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# Complex cocoa agroforestry systems shaped within specific socioeconomic and historical contexts in Africa: Lessons from Cameroonian farmers

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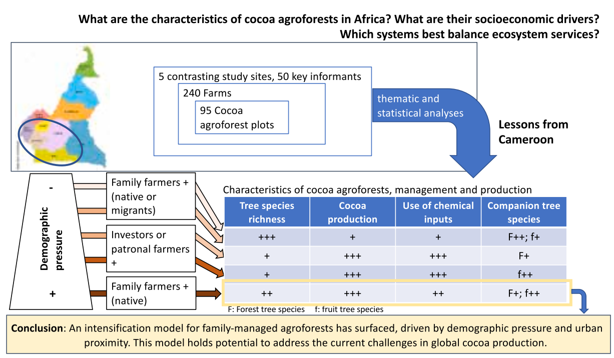
## HIGHLIGHTS

- Complex agroforests are predominant in the oldest cocoa-growing sites in Cameroon.
- Managed by family farmers, complex agroforests are replicated on newly cleared land.
- Investors and patronal farmers develop simplified agroforests with high input levels.
- An intensified model of family agroforests has emerged due to demographic pressure.
- Family agroforests successfully reconcile cocoa production with biodiversity conservation.

## GRAPHICAL ABSTRACT

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## ABSTRACT

*CONTEXT:* In the humid tropics, the socioecological advantages of family-based, multistory agroforestry systems are well recognized. Yet public policies tend to focus on conservation and land-sparing strategies alongside the promotion of modern intensive agriculture, neglecting these biodiverse agroecosystems, which are in decline. This is a particularly central issue in cocoa cultivation. In Africa's two largest cocoa-producing countries (Côte d'Ivoire and Ghana), cocoa plantations with few associated trees contribute to deforestation and biodiversity loss. In contrast, in regions like Cameroon, biodiversity-rich cocoa agroforests prevail. Considering global changes and rising cocoa demand, it is crucial to preserve and develop these agroforestry systems that reconcile cocoa production with ecosystem services.
*OBJECTIVE:* This study, conducted in Cameroon between 2013 and 2017, aimed to pinpoint the socioeconomic factors influencing the characteristics, maintenance, and degradation of cocoa agroforests, with the ultimate goal of identifying intervention strategies to promote their preservation and development.
*METHODS:* The study collected data from (i) on-field measurements in 95 cocoa agroforestry plots, (ii) interviews with the 95 farmers managing the plots, and (iii) historical interviews with 50 key informants. We focused on five sites across a gradient of population density, encompassing various socioecological environments and types of cocoa agroforests. Through thematic and statistical analyses, we evaluated differences between the five sites.

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*RESULTS AND CONCLUSIONS:* Our results indicated contrasting management practices, dendrometric structure, species composition, and cocoa yields between sites. These contrasts largely reflected socioeconomic factors and site-specific dynamics. Cocoa agroforests were less rich in biodiversity in sites where farmers with capital using hired labor had acquired land than in sites where family farmers predominated. A trade-off was found between the richness of companion trees and cocoa yields. Plots managed by smallholder family farmers near urban areas tended to better reconcile cocoa production and biodiversity conservation. These farmers had gradually transformed their traditional agroforests to adapt to increasing demographic pressure by integrating diverse fruit tree species, using pesticides sparingly, and introducing selected cocoa varieties mixed with older varieties.

*SIGNIFICANCE:* The small-scale family-managed cocoa agroforests, which incorporate fruit species as described in this study, could serve as a model for a more sustainable cocoa production strategy. However, developing such a strategy would require greater investment and support from policymakers. This includes supporting the marketing of products from companion trees, stabilizing cocoa prices at a high level, and implementing land policies that protect small and medium-sized family farmers.

## 1. Introduction

Research has shown that family-based agroforestry systems offer significant socioecological benefits and contribute to sustainable agriculture (Noordwijk et al., 2011; Tscharntke et al., 2011; Kull et al., 2013). These systems show the crucial role of agroecological matrices in biodiversity conservation in anthropized areas (Perfecto and Vandermeer, 2010) and can be considered part of a complementary approach to protected areas for both local and global biodiversity conservation and sustainable food production (Valente et al., 2022). However, public policies have often given priority to conservation and land-sparing strategies, alongside the promotion of modern intensive agriculture, both of which overlook the preservation of such diverse systems (Perfecto and Vandermeer, 2010; Carrière et al., 2013). Particularly in the humid tropics, complex multistory agroforests are increasingly being replaced by woody monocultures focused solely on rapid economic gain (Grass et al., 2020). This evolution negatively impacts both biodiversity and the livelihoods of farmers, who depend on the diverse products these systems provide (Schroth et al., 2004). Identifying the levers for ensuring the preservation and development of these agroforestry systems is an urgent research challenge.

Cocoa agroforests are particularly central in this perspective. Cocoa expansion is a significant cause of deforestation and biodiversity loss in leading producer countries such as Côte d'Ivoire and Ghana (Mighty Earth, 2023). Historically, these countries have promoted cocoa cultivation through colonial and post-colonial technical and financial incentives, including policies to encourage population settlement in forested areas. Adopting a productivist model, these policies have led to biodiverse-poor plantations dependent on hybrid cocoa varieties and chemical inputs and characterized by short-lived productivity (Asare, 2005; Ruf et al., 2015). These plantations are often abandoned after the yield declines, leading to the creation of new plantations and to further deforestation (Ruf, 1995). Price fluctuations since the 1980s, in a context of liberalization and globalization, have exacerbated these patterns (Ruf and Siswoputranto, 1995; Lipchitz and Pouch, 2008). Conversely, in countries such as Nigeria, Cameroon and Brazil, cocoa agroforests rich in biodiversity demonstrate the potential for sustainable cocoa production (Ruf and Schroth, 2004; Asare, 2005; Sonwa et al., 2019; Gama-Rodrigues et al., 2021). Amid global challenges and rising demand (ICCO, 2016), this method of cocoa production through agroforestry could be promoted and strengthened by public and international policies. The European Union's recent decision to curb cocoa imports from deforested areas highlights an awareness of this need (EC, 2020, 2022; Sassen et al., 2022). However, conserving and promoting these diverse agroforests requires fine-tuned strategies that consider local socioecological contexts. Place-based research is essential to pinpoint the local dynamics that drive cocoa agroforest sustainability and their ability to deliver a broad spectrum of ecosystem services over the long term (Andres et al., 2016; Bisseleua et al., 2017; Mortimer et al., 2018).

Cameroun, which is also ranked as the sixth-largest cocoa producer globally and the fourth in Africa according to the FAO (2020), is pivotal in understanding the dynamics of cocoa agroforests. As a former German colony, Cameroon initiated cocoa cultivation later than neighboring countries, with technical and financial support discontinued from the late 1980s and without a national policy to colonize already inhabited forest areas (Ruf and Schroth, 2004). The country uses a variety of cocoa plantation systems, including complex and multistory agroforests (Laird et al., 2007; Sonwa et al., 2017, 2019). The latter systems demonstrate both resilience and sustainability (Jagoret et al., 2018), but the socioeconomic factors as well as the numerous feedback loops that affect their characteristics, maintenance, development or degradation are still poorly understood.

This study aimed to deepen understanding of the factors that influence the structure and dynamics of cocoa agroforests in Cameroon, as well as their production potential. Adopting a comparative approach, the research spanned five study sites along a continuum of population density and urbanization levels. This framework covered a broad spectrum of socioeconomic environments and demographic compositions, including native and migrant populations (Michel et al., 2019). To elucidate the key elements that determine the dendrometric structure and biodiversity of cocoa agroforests, as well as the levels of cocoa yields and the utilization of associated tree production, a mixed-methods research protocol was employed. This approach combined interviews with key informants and farmers alongside detailed inventories of cocoa agroforest plots. By integrating these diverse datasets, we gained an in-depth understanding of both historical and contemporary trends that affect cocoa agroforest dynamics. This analysis also helped to clarify how local contexts influence the configuration and performance of cocoa agroforests. The ultimate goal was to pinpoint which cocoa agroforests optimally balance various ecosystem services and to help define strategies to promote their sustainability and productivity.

## 2. Materials and methods

### 2.1. Study sites

The five study sites were located in the two main cocoa-producing regions of Cameroon. One site was in the southwest (South-West administrative region), an English-speaking area, and four sites were in the center and south (Center and South administrative regions), which are French-speaking (Fig. 1). The center and south are the country's oldest and largest cocoa-growing areas, concentrated around the city of Yaoundé. The two main cocoa-producing regions contribute roughly equally to Cameroon's total cocoa production, yet they vary significantly in their geographical and environmental characteristics. The southwest region, close to the Atlantic coast, is nestled at the base of Mount Cameroon within a tropical rainforest. This area has humid equatorial climatic conditions and rich and alkaline nitisols developed on volcanic rock substrata. Conversely, the center and south regions are found on the central Cameroon plateau, characterized by tropical forests with predominantly semi-deciduous tree cover and sub-equatorial climate conditions. The soils here are predominantly poor, acidic, and comprised of ferrosols (Djoufack-Manetsa, 2011). Cocoa was introduced to Cameroon in the late 19th century by German settlers, who established the first plantations in the coastal region using Forastero varieties from Brazil, specifically known as Amelonado. Following World War I and the subsequent division of the country into two protectorates, cocoa farming evolved in diverse ways.

The study sites in the center and south were strategically selected based on a gradient of population density and their proximity to Yaoundé, ranging from recent to long-established access. Near Yaoundé (at a distance of about 40 km), the Obala site, located in the eponymous municipality within the Lekié department, has the highest population density. Moving away from Yaoundé (around 100 km), the Akongo site in the Nyong-et-So'o department is a village with medium population density. The Mintom site, situated in the Dja-et-Lobo department, has a very low population density and is located far from Yaoundé (about 300 km) in a newly cleared forest area, adjacent to the Dja Reserve—a UNESCO World Heritage site since 1987 (Tatuebu Tagne, 2019). The Talba site, in the Mbam-et-Kim department, is a village in a forested area that was isolated until 1979 due to its location on the other side of a difficult-to-cross river; despite its proximity to Yaoundé (around 125 km), it has a medium population density. Finally, the southwest site, referred to as Mbonge, is in the village of Kwakwa (Mbonge municipality, Meme department), near the city of Kumba—an epicenter of cocoa production in a densely populated region.

### 2.2. Sampling design and data collection

Between 2013 and 2017, we collected both qualitative and quantitative data using three distinct methodologies. Initially, to gather insight into the history of cocoa cultivation and the current agricultural dynamics at various sites, we conducted semi-structured interviews with 50 key informants, including village leaders, divisional agricultural delegates, and community leaders, with 6–15 participants per site. These interviews facilitated the preliminary identification of the diverse cocoa growers' profiles and practices across the sites. Next, we began characterizing the socioeconomic profiles of cocoa farmers by conducting preliminary individual interviews with 240 farmers, ranging from 40 to 50 per site. We employed a stratified sampling method to ensure a representative cross-section of the diverse farmer profiles and practices previously identified, supplemented by convenience sampling to maximize participant engagement. These interviews explored aspects such as the farmers' life histories, income sources, workforce types, land ownership, crop types, and the age, history and management strategies of their cocoa agroforests. Lastly, to accurately characterize the farmers' profiles and their cocoa agroforest stands, we conducted comprehensive surveys on 95 farms. The first step involved socioeconomic interviews that collected detailed information on the farmers' profiles and characterized their cocoa agroforest management practices, cocoa yields (the average yield estimated by the farmers based on the last three years of production), and the uses of associated tree production. Subsequently, we visited one cocoa agroforest stand per farmer, chosen to be as representative as possible of the farmer's practices, where we carried out dendrometric and biodiversity assessments. For this purpose, a 50 × 50

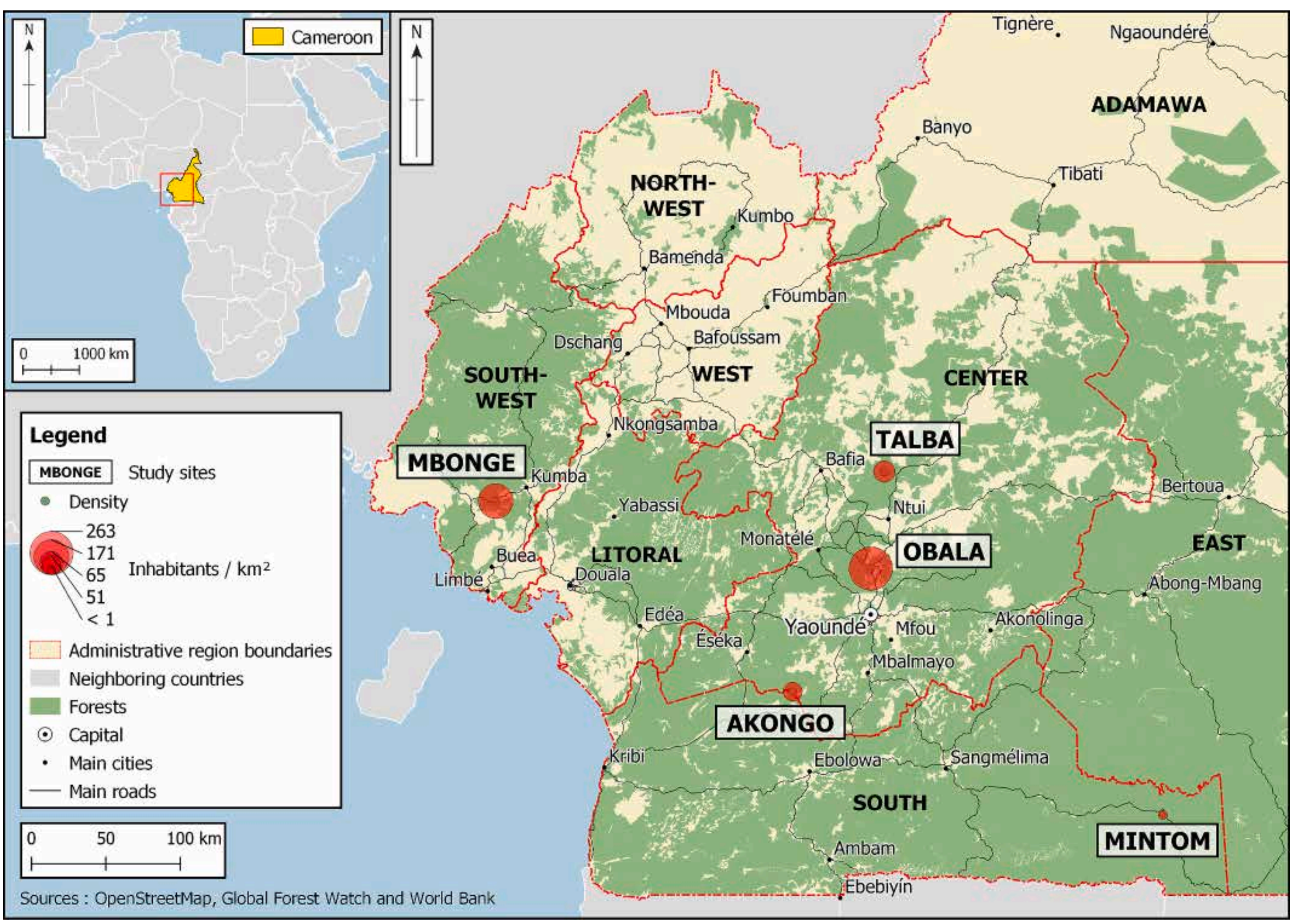


**Fig. 1.** Location of the five study sites.

m plot (2500 $m^2$) was established in each stand to identify and measure companion trees, while a 20 × 50 m subplot (1000 $m^2$) was designated for measuring cocoa trees (Table 1).

### 2.3. Data analysis

To gain an understanding of the historical and current conditions at the various study sites, we first conducted a qualitative analysis of interviews with key informants. We then performed a comparative analysis of the categories of farmers and their cocoa agroforestry management practices, based on key themes from the previous analysis. These analyses were supplemented by descriptive statistics and statistical testing involving 95 farmers from the in-depth survey. To identify differences across sites, we used Kruskal-Wallis and Dunn tests. These non-parametric tests were chosen due to the non-normal distribution of many variables. Second, we examined differences and similarities in cocoa yields, management practices, and the structure and composition of the cocoa agroforests across the sites. This was achieved through two approaches. We applied Kruskal-Wallis and Dunn tests to explore relationships between study sites and key dendrometric metrics, such as cocoa basal area and densities of cocoa and companion trees, alongside management practices and cocoa yields. Additionally, we analyzed the similarity of cocoa agroforest plots based on species composition using hierarchical clustering with the Jaccard distance and Ward's method, implemented in the "vegan" package in R (Oksanen et al., 2022). We also examined the structure of companion tree stands in terms of cocoa agroforest stratification and tree uses. Trees were categorized into vegetation strata: lower (cocoa stratum, 0–8 m), intermediate (8–24 m), and higher (>25 m). Based on interviews about plant uses, tree species were grouped into one or more of the following use categories: edible, firewood, timber, handicrafts, and medicinal.

## 3. Results

### 3.1. Historical and socioeconomic characteristics of the study sites

Cocoa-growing in the center and south of Cameroon began to develop in the 1930s, first under the impetus of the French protectorate and then with the support of the Cameroonian government. This was achieved through the adoption of the crop by the existing local farming population. Initially centered around Yaoundé, cocoa farming later extended to more remote and sparsely populated areas. Local farmers, who combined shifting cultivation with hunting and gathering, integrated cocoa trees into their crop fields, creating complex multistory cocoa agroforests and eventually settling in permanently. They received technical and financial assistance from the Cameroonian government, which enabled them to establish family farms that combined cocoa agroforestry with food crops on long-term fallow land. The *Société pour le développement du cacao* (SODECAO), created in 1974, promoted the use of hybrid cocoa varieties and pesticides against mirid and black pod disease. With the onset of the cocoa crisis in the late 1980s and the government's subsequent withdrawal from the sector, a period marked by high price fluctuations led to successive cycles of abandonment, rehabilitation, and expansion of cocoa farms. During this time, the socioeconomic profiles of cocoa farmers diversified, with new stakeholders entering the scene and investing in available land.

**Table 1**
Summary of the measured and calculated variables used in this study to characterize cocoa agroforest plots, including cocoa and companion trees.

| | Cocoa tree stand *(1000 $m^2$ subplot)* | Companion tree stand *(2500 $m^2$ plot)* |
|---|---|---|
| Direct measurements | Tree height<br>Diameter at 50 cm for all stems | Tree height<br>Diameter at breast height (DBH) |
| Calculated variables | Cocoa tree density<br>Cocoa tree basal area | Companion tree density<br>Companion tree basal area |
| Other assessment variables | Variety (based on farmers' knowledge) | Species name (based on Vivien and Faure, 1985; Onana and Mezili, 2018) |
| | Tree age (based on farmers' knowledge)<br>Pruned vs. unpruned tree | Status: living or cut Traditional uses (based on farmers' knowledge)<br>Stratum: cocoa stratum, intermediate stratum, high stratum |

In the historic cocoa-growing zones near and around Yaoundé, the populations of Obala and Akongo are composed entirely of descendants of the country's pioneer cocoa farmers. All farmers in these areas are native (Fig. 2c) and inherited their plots from their ancestors, whether these were already planted with cocoa or not (Fig. 2a). Despite the significant age variability of the cocoa agroforest plots, indicating ongoing local development, analyses showed that the cocoa agroforests in Obala and Akongo are significantly older than those in other areas (Fig. 2e, Table 2). These farms are generally smaller (Fig. 2d), and predominantly managed using family labor (Fig. 2b). The presence of sharecropping in Akongo could be attributed to young heirs working the land while awaiting their inheritance. The Obala site, located in the densely populated Lekié region, experienced outmigration starting in the early 1970s as descendants sought less crowded areas for farming.

Located about 125 km from Yaoundé, in a forested area that was isolated until 1979, Talba has become a destination for migrants, including urban individuals from Yaoundé. The origins of Talba's farmers vary, encompassing local farmers, urban investors, and multiple generations of migrants from Lekié (Fig. 2c). Cocoa agroforest stands are therefore either inherited (the case of local farmers and second-generation migrants of Lekié) or purchased (by investors and first-generation migrants) (Fig. 2a). Due to their considerable financial resources, investors have driven up land prices and promoted local employment through salaried labor, often provided by specialized agricultural workers from regions such as northwest Cameroon, Chad, and Nigeria. Conversely, local and Lekié migrant farmers typically use a mix of family and hired labor (Fig. 2b). The cocoa plantations are large (Fig. 2d) and recent (Fig. 2e), reflecting the ongoing strong migratory dynamics in the area.

Further away, around 300 km from Yaoundé, in a recently cleared forest region, Mintom began to attract a diverse group of migrants starting in the early 1980s, with the initial group arriving from Lekié. Here, cocoa agroforests are of intermediate age (Fig. 2e), representing a pioneering frontier that, while established early on, is still in the initial stages of development. The diversity of farmers' origins is similar to that observed in Talba (Fig. 2c), but with several marked differences. Native farmers in Mintom, originally hunter-gatherers growing a small amount of subsistence crops, became cacao farmers after participating in the cacao-planting campaigns launched by SODECAO in the early 1970s. Following the company's inactivity post-1990, these farmers largely ceased maintaining their cocoa agroforests, instead prioritizing their traditional hunting activities. Migrants from Lekié and their descendants, on the other hand, developed cocoa agroforests on purchased land, primarily using family labor. The construction of a paved road in the early 2000s transformed Mintom into a burgeoning frontier, attracting a wider variety of stakeholders from various regions of Cameroon. These individuals were drawn by the new economic opportunities emerging from the area's development, such as trade, gold panning, and roles in local governance. Some of them have established small-scale cocoa production businesses by acquiring land either through token payments or gifts, employing a workforce of sedentary Baka Pygmies, thus positioning themselves as investors in the cocoa sector. In an even more unique system, temporary migrants lease cocoa agroforestry plots from native farmers exclusively for the duration of the cocoa harvest season, returning to their original regions afterward. These migrant workers from the English-speaking regions of Cameroon, typically viewed as outsiders, and seldom landowners in Mintom, have revitalized these neglected cocoa agroforests by investing in labor and inputs, while refraining from cutting the tree stands due to limited

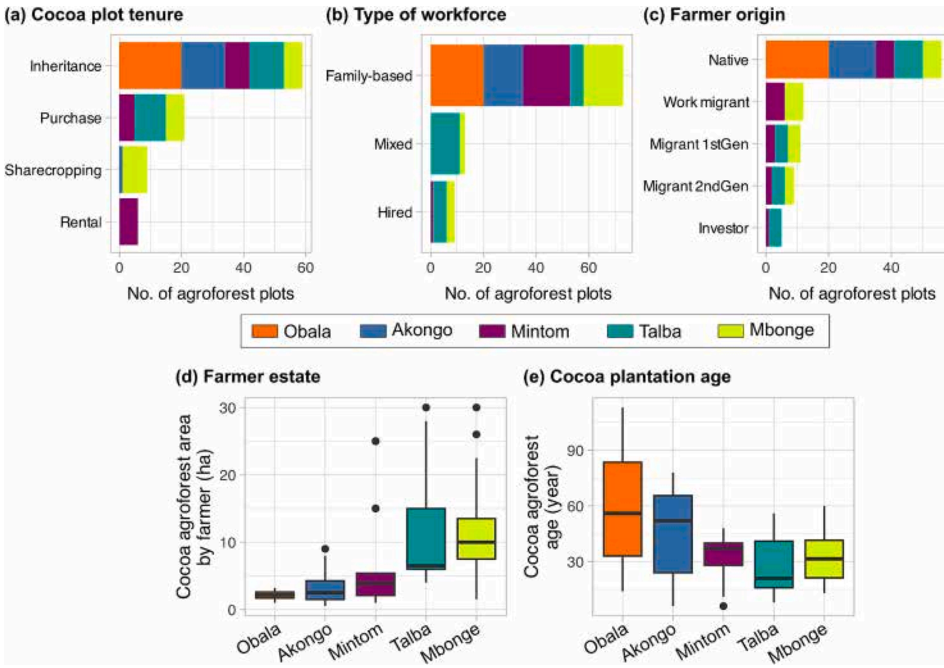


**Fig. 2.** Overview of the main socioeconomic variables of farmers and their cocoa agroforest management strategies at the five study sites (95 farmers).

**Table 2**
Summary of the main socioeconomic characteristics of the five study sites and characteristics of cocoa agroforest plots and management. *P*-values correspond to a Kruskal-Wallis test between sites, and superscripts code for the grouping (1,2,3) operated by a Dunn test (certain sites being in an intermediate position between two groups) (95 plots).

| | Obala | Akongo | Mintom | Talba | Mbonge |
|---|---|---|---|---|---|
| Location | about 40 km from Yaoundé | about 100 km from Yaoundé | about 300 km from Yaoundé | about 125 km from Yaoundé | Southwest region |
| Distinctive socioeconomic features | High demographic pressure<br>Inherited plots<br>Family workforce<br>Native farmers<br>Small estates | Intermediate demographic pressure<br>Inherited plots<br>Family workforce<br>Native farmers<br>Small estates | Low demographic pressure<br>Purchased & rented plots<br>Family workforce<br>Native & migrant farmers<br>Small estates | Intermediate demographic pressure<br>Purchased plots<br>Salaried workforce<br>Migrant & investor farmers<br>Large estates | High demographic pressure<br>Sharecropping<br>Family workforce<br>Native & migrant farmers<br>Large estates |
| Cocoa plantation age (year) *$p < 0.001$*** | $61 \pm 31$ (1) | $46 \pm 25$ (1) | $33 \pm 12$ (1–2) | $26 \pm 15$ (2) | $33 \pm 15$ (1–2) |
| Control treatments (number. year$^{-1}$) *$p < 0.0001$**** | $4.8 \pm 2$ (1–2) | $3.4 \pm 1.8$ (1) | $2.8 \pm 1.4$ (1) | $5.8 \pm 0.7$ (2) | $7.3 \pm 2.1$ (2) |
| Amelonado variety (%) *$p < 0.0001$**** | $73 \pm 29$ (1) | $99 \pm 4$ (2) | $77 \pm 21$ (1) | $33 \pm 48$ (1) | $1 \pm 3$ (3) |
| Cocoa yields (kg.ha$^{-1}$) *$p < 0.0001$**** | $1003 \pm 546$ (2) | $608 \pm 582$ (1) | $461 \pm 135$ (1) | $1115 \pm 221$ (2) | $1094 \pm 404$ (2) |
| Cocoa basal area (m$^2$.ha$^{-1}$) *$p < 0.0001$**** | $10.6 \pm 4.7$ (2–3) | $18.3 \pm 9.9$ (1) | $5.2 \pm 2.4$ (3) | $8.5 \pm 2.4$ (2–3) | $15.7 \pm 19.4$ (2) |
| Cocoa density (ha$^{-1}$) *$p = 0.069$ (NS)* | $1543 \pm 783$ | $1556 \pm 1051$ | $1229 \pm 313$ | $1019 \pm 229$ | $1066 \pm 345$ |
| Cocoa dominant height (m) *$p < 0.0001$**** | $6.7 \pm 1.5$ (2) | $5.9 \pm 1.9$ (2) | $6.4 \pm 1.1$ (2) | $7.5 \pm 0.9$ (3) | $5.4 \pm 0.4$ (1) |
| Density in companion trees (ha$^{-1}$) *$p < 0.0001$**** | $133 \pm 46$ (2–3) | $110 \pm 63$ (2) | $155 \pm 58$ (3) | $40 \pm 20$ (1) | $112 \pm 25$ (2) |
| Species richness *$p < 0.0001$**** | $12.4 \pm 3.7$ (1) | $13.3 \pm 5.9$ (1) | $16.3 \pm 6.9$ (1) | $7.3 \pm 3.3$ (2) | $11.5 \pm 2.3$ (1) |

property rights. Their presence in Mintom has diversified land tenure and farmer profiles (Fig. 2a and c). As a result, with most small cocoa farms (Fig. 2d) predominantly operated by family labor (Fig. 2b), the cocoa agroforest management practices in Mintom closely mirror those in Obala and Akongo.

In the southwest, a region that was initially under the British protectorate and sparsely populated, cocoa farming was long hindered by fungal diseases and was confined to commercial plantations employing workers from neighboring English-speaking areas. However, it began expanding significantly in the 1970s, fueled by state-supported price policies and the availability of fungicides against black pod disease. This late expansion attracted migrant workers from Nigeria and Cameroon's populous northwest region. The initial migrants arrived as agricultural paid laborers and began their farming activities by becoming sharecroppers with established farmers, allowing the latter to expand their cocoa plantation areas. After several years of sharecropping, these migrants were able to purchase land, then hire salaried workers and new migrant sharecroppers, thus becoming patronal farmers who run their cocoa plantations partly with their families and partly with paid labor. In Mbonge, immigration and sharecropping thus catalyzed the rapid development of cocoa farming. By the late 1980s, the cocoa-growing areas were saturated, prompting the last wave of migrants to seek new opportunities in places such as Mintom. Today, this site exhibits a mix of farmer origins similar to other migration hubs (Fig. 2c), as well as a variety of cocoa land tenure systems, with the specificity of sharecropping (Fig. 2a). Family labor remains predominant, with sharecroppers working with their families. The cocoa agroforest management situation in Mbonge is similar to that in Talba, characterized by large cocoa estates and an intermediate age (Fig. 2e and d), in a context of significant demographic pressure close to that of Obala.

### 3.2. Management, dendrometric diversity and yields of cocoa agroforests

The cocoa agroforests across the different sites have contrasting management practices, dendrometric structures, and yields (Table 2). Cocoa yields are significantly lower in Akongo and Mintom, and higher in Talba and Mbonge, and also in Obala. Although the density of cocoa trees per hectare is consistent across all sites, variations in yields can be attributed to differences in management intensity: pesticide use is substantially lower in Akongo and Mintom, higher in Talba and Mbonge, and moderate in Obala. In terms of cocoa varieties, farmers in Akongo mainly grow the Amelonado variety, while farmers in Mbonge and, to a lesser extent, Talba, prefer hybrid varieties. In Mintom, there is a mixture of Amelonado and some hybrid varieties, and this is also the case in Obala, where the cocoa agroforests were the oldest. In Obala, there is a disparity between the average age of the agroforests and that of the cocoa trees, with the former being 61 years and the latter 42 years, suggesting ongoing individual cocoa tree renewal, which has facilitated the introduction of new cocoa varieties in mature agroforests. The average basal area per hectare of a cocoa tree stand is generally positively correlated with its average age, with the highest values observed in Akongo. Obala, with its renewed cocoa trees, presents intermediate values. Of the youngest cocoa agroforests, Mintom has particularly low basal area values, while Mbonge has exceptionally high values. Finally, the density of companion trees shows contrasting values between sites, which required clarification of the tree species involved: it was significantly high in Mintom, closely followed by Obala, low in Talba, and moderate in Akongo and Mbonge.

### 3.3. Diversity of species and uses of companion trees in cocoa agroforests

We found a total of 166 tree species in the 95 cocoa agroforests, including 127 that were identified at the species level, two at the gender level, and 37 that were non-determined. The most frequent species are *Terminalia superba* (found in $N = 65$ cocoa agroforests), *Dacryodes edulis* ($N = 64$), *Persea americana* ($N = 61$), *Elaeis guineensis* ($N = 46$), and *Musa sapientum* ($N = 39$). With a total of 84 recorded species, Mintom has the highest species richness, followed by Obala (60 recorded species). Mbonge and Talba have the lowest species richness with 33 and 44 recorded species, respectively. This site-level trend is also observed at the plot level: on average, Talba cocoa agroforests have the lowest species richness (7.3); those in Mintom have the highest (16.3), closely followed by Akongo (13.3), Obala (12.4), then Mbonge (11.5) (Table 2).

In addition to species richness, species composition varies across the five sites, as shown by hierarchical clustering analysis based on Jaccard distance (Fig. 3). Initially, this analysis distinguished the Mbonge and Obala cocoa agroforest plots from those in Talba, Mintom, and Akongo. Subsequent second-order clustering grouped cocoa agroforests by their respective sites, except for Mintom and Akongo, which were classified together and only differentiated in the third-order clustering (Fig. 3). These clustering results may correlate with the prevalence of fruit tree species in Mbonge and Obala, while forest tree species were more dominant at the other sites (Table 3).

Variation in cocoa agroforest stratification is also evident across the five sites (Fig. 4). In Mbonge, companion trees are primarily found in the lower stratum, whereas in Obala, they populate both the lower and intermediate strata. In contrast, Akongo and Mintom have companion trees in the intermediate and higher strata. Talba's cocoa agroforests,

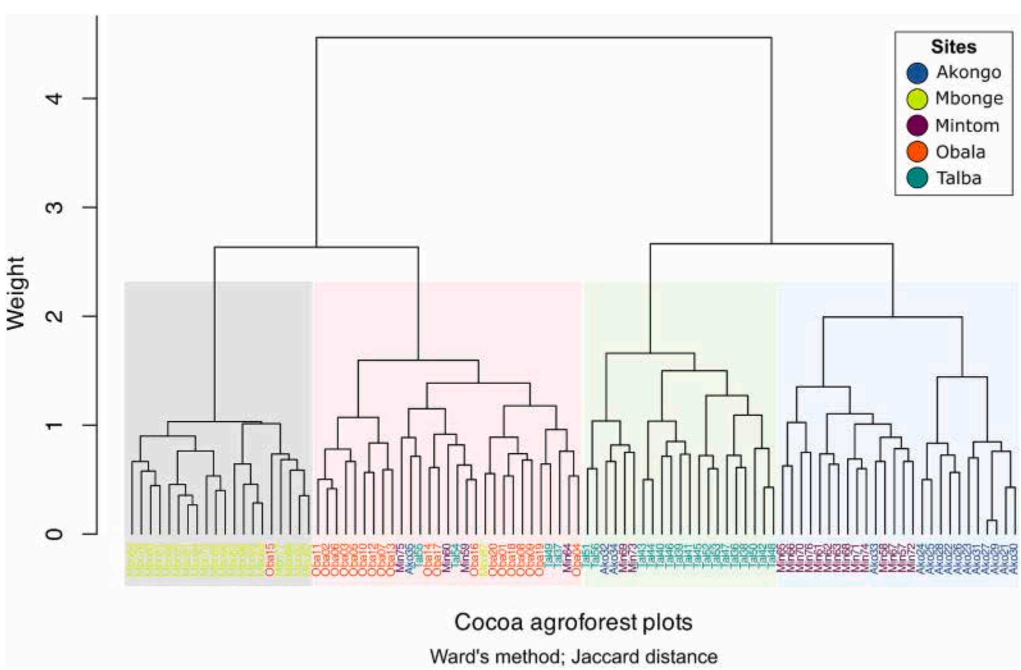


**Fig. 3.** Dendrogram of an ascendant hierarchical clustering analysis performed for the 95 agroforest plots on the basis of their composition in tree species. Jaccard distance was used to calculate distance between plots, and Ward's method was used as the agglomeration method. Cocoa agroforest plot names are colored according to study sites, and four clusters are highlighted by the four colored rectangles.

**Table 3**
List of the 10 most abundant companion tree species at the different study sites (95 plots).

| Obala | Akongo | Mintom | Talba | Mbonge |
|---|---|---|---|---|
| *Musa sapientum* | *Terminalia superba* | *Terminalia superba* | *Terminalia superba* | *Musa paradisiaca* |
| *Persea americana* | *Dacryodes edulis* | *Persea americana* | *Ceiba pentandra* | *Musa sapientum* |
| *Dacryodes edulis* | *Macaranga hurifolia* | *Elaeis guineensis* | *Cola acuminata* | *Dacryodes edulis* |
| *Elaeis guineensis* | *Persea americana* | *Ficus mucoso* | *Sterculia rhinopetala* | *Elaeis guineensis* |
| *Mangifera indica* | *Petersianthus macrocarpus* | *Hevea brasiliensis* | *Ricinodendron heudelotii* | *Persea americana* |
| *Citrus sinensis* | *Alstonia boonei* | *Dacryodes edulis* | *Diospyros crassiflora* | *Citrus sinensis* |
| *Milicia excelsa* | *Mangifera indica* | *Ficus exasperata* | *Milicia excelsa* | *Tilia cordata* |
| *Terminalia superba* | *Phyllanthus discoideus* | *Ricinodendron heudelotii* | *Alstonia boonei* | *Terminalia superba* |
| *Citrus reticulata* | *Irvingia gabonensis* | *Triplochiton scleroxylon* | *Persea americana* | *Milicia excelsa* |
| *Musa paradisiaca* | *Albieia adianthifolia* | *Musanga cecropioides* | *Dacryodes edulis* | *Trichoscypha acuminata* |

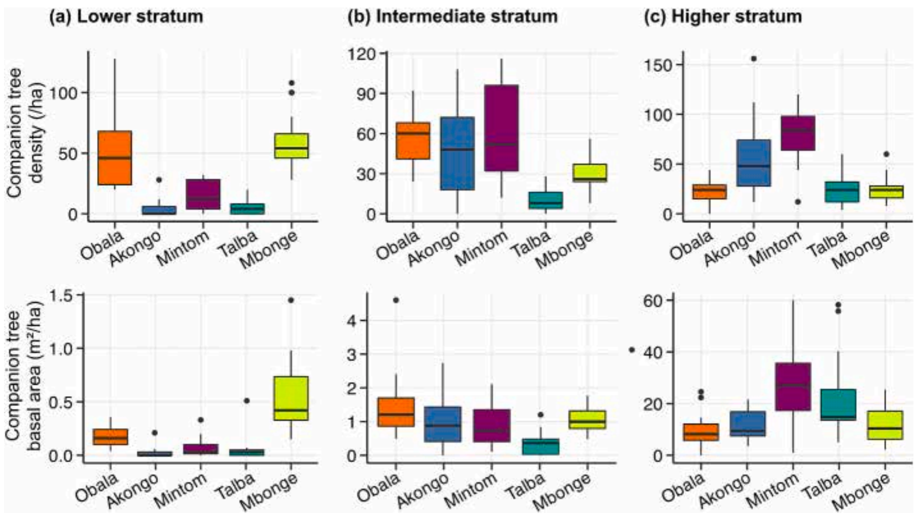


**Fig. 4.** Companion tree stand characteristics in the five study site cocoa agroforests according to their location in the: (a) lower stratum, (b) intermediate stratum, and (c) higher stratum (95 plots).

however, have fewer companion trees across all three strata. At this site, dominated by large forest trees such as *Terminalia superba* and *Ceiba pentandra*, the higher stratum has one of the lowest densities of companion trees in our study, but exhibits the largest basal area.

In addition to assessing the species richness of companion trees, we explored the diversity of their uses at the plot level, considering edible, medicinal, firewood, timber, and handicraft purposes (Fig. 5). Our findings showed that cocoa agroforests in Akongo exhibit the highest diversity of companion tree uses, while those in Talba have the lowest diversity. The specific uses vary by site: Obala cocoa agroforests feature the greatest number of edible tree species; Mintom has the most species used for firewood; and both Akongo and Mintom have the highest counts of timber species. Akongo stands out with the highest variety of trees used for handicrafts and medicinal purposes.

## 4. Discussion

The findings of this study highlight a diverse range of cocoa agroforest dynamics, socioeconomic situations and farming strategies, all of which influence agroforest structure, composition, and performance.

### *4.1. Cocoa farmers' socioeconomic characteristics and cocoa agroforest structures*

Our results indicate that cocoa agroforest structures are different if cocoa production (i) is managed by local families (Obala and Akongo); (ii) is driven by external stakeholders (urban investors using migrant farm workers, or sharecroppers coming from highly populated non-cocoa cropping regions) who have joined a core group of local families (Talba and Mbonge); (iii) is still not developed in forest sites where abundant land is available but local labor is scarce, while cocoa stands abandoned by local farmers are also still present (Mintom). The conditions in Obala and Akongo have been previously documented in the center and south of Cameroon (Carrière, 2003; Jagoret et al., 2018), while those in Mbonge and Talba resemble observations made some decades ago in Côte d'Ivoire and Ghana (Losch, 1995).

Cocoa agroforests in Mintom, Akongo, and Obala are characterized by a relatively high richness in companion trees distributed in two to three strata, echoing other observations made in the center and south of Cameroon (Bisseleua and Vidal, 2008; Gockowski and Sonwa, 2011; Jagoret et al., 2018; Munjeb et al., 2021). Compared to measurements obtained in Ghana, Nigeria, and Côte d'Ivoire, these cocoa agroforests are among the densest in Africa in terms of trees and associated species. However, the low density of companion trees in Talba's cocoa agroforests and, to a lesser extent, in Mbonge's, make them more similar to cocoa plantations studied in Ghana (33–111 associated trees/ha), but still denser than in Côte d'Ivoire (6–56 associated trees/ha) and Nigeria (23 associated trees/ha), where land pressure is high (Gockowski and Sonwa, 2011). The cacao agroforests in Mbonge are unique, combining cocoa with fruit species in a single stratum with moderate diversity and density. In contrast, those in Talba have low diversity of associated tree species, which are primarily forestry species concentrated at low density in an emergent stratum above the cocoa trees.

Of the cocoa agroforests rich in companion trees, the oldest, in situations of high demographic pressure (Obala), are distinguished by several elements: a renewal of cocoa trees with medium pesticide use; a predominance of fruit trees as companion trees distributed in two strata; and high cocoa yields. We also identified three types of cocoa agroforests

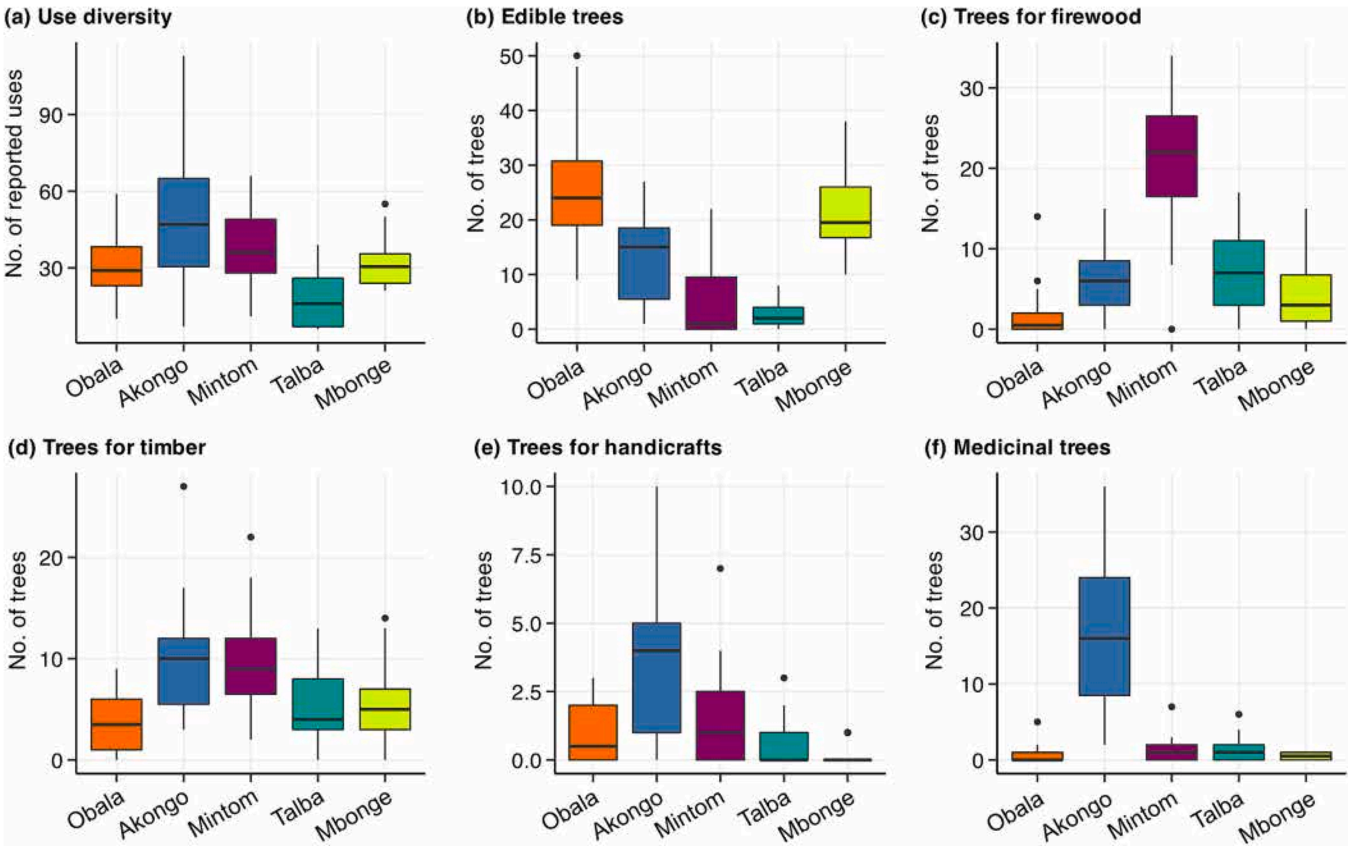


**Fig. 5.** Use diversity and abundance of companion trees in cocoa agroforests at the five study sites. Five key use categories were considered: edible, firewood, timber, handicrafts, and medicinal (95 plots).

managed with intensive practices, each employing distinct approaches: (i) high use of pesticides, a simplified structure with a low density of companion trees of forest species, and the predominance of hybrid varieties of cocoa (Talba); (ii) a robust fruit tree component with relatively high species diversity, distributed over several strata, with moderate pesticide use, and a mix of Amelonado and hybrid cocoa varieties (Obala); and (iii) high pesticide use in simplified single-stratum fruit agroforests, moderate diversity and density, and hybrid cocoa varieties (Mbonge).

In contrast with cocoa plantations in Ghana and Côte d'Ivoire, which are systematically fertilized (Gockowski and Sonwa, 2011), using fertilizers is very uncommon in Cameroon (except in Talba). Regarding pesticide treatments, farmers in Cameroon use more fungicides than insecticides, in particular to control black pod disease, which is favored by shade and humidity—conditions that are themselves promoted by the high density of companion trees (Mahob et al., 2014). In Mbonge, the combination of moderate companion tree density and particularly humid climatic conditions could explain the farmers' heavy reliance on fungicides (Ruf, 2001).

### 4.2. Cocoa yields, biodiversity and multifunctionality of cocoa agroforests

Our results show that the intensity of farming practices is reflected in cocoa yields. Three of the study sites (Talba, Obala, and Mbonge) have high cocoa yield levels compared to the maximum yields observed in Ghana, with 1140 kg.ha$^{-1}$ of dried cocoa beans (456 kg.ha$^{-1}$ on average), or in Côte d'Ivoire, with 710 kg.ha$^{-1}$ (214 kg.ha$^{-1}$ on average) (Gockowski and Sonwa, 2011). It is known that cocoa yields are negatively impacted by the density of companion trees that shade cocoa trees while contributing to diversifying overall plot production (De Beenhouwer et al., 2013; Vaast and Somarriba, 2014; Niether et al., 2020). Yet such tradeoffs can be mediated by the choice of companion tree species, their crown height, density, and spatial distribution (Deheuvels et al., 2012; Somarriba et al., 2018; Blaser-Hart et al., 2021). This is perfectly illustrated by the Obala cocoa agroforests, which, with some of the highest cocoa yields and a high level of density and richness in companion trees, offer the best compromise. These agroforests include many edible fruit-bearing trees distributed across different strata, providing fruit that could be consumed or sold in local markets, thereby generating complementary income for farmers, which is a valuable safety net in periods when market prices for cocoa are low. This economic role of multipurpose trees growing in cocoa and coffee agroforests has also been documented in Indonesia and different regions in Africa and Latin America (Jezeer et al., 2017). Moreover, in a wide range of farming systems with high species diversity, including cocoa agroforests, maintaining species diversity helps control pests and diseases and reduces pesticide use (Ratnadass et al., 2021). Leaf litter and root residues from associated species also contribute to nutrient cycling, avoiding the need for fertilizer applications (Mortimer et al., 2018). The use of shade trees also has the advantage of boosting the long-term sustainability of cocoa agroforests (Niether et al., 2020). It is possible to partially abandon cocoa agroforests and subsequently resume their maintenance, as has been shown in Cameroon (Jagoret et al., 2016; Saj et al., 2017; Jagoret et al., 2018). In Obala and Akongo, cocoa agroforests had almost all undergone periods when they were less maintained, especially at times when they were being passed on to heirs or when cocoa prices had sharply dropped. These agroforestry systems are therefore particularly well adapted to uncertain economic settings.

### 4.3. Cocoa intensification drivers and dynamics

Our results helped to identify the factors determining the intensification modalities and drivers that may hamper or favor the maintenance or the loss of resilient and complex traditional cocoa agroforestry systems. Similar trends and determining factors have also been highlighted by Pédelahore et al. (2022), and these factors are involved at different scales.

At the site level, the combined availability of land and labor is crucial. The extent of pesticide use intensity in cocoa agroforests mirrors the population density pattern. Higher per-ha cocoa production is sought at sites where the demographic pressure is high. Land availability also impacts the cocoa agroforest species composition: the most fruit-bearing species are also observed on sites with high population pressure. Indeed, an increase in demographic pressure prompts farmers to intensify labor and capital in their cocoa agroforest management, while diversifying the associated species so as to make more effective use of the land and curb the economic risks associated with relying on a single crop (Schroth and Ruf, 2013; Pédelahore et al., 2019). In our study sites with high demographic pressure (Obala and Mbonge), a joint per-ha increase in cocoa and fruit production is sought, as was found in Nigeria in a similar situation of high demographic pressure, where the fruit tree composition in cocoa agroforests was very high (86.8 % of all associated trees were fruit trees) (Oke and Odebiyi, 2006). This situation is also favored by the proximity of cities and markets where fruit products can be sold (Degrande et al., 2006; Sonwa et al., 2007). The climatic conditions are also among the determining factors. For example, the very humid climate in Mbonge, where firewood is required to dry cocoa beans, has accelerated the felling of associated forest trees in cocoa agroforests, making way for the inclusion of new species.

The types of farmers, with their resources and strategies in these regional contexts, also play a role (Pédelahore et al., 2019). At all sites, plots purchased and worked by hired labor or sharecroppers include cocoa agroforests with simplified structures, high inputs, and hybrid cocoa varieties. In contrast, cocoa agroforests inherited and managed by family labor have more complex and species-rich structures, while being managed with low to moderate inputs. This trend is clear in Obala and Akongo, where all cocoa agroforests are family-owned and species-rich, but also in Mintom, where some investors implement simplified agroforests and hybrid cocoa varieties alongside existing family-owned complex agroforests.

However, these factors are intermixed and vary significantly depending on the specific historical context, resulting in distinct dynamics of cocoa intensification across different locations. At Talba and Mbonge, among the diverse array of farmer types within the same area, one group swiftly influenced the others. In Talba, urban investors who arrived in the early 1980s adopted practices aimed at cocoa intensification—utilizing inputs, improved varieties, and simplifying structures—which led to the rapid expansion of cocoa farming (Pédelahore, 2014). This expansion has been fueled by the acquisition of large tracts of land worked by migrant laborers encouraged to move to the area. Existing family farms and those established by recent immigrants have been drawn into a competitive race for land and expanding crop areas. They have also benefited from the influx of salaried workers brought in by investors, as well as from the newly introduced inputs and varieties, similar to trends observed in the Bas-Sassandra region of Côte d'Ivoire (Léonard and Vimard, 2005). These dynamics are indicative of rapidly advancing fronts, where cocoa is cultivated on newly cleared land amid prevalent land availability, an influx of investors, and migrant workers from more populated regions. Farmers who can harness both land and labor resources may establish cocoa agroforest stands that yield rapid returns on investment, but at the cost of biodiversity.

The Mbonge site experienced similar dynamics, which started a decade earlier, leading to the rapid saturation of the area. As seen in Côte d'Ivoire (Léonard and Vimard, 2005), a sharecropping system linked to the densely populated origins of the first migrants enabled them to augment their labor force while controlling the land. This phenomenon expanded as sharecroppers became patronal farmers and persuaded local farmers to adopt their strategy of expansion, intensification, and structural simplification of cocoa agroforests. Consequently, intensive cocoa agroforests with low or moderate biodiversity have become concentrated in areas dominated by paid labor, investors, and patronal farmers (Pédelahore et al., 2019).

In contrast, intensification in Obala has evolved gradually, driven by family farmers over successive generations who adapted to changing circumstances. Starting earlier and characterized by complex cocoa agroforests, gradual land fragmentation due to population growth led to several transformations: some senescent companion forest trees were not replaced or were felled, new fruit species were introduced, and there was renewal of the cocoa tree population with the introduction of new varieties and increased input use (Jagoret et al., 2011; Jagoret et al., 2018). Despite these changes, the cocoa agroforests have maintained their complexity and relatively high biodiversity, with only moderate input use. Similar trends have been observed in densely populated coffee-growing areas in Kenya managed by family farmers (Pédelahore et al., 2019), and in clove-growing regions in Madagascar (Michel et al., 2021). Changes in management often occur when ownership transfers to heirs, sometimes after periods of reduced maintenance (Jagoret et al., 2018). These heirs inherit existing cocoa agroforests and also establish new ones for future generations, resulting in both inherited and newly created agroforests coexisting on the same farm, each managed with varying levels of intensity. Over time, the gradual saturation of available local land has eventually led to outmigration, as people move to establish new cocoa agroforests elsewhere.

### 4.4. Prospects and possible action levers to guide the dynamics

In terms of the outlook for the other sites, where family farming prevails under less demographic pressure (Akongo), it is likely that the long-term trends in cocoa agroforest structure and management will be toward progressive intensification (as in Obala). Where only a few small-scale investors coexist with family farms that are generally the result of different types of migration (Mintom), the cocoa agroforest stands could shift toward those observed in Talba and Mbonge, or toward those in Obala. This will depend on the extent and speed of future migration dynamics, which will more or less quickly overcome the current limiting factor: labor. The fact that local farmers are currently able to carry out income-generating activities in the forest area (hunting and gathering of forest products) limits their investment in labor and capital in cocoa agroforests. This has led to the presence of abandoned cocoa agroforests, resulting from a unique agricultural history in which actions to support the development of cocoa cropping carried out in a directive manner in remote forests came to a sudden halt (Michel et al., 2019).

These dynamics are not independent of cocoa prices, whose volatility since the late 1980s has had marked impacts (Clough et al., 2009). Price rises following a slump often amplify migratory phenomena; heirs who have left to try their luck in town may return to the historical sites to take over their fathers' cocoa farms, while migrants move in to the other sites. Where there is no longer any land available, there is substantial outmigration (Obala). Depending on the characteristics of the sites and the resources available, farmers may set up cocoa agroforests with complex (Mintom) or simplified (Talba) structures (Michel et al., 2019). Price rises can also prompt an influx of cocoa business investors, who may establish structurally simplified cocoa agroforest stands with low biodiversity levels in the areas where they have settled (Pédelahore, 2014). Any initiative that is conducive to cocoa price stability and the economic promotion of products from species associated with cocoa (fruit, wood or non-wood products) could bolster the dynamics of biodiversity-friendly family farms, in turn orienting investor dynamics toward less structural simplification of cocoa agroforest stands (Jezeer et al., 2017). The development of quality supply chains promoting ecolabels could also be an effective tool, as shown in Kenya with regard to coffee and tea agroforests managed by investors and patronal farmers (Pédelahore et al., 2019). It would also be beneficial to implement land policies that protect small- and medium-sized family farms and prevent large-scale deforestation by investors. Additionally, developing a policy for rehabilitating abandoned cocoa agroforests could be considered.

### 4.5. Study limitations

To strengthen the results of our research, it would be valuable to complement the estimates provided by farmers, particularly regarding cocoa yields, with independent measurements. While our findings effectively position cocoa agroforest plots relative to one another and identify trends, the estimated cocoa production values should be interpreted with caution. Additionally, incorporating the production from companion fruit trees into these measurements would be necessary. Moreover, integrating our results with in-depth microeconomic analyses at both the farm and plot levels would be relevant. Assessing the total value produced by cocoa agroforests, considering both cocoa and companion trees, and relating it to the labor time required for their management, would enable comparisons of labor productivity and productivity per hectare across different categories of cocoa agroforests, thus enhancing our analysis. Furthermore, these data could help establish a minimum cocoa price necessary for small and medium-sized family farms to sustainably support their agricultural activities.

## 5. Conclusion

Resilient, multistory, multispecies cocoa agroforests, though underrepresented in major production areas, dominate historical sites in Cameroon, driven by small-scale family farming, and produce low to medium cocoa output. These complex systems, often newly established on cleared land by migrating descendants, thrive with minimal inputs. We identified three contrasting models of cocoa agroforestry intensification in Cameroon. The first two, characterized by simplified structures and high inputs, yield high cocoa outputs but support limited diversity of companion trees and uses, with a dominance of either fruit or forest trees. These two models are supported by investors and patronal farmers. The third model modifies the traditional approach by reducing the emergent stratum in favor of fruit trees in the intermediate and lower strata, maintaining high cocoa yields with moderate inputs and greater biodiversity, especially for food. Found near cities at historical sites under high demographic pressure, this model offers a good balance between ecosystem services and socioeconomic benefits and could guide future cocoa farming practices. However, intensification does not eliminate the need for new lands for the descendants of these family farms. To mitigate these issues, it is crucial to control the expansion of cocoa areas and promote the sale of products from companion trees, as well as to stabilize cocoa prices boosted by ecolabels. Preserving forested sites from large-scale clearance by investors and promoting the regeneration of abandoned cocoa plots in forested sites can also enhance cocoa production sustainably, while honoring Africa's unique cocoa heritage.

## CRediT authorship contribution statement

**Isabelle Michel:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Julien Blanco:** Writing – review & editing, Writing – original draft, Software, Methodology, Formal analysis, Data curation. **François Manga Essouma:** Writing – original draft, Investigation. **Stéphanie M. Carrière:** Writing – original draft, Supervision, Methodology, Funding acquisition, Conceptualization.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

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