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Possibility of forest reconstitution from soil seed bank of cocoa and rubber farms in eastern Ivory Coast

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Abstract

What is the capacity of the soil seed bank to restore floristic diversity when forest disturbance is linked to a perennial crop? To answer this question, the main objective of the present study was to assess the contribution of the soil seed bank of cocoa and rubber farms in the process of forest flora reconstitution. To do this, 432 composite soil samples were first collected from 108 farms, 54 of which were from each of the above-mentioned farms in the Indénié-Djuablin region in eastern Ivory Coast. These samples taken at depths of 0 to 5 cm (n=108 samples), 5 to 10 cm (n=108 samples), 10 to 15 cm (n=108 samples) and 15 to 20 cm (n=108 samples) were then placed in a greenhouse for quantitative and qualitative evaluation of viable seeds. The investigations showed that in cocoa and rubber farms the maximum number of viable seeds that could initiate the process of forest reconstitution after abandonment of the crops is stored in the first five centimeters of the soil. However, this species pool contains very few tree species. Consequently, the seed stock in the soil of cocoa and rubber farms alone cannot effectively reconstitute the forest flora after crop abandonment. It would be interesting to explore other research perspectives such as the contribution of spontaneous flora of these farms in the process of reconstitution of forest flora.

Keywords: Soil seed bank; Forest reconstitution; Farms; Ivory Coast

1 Introduction

The restoration of degraded natural ecosystems has always been at the center of development projects in tropical countries. However, huge areas of these ecosystems continue to be lost at an alarming rate [1].

In Ivory Coast, and more precisely in the Guinean-Congolese endemic zone, forest ecosystems have long been subject to multiple anthropogenic pressures and continue to be so [2]. Moreover, these pressures are generally linked to the expansion of agriculture dominated by perennial crops such as cocoa and rubber farms [3]. However, the crop plants commonly used have little tolerance for shade, leading farmers to cut down almost all woody species on farms, which could accelerate forest regeneration after crop abandonment [4]. In such a context, there is reason to be concerned about the resilience of forests because, depending on the intensity or duration of the disturbance, the process of reconstitution of the post-cultivation flora may be affected permanently [5]. As a result, natural regeneration may follow a different trajectory than in reference ecosystems [6].

In terms of the resilience of forest ecosystems under the influence of land use, a lot of work exists on the dynamics of post-cultivation flora [7, 8, 9]. However, the contribution of the soil seed stock of farms is poorly perceived in these

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dynamics. Yet, being more tolerant of adverse conditions than the plant itself, the dormant seed plays an important role in conserving and maintaining the genetic diversity of the species [10]. Moreover, it is widely accepted that the post-cultivation flora is, in part, derived from the floristic potential that is expressed on farms [11, 12]. These are the offspring and seedlings (i.e. vegetative potential), post-canopy inputs (i.e. exogenous seminal potential) and finally the soil seed bank (i.e. edaphic seminal potential). This implies that the soil seed bank of farms would be an important element in the restoration of plant diversity.

In order to clarify this point of view, investigations were carried out in the Indénié-Djuablin region where 90% of the forest cover has been converted into agricultural land, notably cocoa and rubber farms [13]. The main objective of these investigations was to assess the role of the soil seed stock of cocoa and rubber farms in the restoration of floristic diversity. Specifically, the aim was first to determine the depth of the soil containing the maximum number of viable seeds, then to determine the plant species buried at this depth and finally to characterise the typology of the future vegetation.

2 Material and methods

2.1 Presentation of the study area

The study area is the Indénié-Djuablin region, located in the eastern part of Ivory Coast, between latitudes 5°53' and 7°10' north and longitudes 3°10' and 3°4' west. It is subject to sub-equatorial climatic regimes with an average annual rainfall of 1300 mm and an average annual temperature of 26.3°C. The original vegetation belongs to the mesophilic sector of the Guillaumet and Adjanohoun domain [14], specifically to the type "semi-deciduous forest with *Celtis* spp. and *Triplochiton scleroxylon* K. Schum. ". However, this region has lost almost all its forest cover (Figure 1) for a deforestation rate of 3.9% from 1990 to 2015 [3]. The main driver of this deforestation is the expansion of agriculture, particularly cocoa and rubber farming.

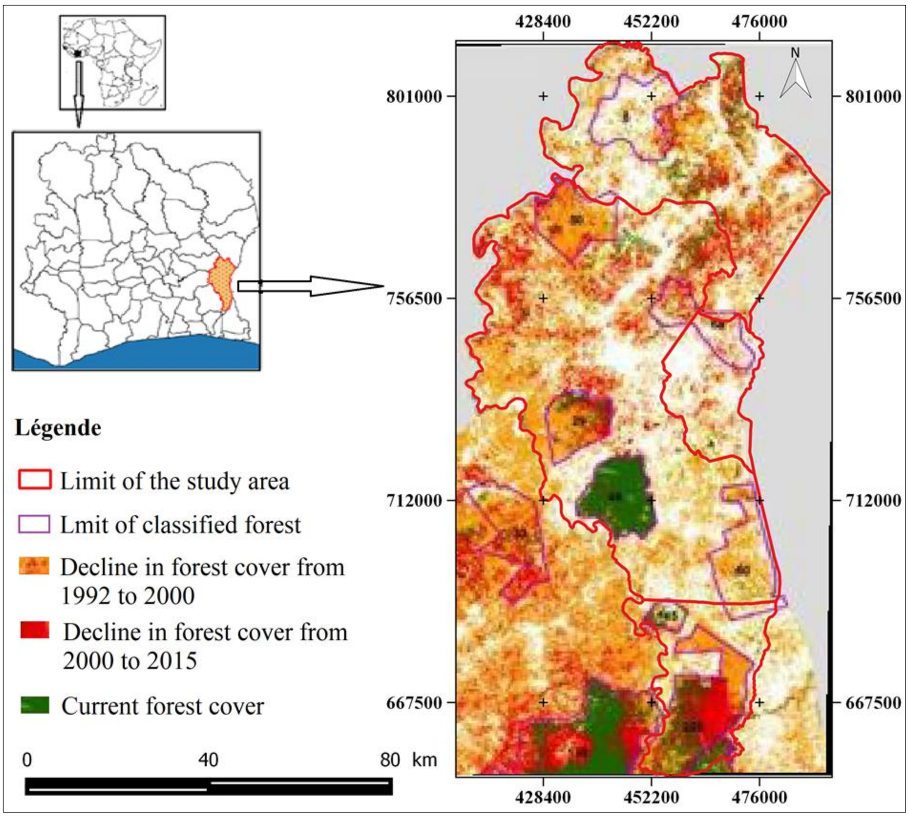

Figure 1 Geographical location and evolution of forest cover from 1990 to 2015 in the Indénié-Djuablin region (Source: [3], modified)

2.2 Data collection

In the Indénié-Djuablin region, 108 farms of different ages including 54 cocoa farms and 54 rubber farms were studied for soil seed bank from August 2018 to July 2019. To do this, a plot with an area of 2500 m^2 (50 m × 50 m) was first laid out inside each of the plots. Then, using a 7.5 cm diameter auger, soil samples were taken from the four corners and the center of these plots, at depths of 0-5 cm, 5-10 cm, 10-15 cm, and 15-20 cm. Finally, for each of the plots, a composite sample was formed per depth level in order to have heterogeneity of seeds present at these sampling levels [15]. These samples were placed in a greenhouse for five months and all germinated seeds were counted. Then the seedlings were identified through the works of Hutchinson and Dalziel [16], Hawthorne and Jongkind [17] and Tardieu-Blot [18]. In addition, floristic inventories were carried out in 18 forest plots chosen as reference ecosystems to better appreciate the capacity of the farms soil seed bank to restore floristic diversity.

2.3 Data analysis

2.3.1 Determination of the area of high viable seed concentration

In order to achieve this objective, for each farm type, the viable seed densities of the different soil depth levels were first compared to each other. Then, the temporal variation in the density of each sampling level was assessed by comparing farms of different age classes with each other. These were for each farm type, plots aged 0-5 years (n=18 plots), 5-15 years (n=18 plots) and 15 years and older (n=18 plots).

These comparisons were carried out in the R software version 3.6.1. by introducing the data sets into a one-factor analysis of variance (ANOVA 1), after checking the normality and homogeneity of the variables.

2.3.2 Assessment of the floristic richness of the soil seed bank

Following the identification of the germinated seedlings, the distribution of species within families and genera was determined. This made it possible to determine the most dominant botanical families in the flora from the the soil seed bank of the farms. This identification also allowed to know the plant species whose seeds are abundant in the soil seed bank of these farms.

2.3.3 Analysis of future flora typology

The aim of this analysis is to find out whether the flora from the soil seed bank of farms would show a similar horizontal structuring to that of forests (reference ecosystems). For this purpose, the biological type spectrum of forests was determined. Then, the biological type spectra of the flora from the soil seed bank of cocoa and rubber farms were made. Finally, a comparison was made between the biological spectra of the flora from the soil seed bank of the farms and that of the flora of reference ecosystems. The biological types used are those adapted to tropical regions as defined by Aké-Assi [19]. These are:

- Megaphanerophyte (MP) : Tree or liana over 30 m high
- Mesophanerophyte (mP) : Tree or liana from 8 to 30 m high
- Microphanerophyte (mp) : Shrub or liana from 2 m to 8 m high
- Nanophanerophyte (np) : Shrub or vine 0.25 m to 2 m high
- Chamephyte (Ch) : Woody or suffructive perennial plants (perennial plant from 0 to 25 cm high) with renewal buds no higher than 50 cm from the ground
- Therophyte (Th) : Annual plants whose seed is the only organ of conservation during the unfavourable season
- Geophyte (G) : Plants whose survival organs (bulb, tuber, rhizome) are buried in the soil and whose aerial part dies during the unfavourable season
- Hemicryptophyte (H) : Perennial plants with renewal buds above the soil surfa

3 Results

3.1 Area of high concentration of viable seeds in the soil of cocoa and rubber farms

3.1.1 Cocoa farms

The temporal monitoring of soil seed bank germination of cocoa farms shows that a limit amount of viable seeds seems to be obtained 16 weeks after placing in the greenhouse, regardless of the soil depth (Figure 2A). An average of 4907.46 seeds/m^2 , 2622.23 seeds/m^2 , 1859.96 seeds/m^2 and 1131.38 seeds/m^2 germinated in soil samples taken from 0 to

5 cm, 5 to 10 cm, 10 to 15 cm and 15 to 20 cm depths respectively (Figure 2B). However, this amount decreased significantly with depth (F = 18.02, P < 0.001). Samples taken from 0 to 5 cm depth contained the most viable seeds compared to the other depths. Furthermore, the seed stock at this depth did not regress significantly (X^2 = 2.14, P = 0.34) from young to old cocoa farms (Figure 2C). Therefore, the area of high concentration of viable seeds in the soil of cocoa farms is in the top five centimeters.

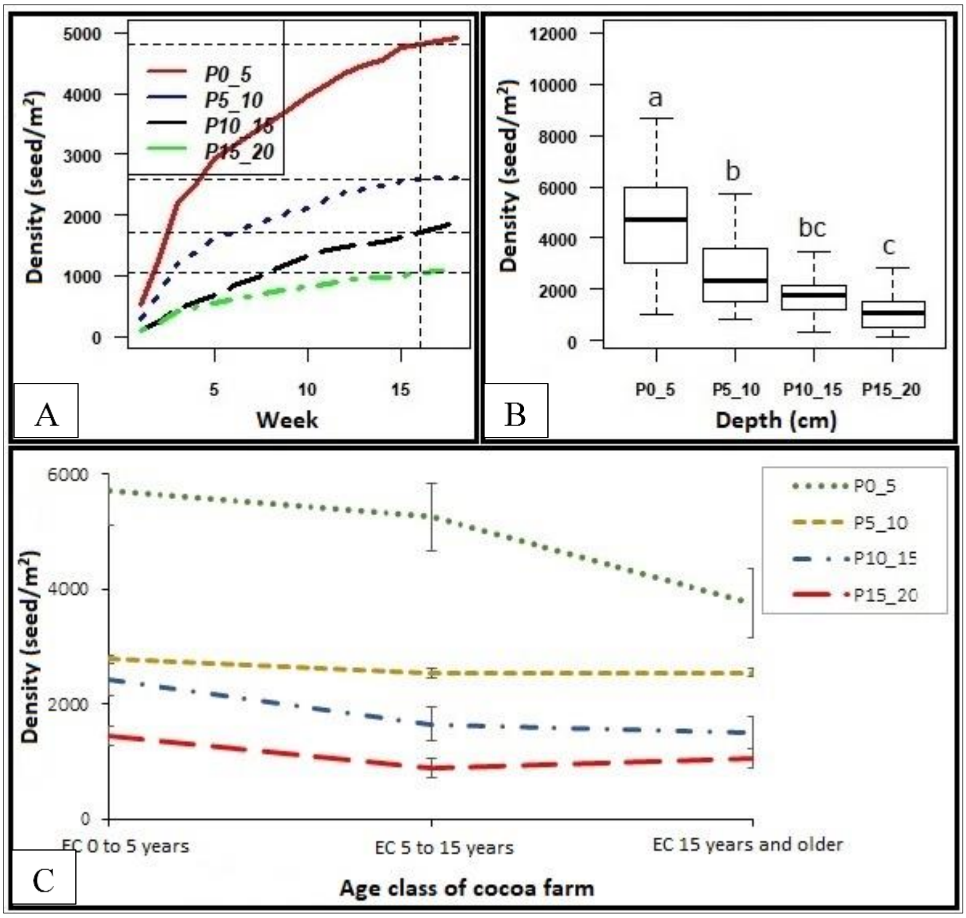

Figure 2 Quantitative soil seed stock on cocoa farms: Cumulative curve of viable seed density (A); Average density as a function of soil depth (B). Density variation as a function of plot age (C). *P0_5: 0 to 5 cm depth, P5_10: 5 to 10 cm depth, P10_15: 10 to 15 cm depth, P15_20: 15 to 20 cm depth; EC 0 to 5 years:* cocoa *farms aged between 0 and 5 years, EC 5 to 15 years:* cocoa *farms aged between 5 and 15 years, EC 15 years and older:* cocoa *farms aged 15 years and older*

3.1.2 Rubber farms

In the soil seed bank of the rubber farms, the maximum number of viable seeds seems to be obtained 16 weeks after the soil samples were placed in the greenhouse, regardless of the depth (Figure 3A). The average amount of germinated seeds was 7020.97 seeds/m^2, 3758.43 seeds/m^2, 2347.81 seeds/m^2 and 1908.09 seeds/m^2 respectively for soil samples taken from 0 to 5 cm, 5 to 10 cm, 10 to 15 cm and 15 to 20 cm depth (Figure 3B). These values differed significantly with depth (F = 7.707, P < 0.001). Samples taken from 5 to 10 cm, 10 to 15 cm, and 15 to 20 cm depths had low amounts of viable seeds on average. In contrast, those taken from 0 to 5 cm depth contained the most viable seeds on average. Furthermore, the seed stock at this depth does not regress significantly (X^2 = 3.94, P = 0.14) from young to old cocoa farms (Figure 3C). Therefore, the area of high concentration of viable seeds in the soil of the rubber farms is in the top five centimeters.

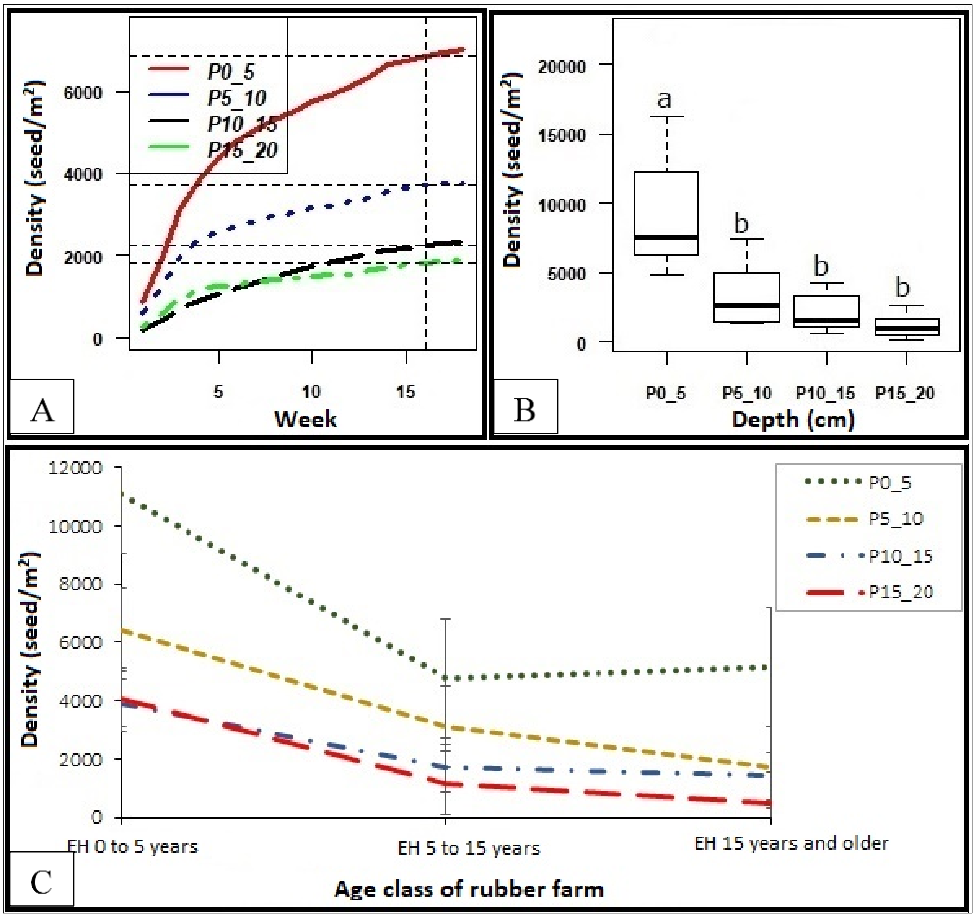

Figure 3 Quantitative soil seed stock in rubber farms: cumulative curve of viable seed density (A); Average density versus soil dept

(B) . Density variation as a function of plot age (C). P0_5: 0 to 5 cm depth, P5_10: 5 to 10 cm depth, P10_15: 10 to 15 cm depth, P15_20: 15 to 20 cm depth; EH 0 to 5 years: rubber farms aged between 0 and 5 years, EH 5 to 15 years: rubber farms aged between 5 and 15 years, EH 15 years and older: rubber farms aged 15 years and older

3.2 Diversity of plants stored in the first five centimeters of soil on cocoa and rubber farms

3.2.1 Cocoa farms

A total of 38 species in 34 genera in 21 families originate from the seed stock in the first five centimeters of the cocoa farm soil. The Poaceae family is the most represented with nine species. It is followed by the Asteraceae (4 species), Euphorbiaceae, Solanaceae (3 species each). Among these germinated plants (Figure 4), the species with the highest seed stock in the soil are *Pityrogramma calomelanos* (L.) Link (320.23 seeds/m2; Figure 5A), *Trema orientalis* (L.) Blume (225.31 seeds/m^2; Figure 5B) and *Digitaria horizontalis* Willd. (167.54 seeds/m2; Figure 5C). They are followed by plants such as *Pouzolzia guineensis* Benth. (88.31 Seeds/m^2), *Fleischmannia microstemon* (Cass.) R.M.King & H.Rob. (87.48 Seeds/m^2), *Laportea aestuans* (L.) Chew (85.01 Seeds/m^2) and *Panicum parvifolium* Lam. (68.50 Seeds/m^2).

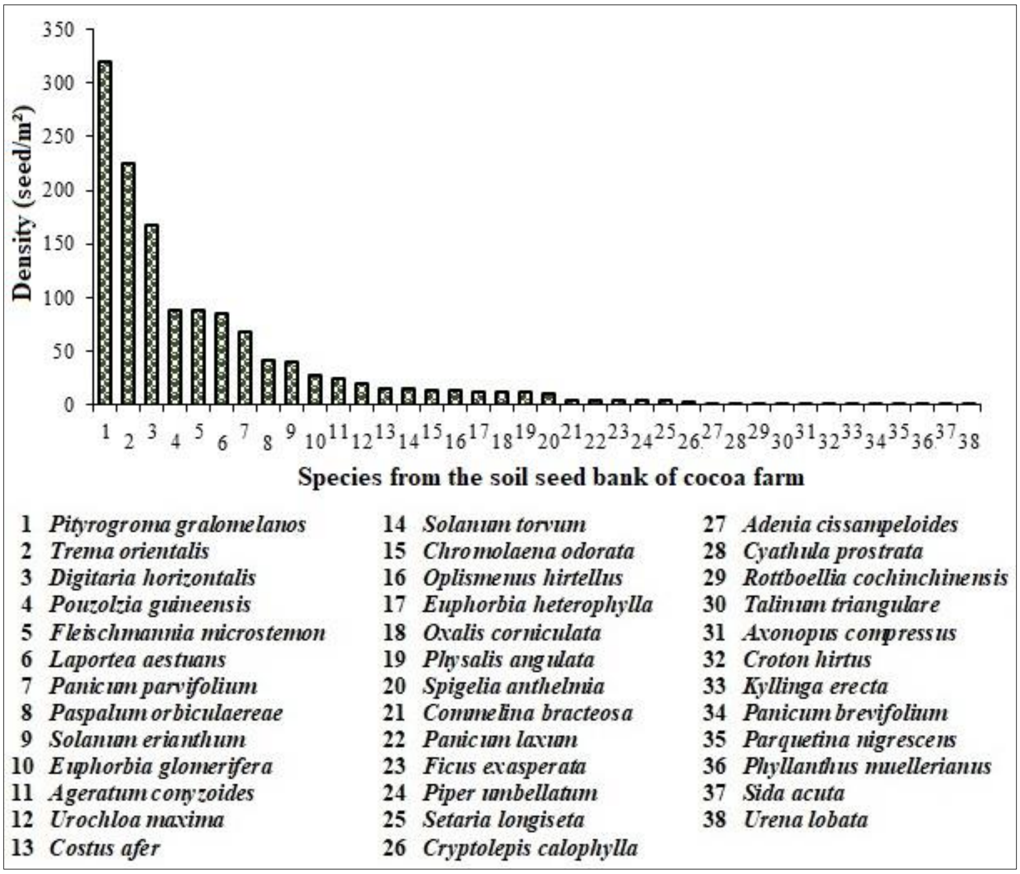

Figure 4 Species richness and density distribution of viable seeds per germinated plant in the soil of cocoa farms

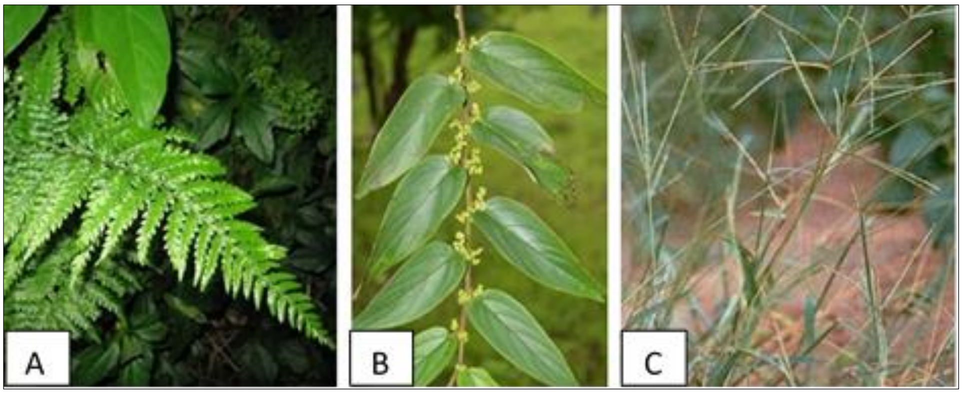

Figure 5 Plants with abundant seed in the top five centimeters of soil on cocoa farms. A) *Pityrogramma calomelanos*, B) *Trema orientalis* and C) *Digitaria horizontalis*

3.2.2 Rubber farms

In rubber farms it is a total of 39 species distributed in 35 kinds belonging to 21 families which germinated. The Poaceae are the most represented with nine species. This family is followed by the Asteraceae (4 species), Euphorbiaceae and Solanaceae (3 species each). In terms of seed density stored in the soil (Figure 6), the plants with the most seeds are *Rottboellia cochinchinensis* (Lour.) Clayton (429.17 Seeds/m^2; Figure 7A), *Digitaria horizontalis* (406.88 Seeds/m^2; Figure 7B) and *Paspalum orbiculaereae* Poir. (335.08 Seeds/m^2; Figure 7C). They are followed by plants such as *Panicum laxum* Sw. (182.40 Seeds/m^2), *Ageratum conyzoides* L. (167.54 Seeds/m^2), *Euphorbia glomerifera* (Millsp.) L.C.Wheeler (91.61 Seeds/m^2) and *Axonopus compressus* P.Beauv. (82.53 Seeds/m^2) and *Pityrogramma calomelanos* (64.38 Seeds/m^2).

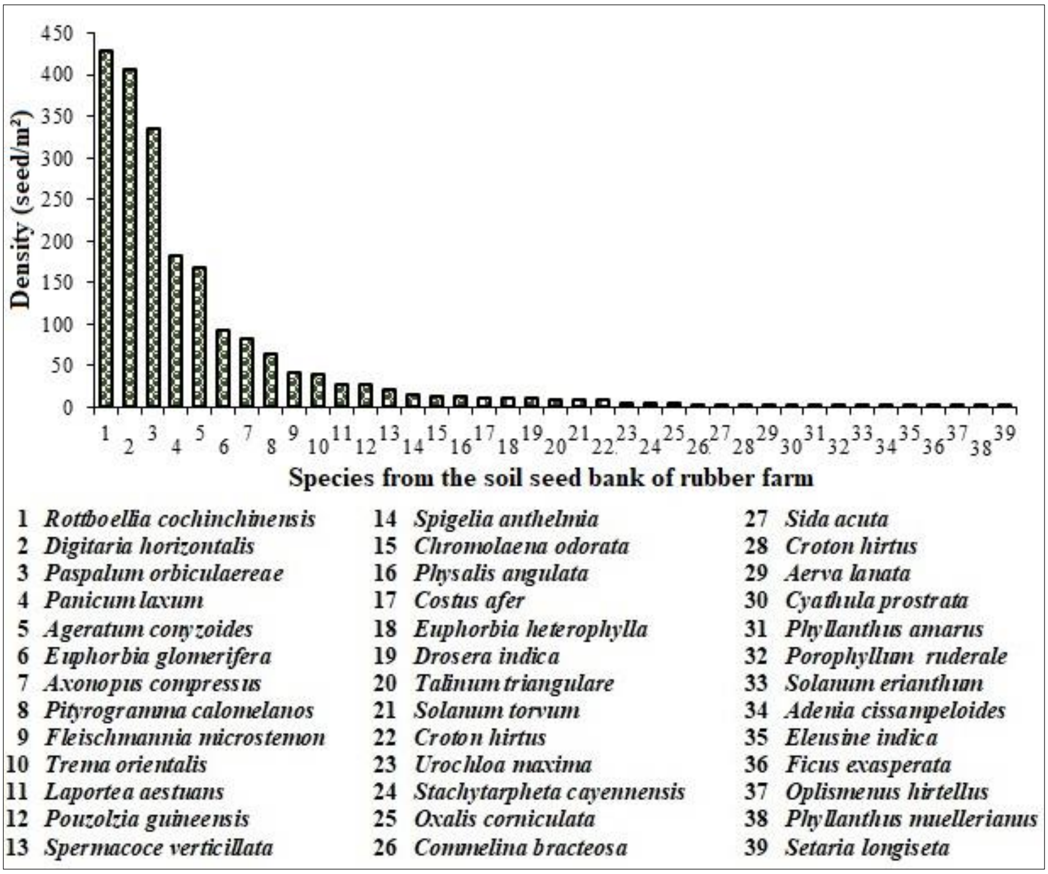

Figure 6 Species richness and density distribution of viable seeds per germinated plant in the soil of rubber farms

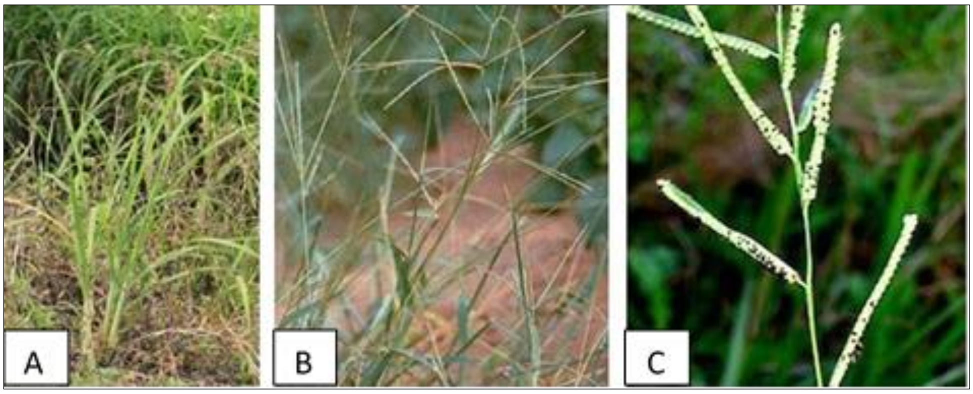

Figure 7 Plants with abundant seeds in the top five centimeters of soil in rubber farms. A) *Rottboellia cochinchinensis*, B) *Digitaria horizontalis* and C) *Paspalum orbiculaereae*

3.3 Vegetation typology likely to emerge from soil seed stock

The inventory of forest flora (reference ecosystems) shows 223 species in 176 genera belonging to 67 families. This flora, which includes all biological types, is 90.58% dominated by phanerophytes (Figure 8). However, more than half (51.49%) of these phanerophytes are shrubs or liana species that can reach 2 to 8 m in height at maturity (i.e. microphanerophytes). They are for example *Glyphaea brevis* (Spreng.) Monach, *Kigelia africana* (Lam.) Benth. *Combretum comosum* G.Don, *Griffonia simplicifolia* (Vahl ex DC.) Baill. etc.

The pattern of flora observed in these reference ecosystems is totally different from that of the flora derived from the soil seed stock of cocoa and rubber farms (Figure 8). The latter is devoid of tree or liana species that can reach 8-30 m in height at maturity (i.e., mesophanerophytes) and over 30 m in height (i.e., megaphanerophytes). Almost all the species of this flora are herbaceous.

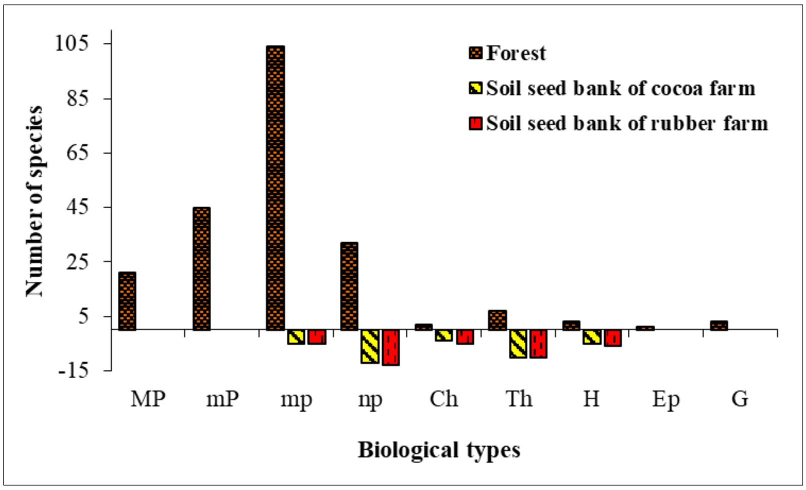

Figure 8 Comparison between the spectra of biological types of flora from the soil seed stock of cocoa farms, rubber farms and forest flora. *CE: cocoa farm, HF: rubber farm, MP: megaphanerophyte, mP: mesophanerophyte, mp: microphanerophyte, np: nanophanerophyte, Ch: chamephyte, Th: therophyte, H: hemicryptophyte, Ep: Epiphyte; G: geophyte*

4 Discussion

In the tropics, forest ecosystems have the capacity to reconstitute themselves following a windfall or a natural disturbance [20]. In the Indénié-Djuablin region, most of the forests are the result of agricultural operations, particularly abandoned cocoa farms [21]. However, the flora of the reference ecosystems inventoried has a similar typology to that observed in 2011 by Bakayoko et *al* [22] in the Bossématié classified forest located in the east of Ivory Coast. This classified forest is considered the most diverse forest of the semi-deciduous forests of Ivory Coast. Consequently, this is a sign of a fairly good reconstitution of forest flora in these reference ecosystems. The research question is therefore whether the soil seed stock of cocoa and rubber farms could contribute to the restoration of the floristic diversity observed in these reference ecosystems.

Investigations show that the soil seed stock of cocoa and rubber farms contains large quantities of viable seeds. However, this quantity decreases significantly with soil depth. This would be due to the fact that seed germination is negatively correlated with depth. More a seed is buried in the soil, more its nutrient reserve is reduced [23]. However, this situation is not an isolated case because as Douh et *al* [24] found in 2014, in tropical forest areas, the density of the soil seed stock decreases significantly with depth, whatever the biotope considered. Beyond the influence of soil depth, the quantity of viable seeds regresses over time. This could be explained by the fact that with time, some species lose their germination power probably under the influence of edaphic factors such as humidity, acidity and mineral element content. Nevertheless, the quantity of viable seeds remains higher in the first five centimeters of the soil in cocoa and rubber farms. As a result, viable seeds likely to involve in the post-cultivation reconstitution process are stored in the top five centimeters of soil, regardless of the age of the farms studied. Furthermore, these seeds are mainly from herbaceous species dominated by the Poaceae family. This situation could be the result of the additional action of three factors, namely clearing, burning and weeding of the plot. The burning of the plot would activate the germination of certain woody species characterized by late maturity and slow reproduction (i.e., k strategy species). However, its lighting due to clearing creates favorable conditions for the germination of sun-loving species, in this case herbaceous species characterized by early maturity and rapid reproduction (i.e., species with an r strategy). Thus, during weeding activities in the plot, large quantities of herbaceous seeds would be stored in the soil to the detriment of those of woody species. This would also explain the low presence of woody species in the soil seed stock of farms. This would also be due to the fact that in the soil, the seeds of herbaceous species have a lower dormancy than those of most woody species [25]. Furthermore, this situation is not without consequence for the process of reconstitution of the post-cultivation flora from the soil seed bnk of farms.

Speaking of post-cultivation reconstitution, studies on the soil seed stock of agrosystems have also been carried out in Niger [26], Cameroon [27] and even in southwest China [28]. They agree that after crop abandonment, the soil seed stock would be ineffective in the reconstitution of the forest flora. In this case study, the regeneration of forest flora from the soil seed stock of cocoa and rubber farms cannot be effective due to the abundance of herbaceous species. Indeed, following a windfall or an intense disturbance of the environment, weeds such as *Rottboellia cochinchinensis*, *Porophyllum ruderale* (Jacq.) Cass, *Chromolaena odorata* (L.) R.M.King & H.Rob. etc. could emerge from the ground and colonize the gaps. These potentially invasive species are known to release allelopathic compounds into the soil, which can inhibit dormancy break and/or the growth of other species [29, 30]. Furthermore, the absence of tree species in the soil seed bank could block the recovery process at intermediate stages, dominated by hemicryptophyte species. Indeed, after a disturbance the successional process starts with therophyte species [31], annual plants whose seed is the only organ of conservation during the unfavorable season. Then, it recruits in the intermediate stages of perennial plants whose renovation buds are flush with the surface of the soil (i.e. hemicryptophyte species) to tend towards the pre-forest stages dominated by phanerophyte species. Furthermore, the dynamics and quality of the post-cultivation flora are partly determined by the diversity of species, regeneration guilds and mode of dissemination of diaspores present in the species pool [4, 32]. However, in both cocoa and rubber farms, the species richness of the soil seed bank represents only 17% of the flora of reference ecosystems. This once again shows the inability of the soil seed bank on cocoa and rubber farms to restore floristic diversity after crop abandonment.

Nevertheless, seen from another angle, the high proportion of herbaceous species observed in the soil seed bank of farms could facilitate the reconstitution process provided that there are forest fragments in the vicinity. Indeed, during the post-cultivation succession, the decomposition of the pioneer species that are the first to settle would favour the availability of nutrients useful for the growth of k-strategy plant species. Thus, the seeds of tree species coming from the surrounding plant formations are disseminated in the reconstituted environment by the potential vectors and then germinate using the available resources. However, this requires the action of two additional factors, namely the remarkable presence of zoochorous, anemochorous seeders and the presence of potential vectors of these modes of dissemination such as mammals, birds and wind. Indeed, the modes of dissemination combined with the presence of seed trees within a radius compatible with the power of the dissemination vector influence the ability of a plant species to appear in a site [33].

5 Conclusion

The ability of the soil seed bank of cocoa and rubber farms to restore floristic diversity after crop abandonment was the main objective of this study.

Research revealed a large amount of viable seed in the top five centimeters of soil on cocoa and rubber farms in the study area. However, a high presence of herbaceous species and a low proportion of tree species were observed in this seed stock. But, it is widely accepted that after an agricultural disturbance, any process of forest flora reconstitution starts with the establishment of plant species characterized by early maturity and rapid reproduction to tend towards the pre-forest stages dominated by phanerophytic species. This reflects the low involvement of the soil seed bank of cocoa and rubber farms in the reconstitution of forest ecosystems. Indeed, in the absence of a diversity of phanerophytes in the soil seed bank of the farms studied, the post-cultivation reconstitution process could be at a stage dominated by invasive grasses. The latter have a negative effect on the dormancy breaking of other plant species. It would therefore be important to explore other potential floristic resources such as the spontaneous flora of farms and the rainfall of seeds from surrounding plant formations. This would allow us to assess the capacity of cocoa and rubber farms to restore floristic diversity after their abandonment.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

There is no conflict of interest.

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