in a contingency table containing the plots in rows and the environmental parameters (plot age, weeding frequency, canopy opening) in columns. Then, an Ascending Hierarchical Classification (AHC) of the plots was performed on this dataset with the HCPC function of the FactoMineR package[18]. Finally, the component "$desc.var" of this function was used to highlight the correlation between the environmental parameters and the AHC result. This analysis was performed with the R software (version 3.6.1.)[19].

Evaluation of the influence of crop development stages on the floristic composition of weeds

In order to carry out this analysis, a contingency table containing the plots in row and the species in column preceded by a column named "Group" was developed beforehand. This column corresponds to the survey groups from the previous AHC. Next, a non-parametric Non-metric Multidimensional Scaling (NMDS) analysis was performed with the PAST software (version 3.13)[20]. It allowed visualizing the distribution of the survey groups in the two-dimensional plane. However, to assess the significance of the influence of age on floristic composition, the ANOSIM 1 test was applied after 999 permutations. Influence is present when the *p-value* < 0.05 and this is reflected in a clear differentiation of survey groups in the two-dimensional plane of the NMDS.

Typological analysis of the weed flora of cocoa and rubber farms

The analysis of the spectrum of life traits of the flora species and the floristic similarity were used in this study to better define the typology of the weed flora on farms. For this, the biological characteristics of weed species on farms were defined according to the work of Aké Assi[21] and Lebrun[22] (**Table n°2**). Then, for each type of farm, a spectrum of biological types, dispersion modes and phytogeographical types was produced. This spectrum made it possible to highlight the life traits most represented in the weed flora of cocoa and rubber farms. In addition, in each agrosystem, the species abundance data were converted into binary data. Then, through a similarity analysis based on Sørensen's index[23] (equation 1), the floristic lists were compared to the global flora of the reference ecosystems.

$$\boldsymbol{S} = \frac{\boldsymbol{2\times a}}{(\boldsymbol{2\times a+b+c})} \qquad \textbf{(1)}$$

In this equation, (**S**) is Sørenen's coefficient, (**a**) represents the number of species specific to the first habitat, (**b**) represents the number of species specific to the second habitat and (**c**) represents the number of species common to both habitats. The similarity between two habitats is high when the value of Sørensen's index tends towards 1.

Table n°2 : Classification of biological characteristics used

Biological characteristics	Classification	Sources
Phytogeographic types	Guinean-Congolese species (GC), Guinean-Congolese species endemic to the West African forest block (GCW), Guinean-Congolese species endemic to Ivory Coast (GCi), species common to the Guinean-Congolese region and the Sudan-Zambezi region (GC-SZ)	Aké Assi[21]
Biological types	Megaphanerophyte (MP), Mesophanerophyte (mP), Microphanerophyte (mp), Nanophanerophyte (np), Champephyte (Ch), Therophyte (Th), Hydrophyte (Hyd), Epiphyte / Semi-epiphyte (E), Geophyte (G), Hemicryptophyte (H), Parasite (Par)	Aké Assi[21]
Dissemination modes	Anemochory, Endozochory, Epizoochory, Barochory, Hydrochory	Lebrun[22]

III. Result

Specific richness and dominant botanical families of the adventive flora of cocoa and rubber farms

A total of 322 spontaneous plants ranged in 244 genera in and 76 families were recorded in the undergrowth of cocoa farms. Fabaceae (36 species), Apocynaceae (27 species), Rubiaceae (15 species), Poaceae (14 species) and Asteraceae, Euphorbiaceae, Malvaceae (13 species each) are the richest families (**Figure n°1a**). Moreover, these families represent 41.07% of the families inventoried in the cocoa farms.

In the undergrowth of the rubber farms, the specific richness of the weed flora amounts to 331 plants distributed in 247 genera belonging to 77 families. The most represented families in this flora are Fabaceae (37 species), Apocynaceae (28 species), Rubiaceae (24 species), Malvaceae (17 species), Euphorbiaceae (15), Poaceae (14 species) and Asteraceae (11 species). They represent about 44.11% of the families inventoried in the undergrowth of rubber farms (**Figure n°1b**).

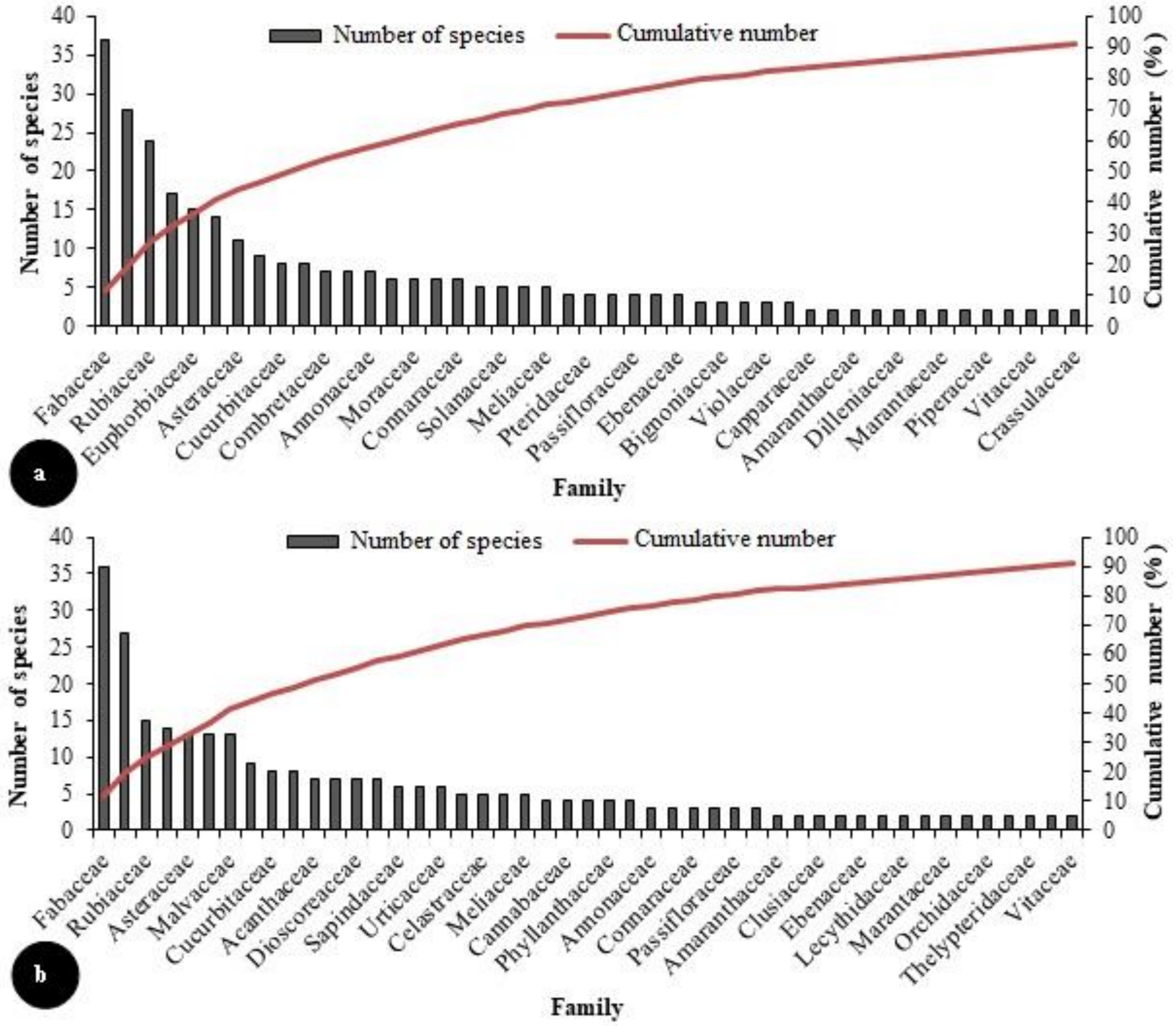

Figure n° 1 : Spectrum of multispecies families present in the weed flora of cocoa (a) and rubber farms (b)

Variability in the floristic composition of weeds according to the development stage of cocoa and rubber farms

Classification of the development stage of cocoa and rubber farms

The cocoa farms inventoried are divided into three development stages (**Figure n° 2a**) that are strongly correlated with variables such as plot age ($r = 0.65$; P-value < 0.001), canopy openness ($r = 0.64$; P-value < 0.001), and weeding frequency ($r = 0.72$; P-value < 0.001). These are plantations of 1 to 8 years old, 9 to 19 years old, and 20 years old and more. Rubber farms are also divided into three developmental stages (**Figure n° 2b**) correlated with plot age ($r = 0.76$; P-value < 0.001), canopy openness ($r = 0.68$; P-value < 0.001) and weeding frequency ($r = 0.82$; P- value < 0.001). These are farms of 1-5 year old, 6-14 year old, and 15 year old and more.

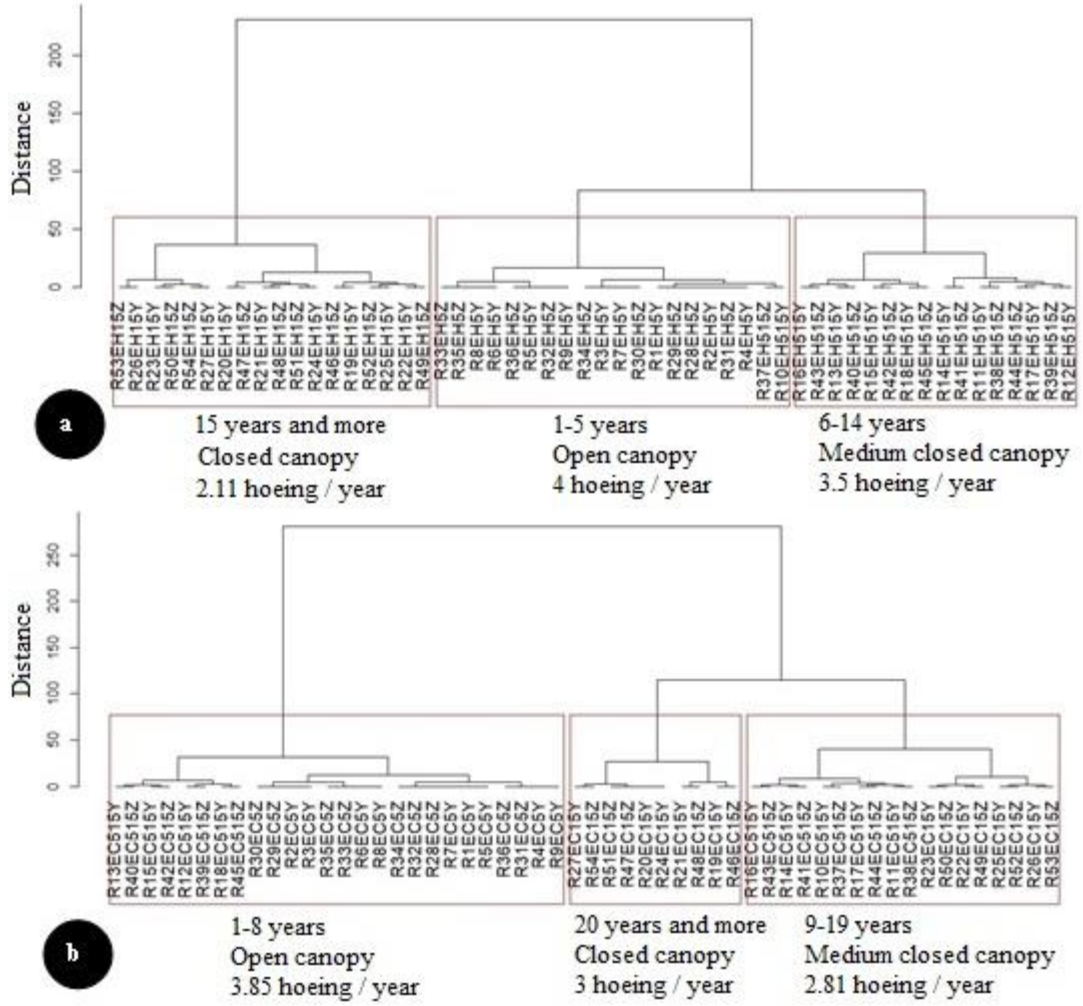

Figure n° 2 : Classification of developmental stages of cocoa (a) and rubber farms (b) based on plot age, degree of canopy openness, and weeding frequency.

Influence of the development stages of cocoa and rubber farms on the floristic composition of weeds

The floristic comparison made between the three age classes of cocoa farms (**Figure n° 3a**) indicates a similarity in the floristic composition of weeds (ANOSIM, R = 0.05471, P-value > 0.05). In the rubber farms (**Figure n° 3b**), a similarity in the floristic composition of the weeds was also observed between the three age classes (ANOSIM, R= 0.02727, P-value > 0.05). This means that in cocoa and rubber farms, the crop development stage does not significantly influence the floristic composition of weeds.

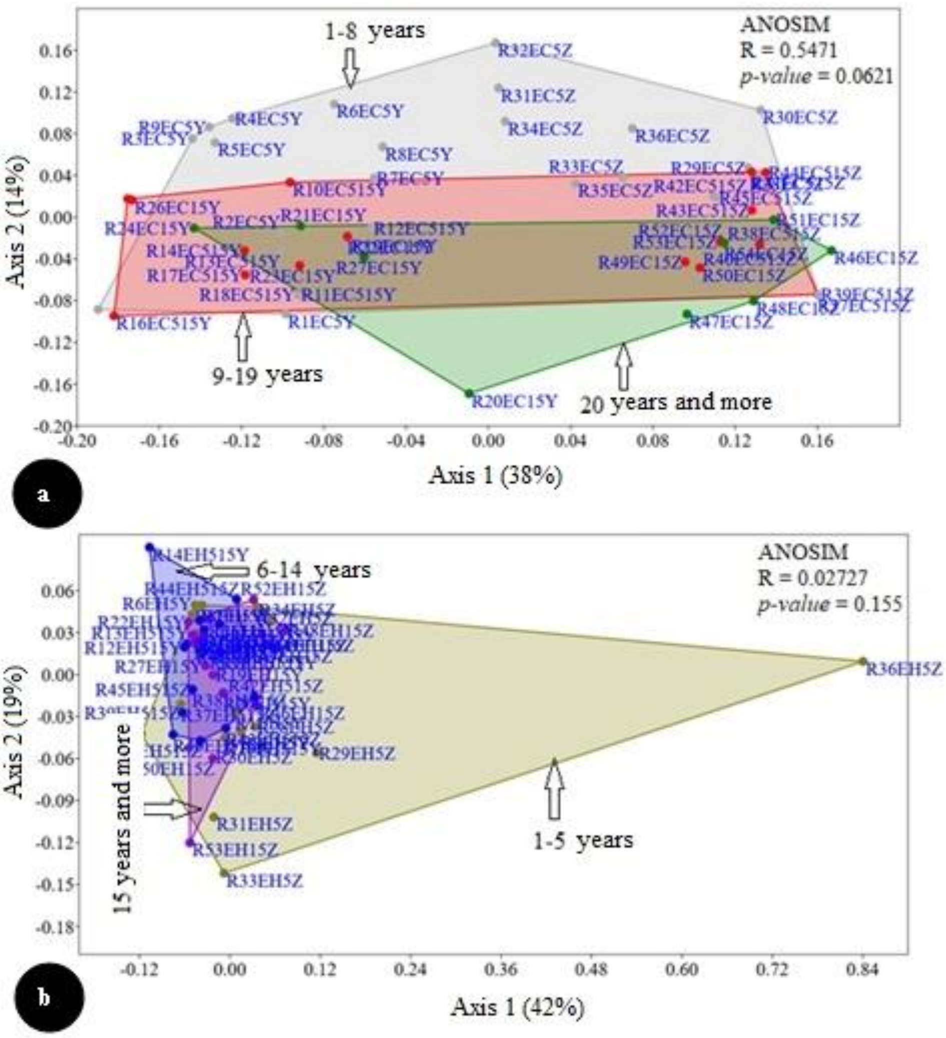

Figure 3 : Variability in weed composition according to developmental stage in cocoa (a) and rubber farms (b).

Typology of the adventive flora of cocoa and rubber farms
Types of phytogeographical distribution of the adventive flora

A spectrum analysis of phytogeographic distribution types revealed that the weed flora on cocoa (**Figure n° 4a)** and rubber farms (**Figure n° 4b**) was more than 65% dominated by species from the Guinean-Congolese (GC) region. Species common to the Guinean-Congolese and Sudan-Zambezi regions (GC-SZ) as well as Guinean-Congolese species endemic to the West African forest block (GCW) are poorly represented. In contrast to the weed flora of the rubber farms, there is a very small proportion (1%) of species endemic to Ivory Coast in the weed flora of cocoa farms. This proportion includes species such as *Baphia bancoensis* Aubrév. and *Albertisia cordifolia* (Mangenot and J. Miège) Forman.

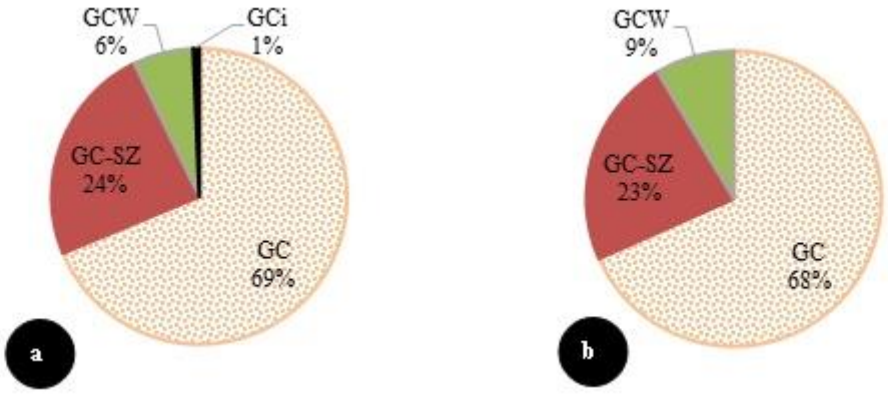

Figure 4 : Spectra of plant types present in the weed flora of cocoa farms (a) and rubber farms (b)

Morphological and biological types of the adventive flora

The weed flora of cocoa and rubber farms was composed of tree, liana and herbaceous species(**Figure n° 5**). Moreover, this flora was marked by a strong presence of tree species (50% in cocoa farms and 52% in rubber farms).

In terms of biological types, the overall biological spectrum of weeds inventoried showed that phanerophytes dominated the undergrowth of cocoa (**Figure n° 5a**) and rubber farms (**Figure n° 5b**). Chamephytes, therophytes, hemicryptophytes, epiphytes and geophytes were poorly represented. Among the phanerophytes, shrub or liana species that can grow to 2-8 meter in height at maturity (i.e., microphanerophytes) are the most represented (approximately 51% of phanerophytes). Megaphanerophytes (tree or liana species that can grow to over 30 meter height at maturity), mesophanerophytes (tree or liana species that could grow to 8-30 meter height at maturity), and nanophanerophytes (shrub or liana species that can grow to 2-25 meter height at maturity) correspond to about 9%, 17%, and 21% of the total number of phanerophytes inventoried respectively.

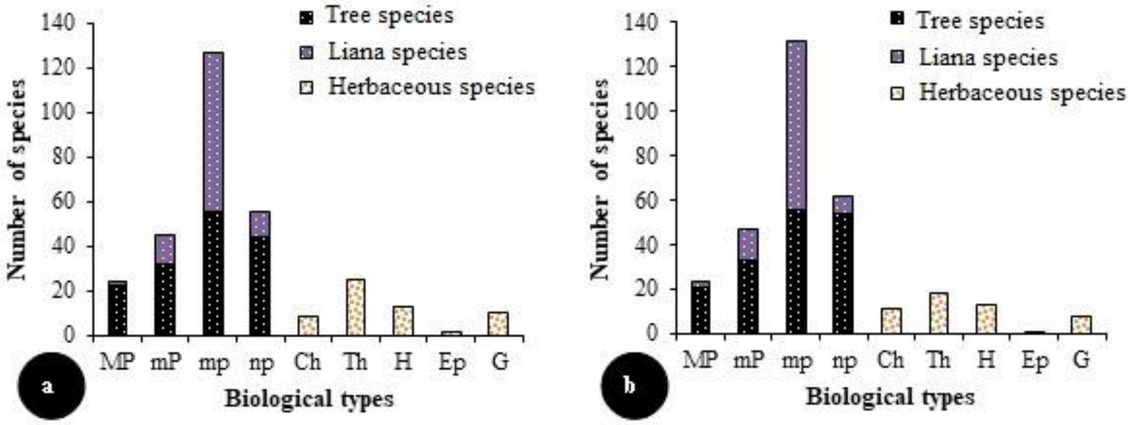

Figure n° 5 : Spectrum of biological types present in the weed flora of cocoa (a) and rubber farms (b). MP: Megaphanerophyte, mP: Mesophanerophyte, mp: Microphanerophyte, np: Nanophanerophyte, Ch: Champephyte, Th: Therophyte, H: Hemicryptophyte, Ep: Epiphyte, G: Geophyte

Dissemination modes of diaspores of the adventive flora

The weed flora of the undergrowth of cocoa and rubber farms was composed of four modes of diaspora dissemination (**Figure n° 6 and b**). These are dissemination by anemochory, zoochory, barochory and hydrochory. However, more than 50% of this flora is dominated by species whose seeds are disseminated by intestinal transit (Endozoochory). Among these species we can mention plants like *Diospyros cooperi* (Hutch. et Dalziel) F.White, *Cola millenii* K.Schum., *Sterculia tragacantha*, *Ruthalicia eglandulosa* (Hook.f.) C.Jeffrey, *Cardiospermum grandiflorum* Sw., *Morinda morindoides* (Baker) Milne-Redh, *Trema orientalis*, *Kigelia africana*, *Ficus sur* Forssk, *Baissea baillonii* Hua, *Landolphia hirsuta* (Hua) Pichon and *Mondia whitei* (Hook. f.) Skeels. There was also a relatively high proportion (about 30% of the total flora) of species whose seed dispersal is facilitated by the wind (Anemochory).

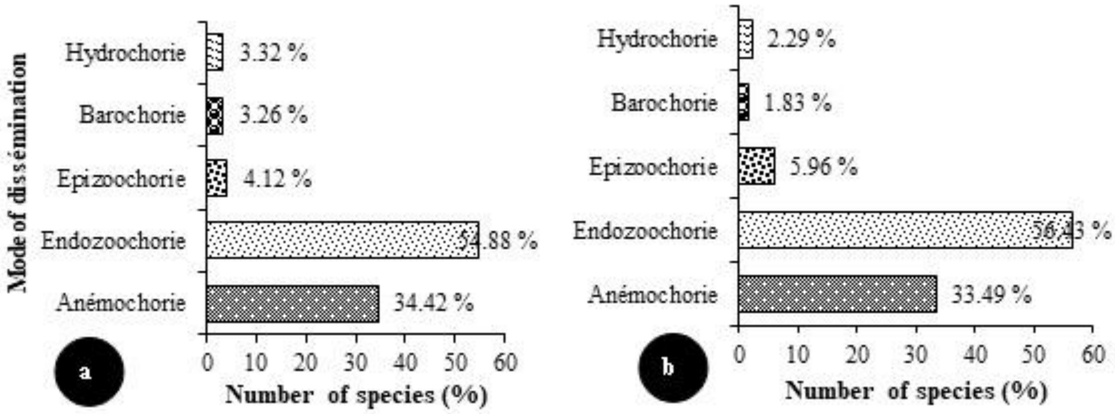

Figure n° 6 : Spectrum of edissemination modes present in the weed flora of cocoa (a) farms and rubber farms (b)

Similarity between the weed flora of farms and the overall flora of restoring forests

The inventory of the forests flora, reference ecosystems, showed 223 species divided into 176 genera belonging to 67 families. This flora which contained all biological types is 90.58% dominated by phanerophytes. Moreover, the families richest in species are Fabaceae (25 species), Apocynaceae (18 species), Rubiaceae (16 species), Malvaceae (14 species) and Moraceae (9 species). Only 5.12% of the inventoried genera are multispecies. These are the genera: Albizia, Cola, Combretum, Ficus (4 species each), Comelina, Diospyros, Garcinia, Millettia, Morinda (3 species each). In contrast to these multispecific families and genera, the overall flora consists of a high proportion of monospecific families (46.27%) and genera (80.68%). This together with the low value of the E/G coefficient showed that the overall flora is well diversified.

The weed flora of the cocoa farms was similar to the overall flora of the forests being restored (S = 0.67). Furthermore, the composition of tree species inventoried in the undergrowth of these farms was similar to that of the tree stratum of plant formations (S = 0.65). Seventy (70) tree species accounted for this similarity (**Figure n° 7a**). These include 38 microphanerophytes, 20 mesophanerophytes and 12 megaphanerophytes. The latter consist of anemochorous species such as *Entandrophragma angolense*, *Nesogordonia papaverifera*, *Ceiba pentandra*, etc., and endozoochorous species such as *Anthonotha fragrans* (Baker f.) Exell et Hillc., *Milicia excelsa* and *Parkia bicolor*.

As for the weed flora of the rubber farms, it is also similar to the overall flora of the forests under reconstitution (S = 0.66). Moreover, the flora of tree species inventoried in the undergrowth of these farms is similar to that of the tree stratum of these plant formations (S = 0.68). Seventy-four (74) species accounted for this similarity (**Figure n° 7b**). These include 42 microphanerophytes, 21 mesophanerophytes and 11 megaphanerophytes. The latter were composed of anemochorous species such as Guibourtia ehie, *Nesogordonia papaverifera*, *Triplochiton scleroxylon* etc. and endozoochorous species such as *Anthonotha fragrans*, *Milicia excelsa*, *Scottellia klaineana*, etc.

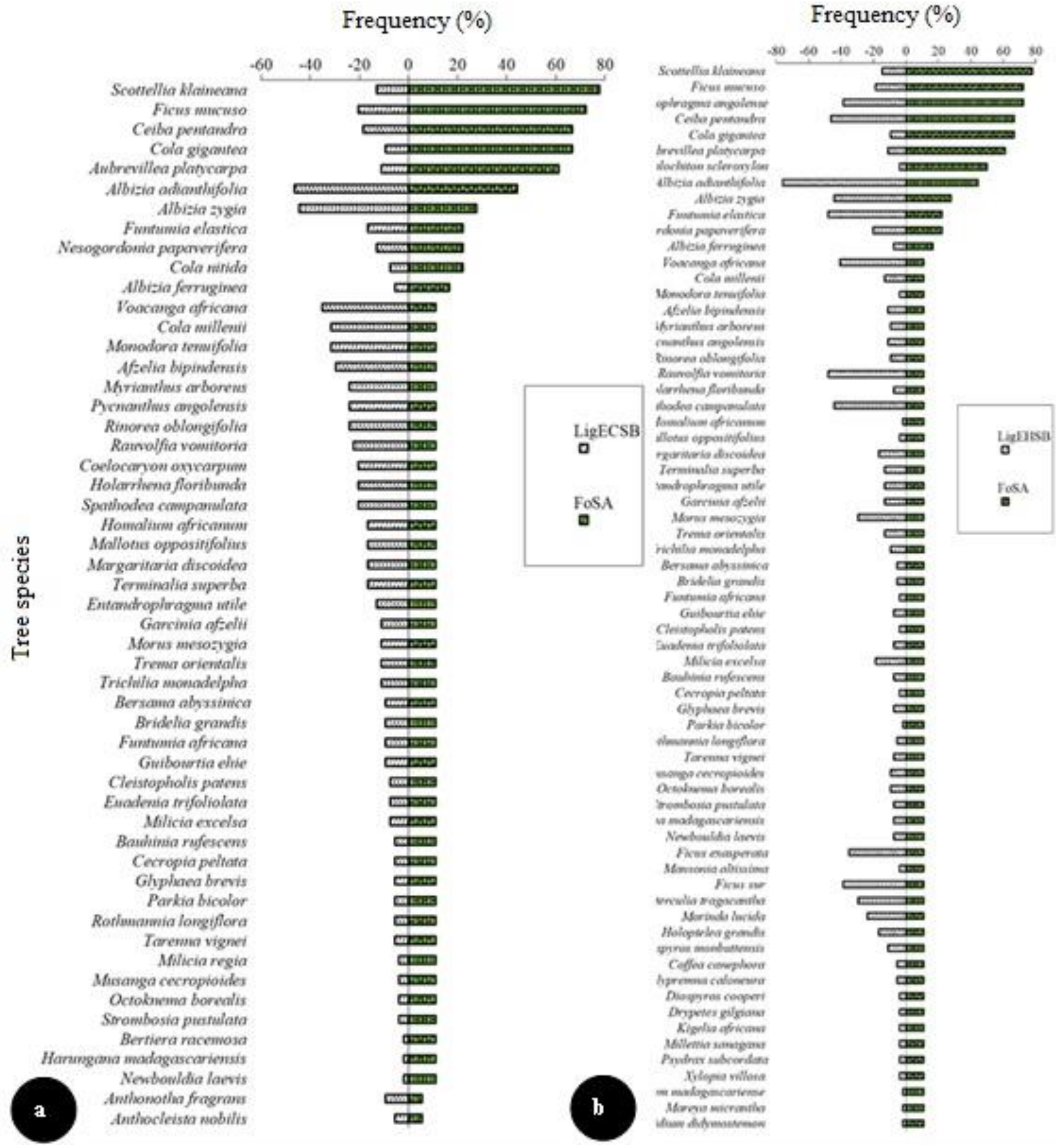

Figure n° 7 : Similarity between the tree stratum of forests under reconstitution (FoSA) and the tree species undergrowth of cocoa (a) and rubber farms (b)

IV. Discussion

In Ivory Coast, the research for solutionson the reconstitution of the forest is still ongoing. Meanwhile, ecologically important areas such as classified forests, parks and reserves continue to lose their biodiversity to the expansion of export crops such as cocoa and rubber. However, little is known about the floristic potential for restoring the forest flora after the abandonment of these crops.

Investigations carried out on cocoa and rubber farms in the Indénié-Djuablin region have revealed low floristic diversity in the spared woody plants[24] and flora from the soil seed bank[25]. On the other hand, the weed flora of these farms is very rich in species and differs significantly from the flora of the two previous species pools. Given that stumps and suckers were completely eliminated as a result of stump removal activities during plot preparation, it is believed that the understory flora of cocoa and rubber farms is derived from exogenous seminal potential. This can be explained by the fact that these farms constitute "ecological corridors" allowing animals to reach secondary forests. In this way, the plants settle following the nucleation hypothesis evoked by Yarranton and Morrison[26] and Carrière[27]. Indeed, as these authors point out, the high woody density in the fields increases the external flow of seeds by serving as perch for animals that contribute to the dissemination of the seeds, and then creates a microclimate that is favourable to the growth of the seedlings from these seeds. Furthermore, if we consider these farms as islands included in a mosaic of secondary forests, the floristic diversity of their undergrowth would also be the result of the complementarity between the theory of island biogeography of MarcArthur and Wilson[28] and that of Lack[29]. Indeed, MarcArthur and Wilson consider that the species diversity on an island is higher the closer the island is to a source generating migratory flows, whereas for Lack, this species diversity depends on the biotic and abiotic conditions of the environment. Thus, seeds from the flora of the surrounding plant formations are disseminated in the undergrowth of farms thanks to potential vectors and then germinate according to the availability of resources. This would explain the high proportion of woody species observed in the undergrowth of farms, as the seeds of these species often germinate shortly after their dissemination[30].

From the above, a possible reconstitution of the forest flora follows from the parallelism between the temporal evolution of adaptive strategies developed by Grime[31] and that of life forms observed by Bangirinama and collaborators[6]. Indeed, these authors consider that post-cultural succession begins with species with ruderal strategy (i.e. therophytes), recruits in the intermediate stages competitive-stress-tolerant species (i.e. hemicryptophytes) to tend towards the pre-forest stages dominated by competitive species (i.e. phanerophytes). Furthermore, the similarity observed between the diversity of phanerophytes in the tree stratum of forests and that of the undergrowth of cocoa and rubber farms also testifies to the possibility of forest reconstitution after the crops have been abandoned. Such an observation was made by Adou Yao and Roussel[32] in southwestern Ivory Coast. According to these authors, young fallows and certain cocoa farms can have a high potential for reconstitution of natural vegetation. Moreover, the positive impact of cocoa farms in the reforestation of our study area was observed in 2013 by Koné and collaborators[33]. Indeed, according to these authors, in the decade 2000, approximately 1000 hectare of forest where created by the regeneration of abandoned farms and other thematic units. Nearly 50% of the cocoa farms are affected by this phenomenon, which is explained by the abandonment of plantations due to aging and bush fires that ravaged the region during the 1980s. In this study, the dominance of zoochory and anemochory would guarantee a reconstitution of floristic diversity on a much larger scale. Indeed, species with these dissemination modes are known to disperse their seeds over long distances[34]. Moreover, the high proportion of Guinean-Congolese species would reflect a high maturity of the post-cultural flora[35,36].

V. Conclusion

The main objective of this study was to determine the role that weed flora of cocoa and rubber farms could play in the reconstitution of forest ecosystems. In this regard, it was found that in the Indénié-Djuablin region, the flora of the undergrowth of cocoa and rubber farms has an excellent specific richness regardless of the development stage of the crops. Moreover, this component of the flora of the farms studied has a similar floristic composition to that of the surrounding forest formations. The significant presence of phanerophytes, Guinean- Congolese species, zoochorous and anemochorous species observed in the undergrowth of the cocoa and rubber farms could allow for a possible reconstitution of the forest flora if these farms are left to be abandoned.

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