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Agroforestry Systems

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Characterization and ecological importance of cocoa and oil palm agroforestry systems on the outskirts of a forest concession in southern Cameroon

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Abstract Traditional production systems, agroforestry systems (SAFs) in southern Cameroon combine various types of trees of socio-economic interest which can contribute to the conservation of biodiversity. The objective of this work is to analyze the contribution of these agroforestry systems based on cocoa and oil palms in the sustainable management of

peripheral resources of a forest concession in southern Cameroon. The methodological approach adopted consisted of carrying out socio-demographic surveys with 66 SAF operators using survey forms. A sampling rate of 10% was applied in seven villages in the Commune of Djoum. These interviews were supplemented by floristic inventories carried out on 69 plots of 40 × 60 m for a total area of 15.84 ha. The data collected allowed us to calculate various diversity and ecological indices, woody biomass and carbon stock, to which various statistical tests and Analyses of variance were applied. The floristic potential is made up of 8,355 individuals divided into 177 species, 153 genera, 47 families, and classified into 3 woody groups, namely introduced, preserved and perennial species. The Shannon index between land use types varies from 2.15 bits in palm agroforests to 3.9 bits in forests while it is 2.81 bits in cocoa agroforests. The forests of the UFA and the peripheral SAFs share 42 forest species out of 63 inventoried species, ie 66.7% of forest species preserved in cocoa agroforests, proof of the effectiveness of the conservation potential of these SAFs in the region. The largest diameter class is [10–20] cm while the largest height class is the stratum of [5–10] m. Tree density and basal areas are highest in forests with 110.51 stems/ha and 42.08 m²/ha. Three types of architectural profiles for cocoa-based SAFs and two types of architectural profiles for oil palm-based SAFs were identified with a typology that shows 4 groups of TUTs based on ecological interactions. Forests are the type of land use that

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stores the most carbon (115.81 tC/ha) compared to 93.54 tC/ha for palm agroforest and 58.8 tC/ha for cocoa agroforests. Gradients of diversity, density and complexity vary with proximity to the forest concession. These results could be considered as effective and quantifiable tools for the certification of numerous cash crops such as cocoa and oil palm, which will make it possible to promote this endogenous knowledge scientifically and in the development of various programs and publications. technical notes.

Keywords Agroforestry system · Biodiversity · Conservation · Carbon stock · Forest concession

Introduction

Tropical rainforests are home to most of the Earth's biodiversity with a forest cover of about 70% for the Congo Basin in Central Africa (Megevand et al. 2013). Of the 200 million ha of dense rainforests in Central Africa, Cameroon covers nearly 20 million hectares, with overall nearly 54 million ha of forest or 27% classified as production forests of various types in Central Africa, mainly in the form of logging concessions (AfDB/FRMi 2018; Vancutsem et al. 2021; Eba'aAtyi et al. 2022). According to Ordway et al. (2019), these forests contain approximately 25 to 30% of the carbon present in the world's tropical forests. Despite their importance, the forests of the Congo Basin are subject to deforestation. More than a quarter of deforestation (27%) is driven by land-use change due to commodity production (Curtis et al. 2018). Estimates of tropical forest loss attributed to the expansion of crops, pastures, and forest agroforests range from 62 to 80%, with 26% of this loss attributed to international demand for commodities such as palm oil, cocoa, coffee, rubber, timber, and cotton (Hosonuma et al. 2012; Pendrill et al. 2019). It is important to note that agriculture and gross domestic product significantly drive deforestation in the Congo Basin, often at the expense of natural forest vegetation (Ordway et al. 2017; Eba'a Atyi et al. 2022). This deforestation is observed mainly in forested areas with high human population densities (Megevand 2013). A phenomenon which according to Eba'a Atyi et al. (2009) has a negative impact in the fight against climate change, the preservation of biodiversity, as well as other functions of the forest.

However, despite the fact that tropical deforestation, the second largest source of anthropogenic greenhouse gas emissions (Smith et al. 2014) recognized as a major driver of biodiversity loss (Tilman et al. 2017), is increasingly driven by international demand for agricultural products (DeFries et al. 2010). On the periphery of forest concessions in Cameroon, agricultural pressure is increasing, particularly for cocoa, but also for oil palm and coffee depending on the region (Pédelahore 2014; Levang et al. 2015). These commodities are very often produced in agroforestry systems in which species producing wood and non-timber forest products (NTFPs) are conserved or introduced. These agroforestry systems, which are similar to those of forests, contribute to the conservation of wood diversity (Sonwa et al. 2007); and carbon sequestration (Norgrove and Hauser 2013; Saj et al. 2017). Agroforestry practices can therefore provide a realistic compromise between economic forces and ecological needs, with certification systems for shade crops providing a market-based mechanism to slow current intensification trends (Steffan-Dewenter et al. 2007; Carsan et al. 2014). The existence of these agroforestry systems induces changes in land use patterns, but also in the ecosystem and socio-economic products and services provided by the natural ecosystems that preceded them, hence the interest of this study. The overall objective is to characterize peripheral agroforestry systems of forest concessions for better sustainable cocoa productivity, particularly in terms of deforestation and biodiversity loss. More specifically, it will involve analyzing and comparing the diversity and floristic composition of these production systems, studying the structure, typology and ecological interactions of these systems and finally evaluating their carbon sequestration potential in the fight against climate change.

Materials and methods

Study area

The Commune of Djoum was created on August 21, 1952 by Order No. 537 of August 21, 1952 under the name of Mixed Rural Commune. It is located in the Southern Region of Cameroon in the Department of Dja and Lobo (Fig. 1). It extends

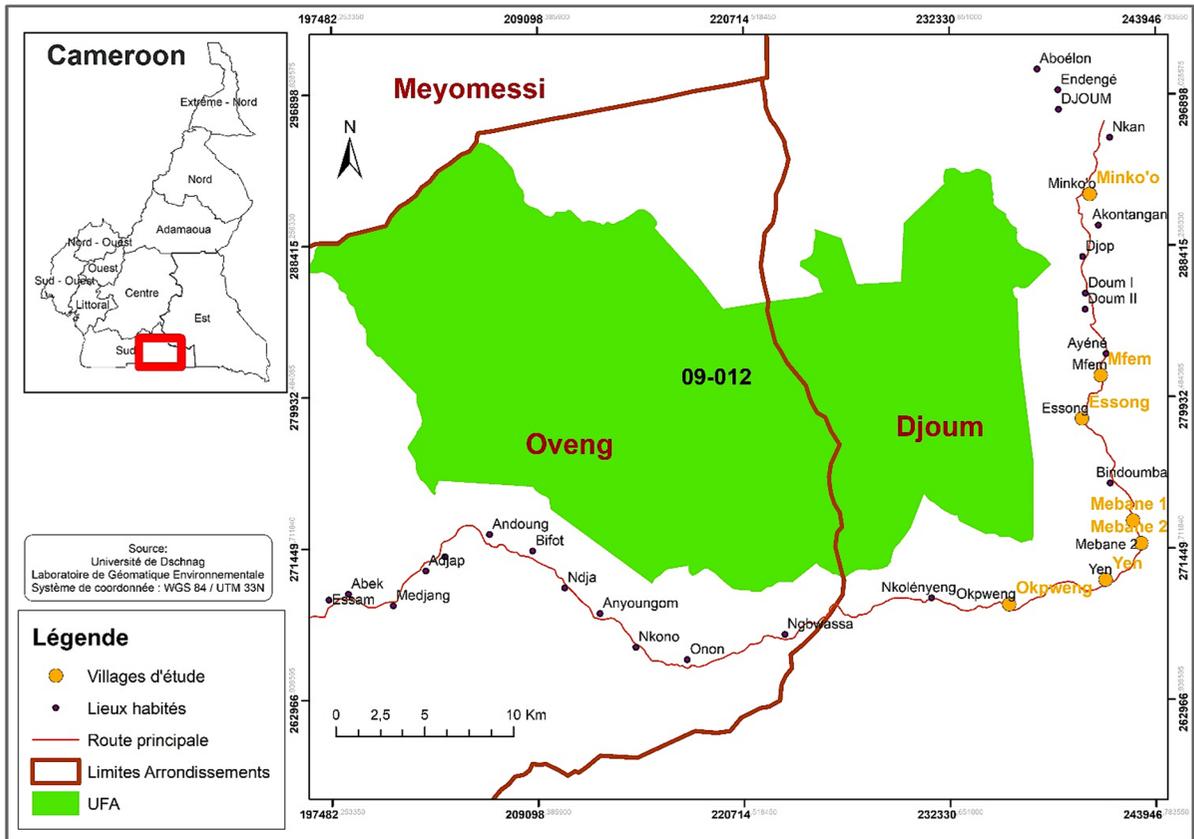


Fig. 1 Location map of sample villages, on the outskirts of CUF 09012. Source: <https://fr.climate-data.org/afrique/cameroun/south/djoum-896697>

between 2° 38' 00" and 2° 25' 00" North latitude and 12° 37' 00" and 12° 42' 00" East longitude and includes 44 villages (Zapfack and Ngobo 1999). These villages are linear and are spread over three axes, hence its name “the city of 03 axes”. The villages of the Fang canton are on the Oveng axis, those of the Zamane canton are on the Mintom axis, and the villages of the Bulu canton are on the Meyomessi axis. The relief of this area is a flat, slightly undulating plateau, whose average altitude varies between 520 and 680 m. Its topography presents areas of plains, valleys and hills. The soils are mainly ferralitic, lateritic and sandy clay and sometimes hydro-morphic in the marshy areas. Thus, they are favorable to agriculture and the development of vegetation. The climate of the locality of Djoum belongs to that of the equatorial domain of the Guinean type. It is a four-season climate of the

southern Cameroonian plateau. Its average temperature is 25 °C with an amplitude of 2 to 3 °C. The average annual relative humidity is 81% and precipitation ranges between 1500 and 3000 mm/year (CA CUF, 2011).

The flora of Djoum is an integral part of the dense humid semi-deciduous Guinean-Congolese forest with some floristic elements of the evergreen forest. Human activity has profoundly modified the physiognomy of the flora of this region (logging and itinerant agriculture on slash and burn, fallows, as well as young secondary forests). Pioneer species are abundantly represented there: *Musanga cecropioides*, *Trema orientalis*, *Myrianthus arboreus*, *Tetrochidium dydinostemon* (Zapfack and Ngobo 1999). As a forest unit, we can note the presence of forests: 01 communal, 07 community, 01 ZIC, 07 UFA, 05 sales of cuts (CA CUF, 2011).

Methodology

The methodological approach adopted is participatory and reiterative. To do this, semi-structured individual or group interviews (focus group) using a previously established questionnaire with open and closed questions were carried out following the method adapted from Ingram (2010, 2018) and Etchike et al. (2020). A sampling rate of 10% was used for sampling the households surveyed, i.e. a total of 101 heads of cocoa and/or oil palm producing households distributed in (7) villages namely: Essong (14 farmers), Mebane 1 (22), Mebane 2 (10), Mfem (7), Minko'o (15), Okpweng (17) and Yen (16). These surveys were coupled with floristic inventories following the recommendations of White and Edwards (2001) and Hariath et al. (2010). They were carried out on 73 plots of 40 × 60 m (2400 m² or 0.24 ha) including 6 controls in the forest of UFA 09012, for a total surface area of 175,200 m² or 17.52 ha. Any shrub and tree whose trunk diameter at breast height (dbh measured at 1.3 m from the ground for trees without buttresses and without anomalies) was greater than or equal to 10 cm was identified and measured. Individuals smaller than 10 cm considered as regeneration are not taken into account in this study even in the diversity and ecological analyses. The botanical nomenclature used is that adopted by the Angiosperms Phylogeny Group (APG III).

Various ecological indices were calculated, allowing to study the structure of the stands and to have a quantitative evaluation of the diversity of the stand. This involves the calculation of the Shannon–Weaver and Simpson indices. Calculations of densities, dominance and relative frequencies were also carried out to better appreciate the ecological importance of species and families, precisely by calculating the Importance Value Index (IVI) and the Family Importance Value (FIV).

The Shannon and Weaver index is an abundance index based on specific diversity and which, together with other indices, makes it possible to describe the structure of a community (Sonké, 1998; Etchike et al. 2020).

$$\text{ISH} = - \sum ((N_i/N) * \log_2(N_i/N)) \text{ or}$$

$$\text{ISH} = -\text{Sum of } i = 1 \text{ to } s (p_i * \log_2 p_i)$$

With N_i = Number of species and N = Number of all species.

Pielou's equitability corresponds to the ratio between the observed diversity and the maximum possible diversity of the number of species (N) (Sonké, 1998; Etchike et al. 2020).

$$\text{EQ} = \text{ISH}/\text{Log}_2 N$$

The Simpson index measures the probability that two randomly selected individuals belong to the same species (Tchaleu 2018).

$$D = \sum N_i (N_i - 1) / N (N - 1)$$

With N_i = Number of species and N = Number of all species.

The density of a species is the number of individuals of that species per hectare (Nangndi et al. 2021).

$$\text{Relative density} : d = \frac{n}{s}$$

With n : number of individuals of a species present on a surface considered; s : surface considered; d : Density (number of individuals/ha).

Dominance is defined as the ratio of basal area occupied by individuals belonging to a taxon. It takes into account the size of individuals and provides information on the taxon that occupies more space in a stand (Ndonmou et al. 2022).

$$\text{Relative dominance} = \sum (St_i/St) * 100$$

With St_i = Basal area of a species or family and St = Total basal area in the sample; St (m²/ha); D = diameter (m).

The basal area of a tree is the cross-sectional area of that tree at breast height or reference height (1.30 m from the ground for trees and 30 cm from the ground for shrubs) per hectare (Nangndi et al. 2021).

$$St = \left(\sum \prod D^2 \right) / 4;$$

With \prod = 3.14; D^2 = diameter of woody plants squared; 4 = constant; St (m²/ha).

Frequency is the number of times a taxon appears in a plot. It provides information on the social behavior of the taxon and its distribution in space (Sonké, 2004).

$$\text{Relative frequency} = \sum (N_i/N) * 100$$

With N_i = Absolute value of the frequency of the species at the population scale; N = Sum of the frequency values of all species at the population scale.

The Importance Value Index is the sum of relative frequency, relative density and relative dominance. It is a synthetic and quantified expression of the importance of a species in a population (Gonmadjé et al. 2011; Etchike et al. 2020).

$$\text{IVI} = \text{Relative density} + \text{Relative dominance} \\ + \text{Relative frequency}$$

The Family Importance Value is the sum of density, dominance and relative diversity (Gonmadjé et al. 2011; Etchike et al. 2020).

$$\text{FIV} = \text{Relative density} + \text{Relative dominance} \\ + \text{Relative diversity}$$

With Diversite relative (Dr)

$$= \frac{\text{Nombre de 'spces au sein d'une famille}}{\text{Nombre totale des familles}} (100)$$

The typology of interactions and architectural profiles were illustrated on a two-axis plan (height and length) following the methods of Ngomeni et al. (2023) and Etchike et al. (2024, 2025) for a better appreciation of the landscape, structure and complexity of these characteristics of the agroecosystem of the study area. The methods adapted from Sénécal and Saint-Laurent (2004) and Etchike et al. (2024, 2025) were used to assess the coverage rate of the agroforestry canopy. Indeed, the canopy is called "Open" when its coverage rate is less than 30%, "Shaded" when it varies from 30 to 60%, and finally "Closed" (> 60%).

Biomass and carbon stock in SAFs

The aboveground biomass of trees was estimated from the pantropical allometric equation of Chave et al. (2014) established from a dataset consisting of 4004 trees collected in the tropics (Africa, Asia and America). The choice was made on the allometric equation of Chave et al. (2014) to ensure better consideration of agroforestry systems in global biomass estimates, a model recommended in the good practice document of Duncanson et al. (2021). Their work aimed to standardize the biomass estimation procedure, from the tree

scale to satellite observations. Furthermore, the work of Fayolle et al. (2018), carried out on a robust dataset collected in 6 countries of the Congo Basin, demonstrated that the use of local models does not produce aboveground biomass estimates significantly different from those obtained with the pantropical model of Chave et al. (2014). This equation of Chave et al. (2014) is written as follows:

$$\text{BA (kg)} = 0.0673 (\rho D^2 H)^{0.976}$$

With BA = aerial biomass (kg); ρ = density of the wood of the species considered; D = diameter of the tree (cm); H = height of the tree (m).

The aboveground biomass of cocoa trees was estimated from the allometric equation of Fomekong et al. (2024):

$$\text{Bc} = \text{Exp} (-1.613 + 1.83 \times \ln (D))$$

Oil palm carbon

The equation by Aguaron and McPherson (2012) was retained with the sole variable being the height of the stipe. It is written:

$$\text{Bp} 1.282 \times (7.7H + 4.5) =$$

With: H = Height of the stipe; Bp = Below Ground Biomass or Root Biomass (Kg).

Estimation of root biomass

The subsurface biomass in the study area was estimated from the relationship of Mokany et al. (2006); Ngoufo et al. (2019) opposite:

$$\text{BS} = 0.235 \times \text{Ye}$$

With BS = Hypogeeal biomass, BA = Aerial biomass (kg) and BT = total biomass.

The carbon stock was obtained by multiplying the sum of biomass (aboveground and belowground) by the ratio of 0.47 and the carbon dioxide (CO₂) stock by 3.67 (IPCC 2006; Zapfack et al. 2013).

$$\text{SC (kg)} = 0.47 \cdot \text{BT}; \text{SC (CO}_2\text{)} = 3.67 \cdot \text{SC}$$

The Ecological Value (EV) was calculated according to the resolutions of Ecosystem Marketplace Insights Report (2023) where the average price of

the ton eq CO₂ is estimated at \$75 or approximately 45,187.5 FCFA. It is important to note that the carbon stock for regenerating species (diameter less than 10 cm) was not considered in this study due to financial, material and logistical limitations.

Data analysis

The data from the surveys were coded and processed using Microsoft Excel 2013 spreadsheet and analyzed using SPSS version 2022 software. The data on floristic inventories and dendrometric parameters were coded and processed using Excel spreadsheet. The diversity indices were calculated using PAST (3.0) 2017 software. Using SPSS 2022 and R software, univariate tests (ANOVA at a 5% probability threshold) were performed on several parameters to determine significant differences (H0 indicating equality and H1 indicating at least one difference). When a significant difference is observed, we complete the ANOVA with multiple comparisons by performing Duncan and/or Tukey tests to identify the smallest significant differences (ppds).

Results and discussion

Floristic characteristics and specific richness

A total of 8355 individuals distributed in 177 species, 153 genera and 47 families were inventoried in the different SAFs of the study area. The Shannon index between land use types varies from 2.15 bits in palm agroforest to 3.9 bits in forests (Table 1). This Shannon index is 2.81 bits in cocoa agroforests

with a Shannon index of 4.18 bits for forest trees and 1.44 bits for fruit trees. In palm agroforest, the Shannon index is 2.8 bits for forest trees encountered and 1.49 bits for fruit trees. The average Shannon index over the entire area is 2.95 bits, which illustrates significant diversity in the SAFs and surrounding forests. The Simpson index varies from 0.84 in cocoa agroforests to 0.97 in forests with 0.87 in palm agroforest.

Our results also show that the Shannon indices in the proximity zones to UFA 09 012 vary from 2.47 bits in zone 1 (2–3 km) to 2.58 in zone 4 (≥ 5 km). These Shannon indices are respectively 2.61 bits for zone 3 (4–5 km) and 2.7 in zone 2 (3–4 km). Overall, it can be seen that the Shannon diversity index increases along the distance gradient from the UFA.

As in the case of land use types, this Shannon index remains more important for forest trees compared to the indices of fruit trees. The Shannon diversity index is the most important for forest species in zones 2 and 3 with 4.21 bits and 3.99 bits respectively while it is the most important for fruit species in zones 4 and 1 with 1.37 bits and 1.36 bits respectively (Table 2). The analysis of variance shows a significant difference between these diversity indices of zone 1 with those of zones 2, 3 and 4 on the one hand, and a significant difference between forest trees and fruit trees in all four proximity zones to UEFA on the other hand.

The graphical observation of these indices by proximity zone reveals significant variations in the numbers of individuals in zone 1 compared to the numbers of individuals in zones 2, 3 and 4. Figure 2A, B, complementary to each other, respectively present the frequencies of variation in numbers and diversity by proximity zone and the significance of these variations in numbers and diversity by proximity zone at a

Table 1 Diversity indices in different TUTs

Diversity Index	Cocoa agroforest			Palm agroforest			Forest
	fruit tree	Forest tree	Mean ±SD	fruit tree	Forest tree	Mean ±SD	Mean ±SD
Simpson	0.7a	0.98a	0.84 (± 0.2)a	0.81b	0.94b	0.87 (± 0.09)b	0.97 (± 0.05)b
Shannon	1.44a	4.18a	2.81 (± 1.93)a	1.49b	2.8b	2.15 (± 0.93)b	3.9 (± 0.41)b
<i>E. pielowi</i>	0.66a	0.84a	0.76 (± 0.11)a	1.08b	0.99b	1.03 (± 0.06)b	0.94 (± 0.05)b
Fisher α	1.59a	44.8a	23.2 (± 30.55)a	3.88b	10.38b	7.13 (± 4.6)b	38.56 (± 26.05) b
<i>P</i> -value	<i>p</i> -value < 0.05						

Mean ± standard deviations. Means were separated by Tukey's test (*P*-value = 0.05). Means by columns followed by the same letters are not significantly different (*p* > 0.05)

probability threshold of 5% carried out by the Tukey test. Zone 1 shows a significant variation in its numbers and diversity compared to proximity zones 2, 3 and 4.

Ecological importance of species and families

Elaeis guineensis ranks first among local species with an overall Ecological Importance (IVI) of 13.08% ahead of *Persea americana* (12.29%), *Musa sp.* (7.87%), *Terminalia superba* (6.19%) and *Funtumia elastica* (5.01%) (Table 3). Ecologically important families include the Fabaceae (38.99%), Arecaceae (27.34%), Phyllanthaceae (24.20%), Malvaceae (22.88%) and Apocynaceae (15.89%). Analysis of variance shows a significant difference between families (P -value < 0.001). Due to their high relative density, certain species belonging to these families have an original appearance and their dominance in the agroforestry landscape of the area.

These families are mainly made up of species belonging to mature secondary and young primary forests. The most common in these agroforestry systems are: *Albizia glaberrima*, *Elaeis guineensis*, *Macaranga sp.*, *Ceiba pentandra*, *Dacryodes edulis*, *Ficus mucoso*, *Funtumia elastica*, *Mangifera indica*, *Markhamia tomentosa* and *Milicia excelsa*.

Jaccard proximity index and specific rarefaction

The Jaccard proximity index reveals that there is a significant proximity between the floristic components of the UFA forests and the cocoa agroforests of the area, particularly with regard to forest species associated with cocoa trees. These two types of land use share 42 forest species out of 63 species inventoried, i.e. 66.7% of forest species conserved in these cocoa agroforests, compared to only 4 forest species in the palm agroforest, i.e. 6.34% of forest species conserved. The cocoa agroforests and palm agroforest share 11 of these species, i.e. a rate of 17.46%. The four species shared between these three TUTs are *Macaranga staudtii*, *Memecylon breteleranum*, *Musanga cecropioides* and *Myrianthus arboreus*. The most common species shared between cocoa agroforests and forests of the UFA are *Distemonanthus benthamianus*, *Pycnanthus angolensis*, *Albizia zygia* and *Dacryodes edulis*.

Table 2 Diversity indices according to the proximity zones to the UFA

Area Diversity Index	Zone 1 (2–3 km)		Zone 2 (3–4 km)		Zone 3 (4–5 km)		Zone 4 (≥ 5 km)	
	fruit tree	Forest tree	fruit tree	Forest tree	fruit tree	Forest tree	fruit tree	Forest tree
Simpson	0.71a	0.96b	0.63a	0.98b	0.64a	0.97b	0.69a	0.96b
Shannon	1.36a	3.57b	1.19a	4.21b	1.24a	3.99b	1.37a	3.79b
E. Pielou	0.85a	0.96b	0.61a	0.91b	0.64a	0.91b	0.70a	0.89b
Fisher α	1.81a	23.70b	1.60a	43.36b	1.48a	34.17b	1.54a	27.65b
P-value	p -value < 0.05 (a)		p -value < 0.05 (b)		p -value < 0.05 (b)		p -value < 0.05 (b)	
Mean \pm SD	0.84 (\pm 0.18)a	2.47 (\pm 1.56)a	0.8 (\pm 0.24) b	2.7 (\pm 2.13) b	0.81 (\pm 0.23)b	2.61 (\pm 1.94)b	0.77 (\pm 0.19)b	17.83 (\pm 23.11)b
Mean \pm SD	0.83 (\pm 0.19) b	2.58 (\pm 1.71) b	0.79 (\pm 0.13) b	14.59 (\pm 18.47)b				

Means by columns followed by the same letters are not significantly different ($p > 0.05$)

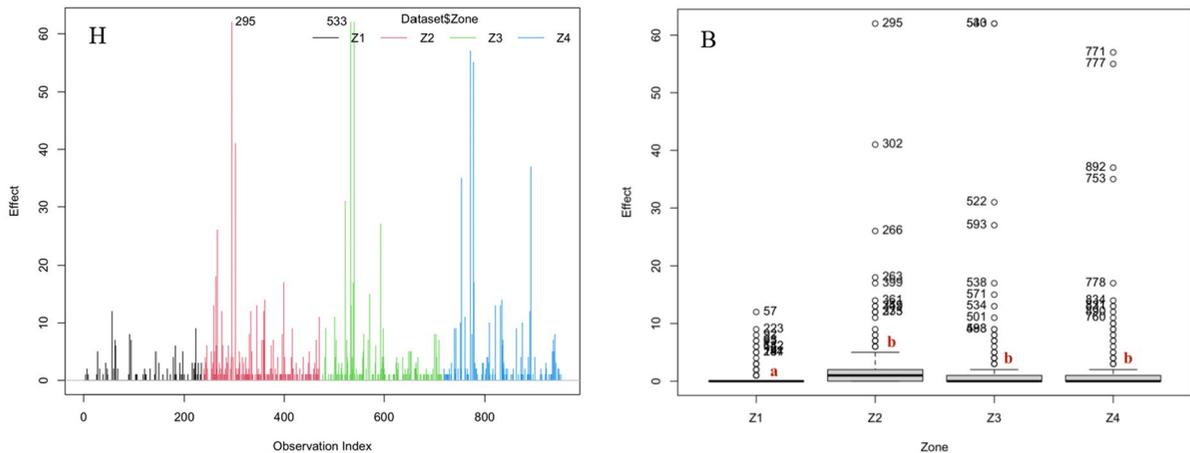


Fig. 2 Graph of the forecast plot of indices by proximity zone (A) and Boxplot of the extreme values of the numbers by proximity zone to the UFA (B). Means separation by Tukey test

(P-value = 0.05). ind = individual; Z1 = Zone 1 (2–3 km); Z2 = Zone 2 (3–4 km); Z3 = Zone 3 (4–5 km); Z4 = Zone 4 (\geq 5 km)

It is important to note that this proximity floristic potential is reduced with the addition of associated fruit species in the SAFs which brings a completely different configuration to the floristic component. From this point of view, cocoa agroforests only share 47% of this floristic potential with the UFA forests against only 0.4% of this same floristic potential shared between palm agroforest and forests (Fig. 3A). The correlation matrix reveals a weak correlation between the floristic components of these different TUTs (values lower than 50%).

This Jaccard proximity index was completed by the curve of evolution of the specific richness according to the number of individuals (Fig. 3B) which shows a clear difference between the populations of these TUTs. This specific richness effectively increases with the number of individuals in the different TUTs. It should be noted, however, that the two curves are far from reaching the asymptotic stage. It is noted that 58 species out of 164 are very rare (Absolute frequency = 0.01) therefore very infrequent and are only found once in the SAFs mainly in cocoa agroforests. Among these species are *Autranella congolensis* which is critically endangered (CE) according to the IUCN status with 62.7% of these species which are classified as vulnerable according to this same status. A total of 21 species are found twice in these SAFs and only 11 are found three times.

Biophysical characteristics of SAFs

Horizontal and vertical structure

The distribution of the histograms in diameter class has an overall bell-shaped appearance for all woody types in the different TUTs with lower values in the class (< 10 cm). These values rise in the class [10–20] cm to gradually fall in the classes [20–30], [30–40], [40–50] cm with sometimes significant peaks in the class (\geq 50 cm). The diameter classes which show the highest number of stems per hectare are the species classes in the UFA forests which vary from 44 to 4 stems/ha monitoring of forest species classes in the palm agroforest (between 18 and 13 stems/ha) and cocoa agroforests (between 24 and 8 stems/ha). The diameter classes of fruit species in cocoa and palm agroforest, on the other hand, have an “L” shape with a lower number of stems per hectare which vary from 23 to 6 stems/ha for cocoa agroforests and 8 to 4 stems/ha for palm agroforest with additional missing diameter classes for these two woody types (Fig. 4A). The diameter class (> 50 cm) is the most represented in forests with 44 stems/ha and 24 stems/ha for forest species in cocoa agroforests. The diameter classes (< 10 cm) and [10 to 20] cm are the most important for fruit species in cocoa agroforests, for fruit and forest species in palm agroforest.

The distribution of histograms in height strata, on the other hand, has an “L” shaped appearance for

Table 3 Ecological importance of species (IVI) and families (FIV)

Species	Fr(%)	Dor(%)	Der(%)	IVI	Family	Der(%)	Dor(%)	Dir(%)	FIV
<i>Elaeis guineensis</i>	1.64	0.84	10.60	13.08	Fabaceae	10.99	13.02	14.98	38.99
<i>Persea americana</i>	1.41	0.28	10.60	12.29	Arecaceae	9.42	16.95	0.97	27.34
<i>Musa</i> sp	1.17	0.16	6.54	7.87	Phyllanthaceae	9.20	8.72	6.28	24.20
<i>Terminalia superba</i>	1.41	1.13	3.65	6.19	Malvaceae	12.16	3.00	7.73	22.88
<i>Funtumia elastica</i>	1.41	0.46	3.14	5.01	Apocynaceae	5.11	5.94	4.83	15.89
<i>Macaranga</i> sp	1.64	0.37	2.68	4.69	Rubiaceae	4.67	8.71	2.42	15.79
<i>Ricinodendron heudelotii</i>	1.41	0.68	2.42	4.51	Lauraceae	9.24	5.52	0.48	15.24
<i>Musa paradisiaca</i>	0.70	0.12	3.19	4.02	Moraceae	4.13	4.74	4.83	13.70
<i>Markhamia tomentosa</i>	1.41	0.29	2.32	4.01	Musaceae	9.24	2.97	1.45	13.66
<i>Margaritaria discoidea</i>	1.17	0.47	2.26	3.91	Combretaceae	3.23	7.81	0.97	12.01
<i>Albizia glaberrima</i>	1.64	0.53	1.70	3.87	Annonaceae	1.39	1.31	4.83	7.53
<i>Musanga cecropioides</i>	1.41	0.52	1.85	3.78	Cecropiaceae	3.28	2.86	0.97	7.10
<i>Alstonia boonei</i>	1.17	0.78	1.70	3.65	Rutaceae	1.26	1.08	3.38	5.72
<i>Ficus exasperata</i>	1.17	0.45	2.01	3.63	Meliaceae	0.67	0.61	3.86	5.14
<i>Pentacleithra eetveldeana</i>	1.41	0.83	1.39	3.63	Burseraceae	1.62	1.23	1.93	4.78
<i>Mangifera indica</i>	1.41	0.42	1.70	3.52	Bignoniaceae	2.15	1.48	0.97	4.60
<i>Myrianthus arboreus</i>	0.94	0.31	2.11	3.36	Irvingiaceae	0.72	1.67	1.93	4.32
<i>Ceiba pentandra</i>	1.41	1.00	0.77	3.18	Anacardiaceae	1.75	1.50	0.97	4.22
<i>Petersianthus macrocarpus</i>	1.41	0.58	1.18	3.18	Myristicaceae	1.03	1.51	0.97	3.51
<i>Albizia zygia</i>	1.17	0.27	1.70	3.15	Ulmaceae	0.76	0.78	1.93	3.48
<i>Ficus mucoso</i>	1.41	0.58	1.13	3.12	Sapotaceae	0.31	0.35	2.42	3.08
<i>Triplochiton scleroxylon</i>	0.94	1.23	0.93	3.09	Clusiaceae	0.31	0.25	2.42	2.98
<i>Albizia ferruginea</i>	1.17	0.52	1.39	3.08	Lecythidaceae	1.03	1.30	0.48	2.82
<i>Desbordesia glaucescens</i>	1.17	1.13	0.62	2.92	Olacaceae	0.36	0.30	1.93	2.59
<i>Dacryodes edulis</i>	1.41	0.23	1.24	2.88	Melastomataceae	0.67	0.74	0.48	1.90
<i>Distemonanthus benthamianus</i>	1.17	0.37	1.18	2.73	Rhamnaceae	0.49	0.40	0.97	1.86
<i>Excellent Militia</i>	1.41	0.79	0.51	2.71	Asteraceae	0.36	0.50	0.97	1.83
<i>Pycnanthus angolensis</i>	0.94	0.69	1.08	2.71	Ebenaceae	0.13	0.13	0.97	1.23
<i>Maesobotryasp</i>	0.70	1.72	0.15	2.57	Ochnaceae	0.13	0.11	0.97	1.21
<i>Albizia laurentii</i>	0.94	0.59	1.03	2.56	Myrtaceae	0.18	0.07	0.97	1.21
<i>Memecylon breterlanum</i>	1.17	0.51	0.77	2.45	Sapindaceae	0.09	0.06	0.97	1.11
<i>Nauclea diderrichii</i>	1.17	0.63	0.57	2.37	Lamiaceae	0.31	0.30	0.48	1.10
<i>Piptadeniastrum africanum</i>	0.94	0.94	0.41	2.29	Connaraceae	0.18	0.18	0.48	0.84
<i>Entandrophragma cylindricum</i>	0.23	1.89	0.05	2.17	Araliaceae	0.18	0.08	0.48	0.74
<i>Fagara tessmanii</i>	1.17	0.58	0.41	2.17	Boraginaceae	0.13	0.10	0.48	0.72
<i>Celtis tessmannii</i>	0.94	0.54	0.67	2.14	Pandacea	0.13	0.09	0.48	0.71
<i>Amphimas pterocarpoides</i>	0.70	0.81	0.62	2.13	Urticaceae	0.04	0.10	0.48	0.63

Fr, Relative frequency; Dor, Relative dominance; Der, Relative density; Dir, Relative diversity

almost all woody types in the different TUTs with higher values in the [5–10] m stratum except for the significant peak of 43 stems/ha in the (≥ 30 m) stratum observed in the control. These values decrease progressively in the [10–15], [15–20], [20–25] m strata with sometimes slight increases in values in

the [25–30] m and (≥ 30 m) strata. The most important strata in terms of number of stems per hectare are found in the forests of the UFA (vary from 43 to 15 stems/ha) followed by those of cocoa agroforests which vary from 23 to 5 stems/ha for fruit and vegetable species 19 to 13 stems/ha for the conserved forest

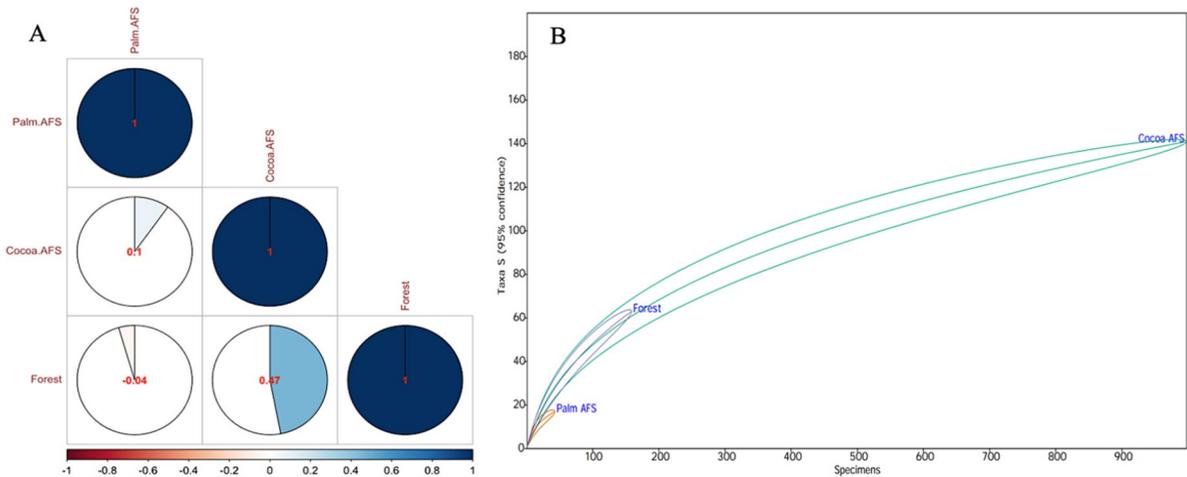


Fig. 3 Correlation matrix of Jaccard proximity indices between TUTs (A); Rarefaction curve of specific richness as a function of the number of individuals for each TUT (B)

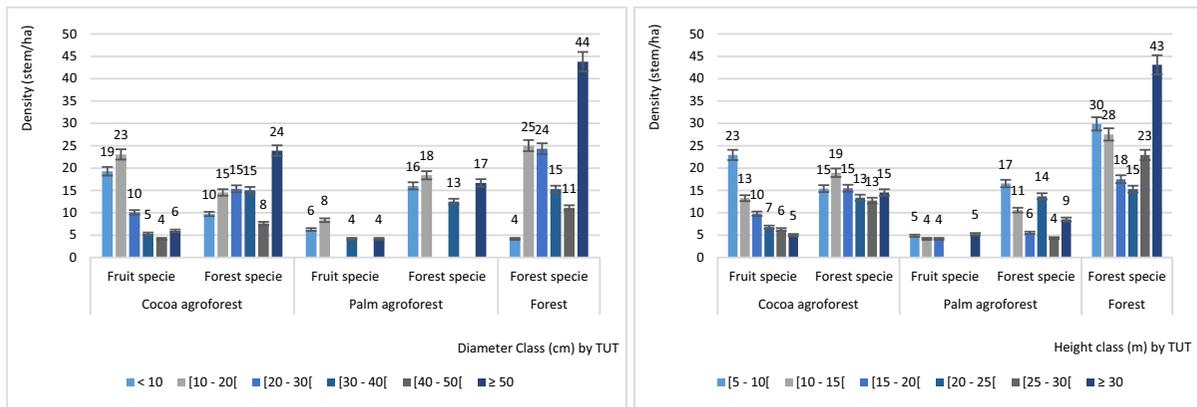


Fig. 4 Distribution of tree diameter and height classes in SAFs

species (Fig. 4B). This density of stems per hectare is the most important for forest species in cocoa agroforests compared to that of less important forest species in palm agroforest. The same observation is made for the height strata of fruit species which has an “L” shape in cocoa agroforests and a horizontal shape in fruit species found in palm agroforest. The most important height stratum is that (≥ 30 m) found in forests with 43 stems/ha. On the other hand, the strata [5 to 10] and [10 to 20] m are the most important for fruit species in cocoa agroforests, forest species in cocoa agroforests and palm agroforest.

Density and basal area

The density and basal areas of woody types in land use types vary from one plot to another and from one age class to another for agroforestry systems. Tree density is highest in forests with 110.51 stems/ha. The average density of cocoa trees is 1343.35 stems/ha compared to 28.49 stems/ha for palm trees. Regarding trees associated with these perennial crops, it appears that the density of forest trees is highest with 97.55 stems/ha compared to 36.44 stems/ha for fruit trees (Table 4). Regarding basal areas, it appears overall

that cocoa agroforests cover a basal area of 9.44 m²/ha compared to 13.99 m²/ha for palm trees. In agroforestry systems, the basal areas of forest trees are the largest with 36.09 m²/ha compared to only 1.77 m²/ha for fruit trees. Compared to forests, the basal areas of forest species are the highest with 42.08 m²/ha.

Overall, it appears that the density and basal areas of cocoa trees and palm trees are higher in the age classes of [30 to 45 years], which is not the case for fruit and forest species which have the highest values in the class (< 15 years).

The analysis of variance shows a significant difference between the densities of cocoa agroforests and the rest of the woody types. There is also a significant difference between the density of forest species and that of fruit species and palm trees (Fig. 5). Concerning the basal areas, a significant difference emerges between the basal area of forest species and the basal area of fruit species.

Architectural profiles of SAFs

Overall, our analyses reveal three types of architectural profiles for cocoa-based SAFs and two types of architectural profiles for oil palm-based SAFs.

Four-layer profile

This type of profile is found in young cocoa agroforests between 0 and 15 years old. In this model, the denser cocoa plants belong to height strata A and B, which are respectively between 0 and 2 m in height for the youngest stems and between 2 and 8 m for mature stems (Fig. 5A). Here, ground level lighting is greater (over 60%) with regular pruning of the more accessible medium-sized tree branches. The branches of the less accessible large trees provide partial coverage of the plot and the underlying crops.

Three-layer profile

This profile characterizes adult cocoa agroforests between 15 and 45 years old. Cocoa plants of varying density belong to stratum A and B between 0 and 8 m in height with the particularity of denser tall cocoa stems (Fig. 6B). Associated species, most often consisting of fruit species, are denser and larger. A similar profile is observed for old cocoa agroforests (over 45 years old), with the particularity of a higher

Table 4 Density (stem/ha) and basal area (m²/ha) of cash crops, associated species and control by age class

Area Age group	Agroforestry system (AFS)				Witness				
	Cocoa tree		Palm		fruit tree		Forest tree		
	D (ti/ha)	ST (m ² /ha)	D (ti/ha)	ST (m ² /ha)	D (ti/ha)	ST (m ² /ha)	D (ti/ha)	ST (m ² /ha)	
< 15	897.5 (± 398.99)	7.01 (± 8.05)	27.1 (± 25.04)	14.94 (± 12.13)	45.03 (± 24.37)	2.1 (± 1.94)	163.19 (± 134.85)	10.17 (± 1.42)	110.51 (± 38.47)
[15—30]	1393.75 (± 904.88)	8.44 (± 6.45)	15.29 (± 13.62)	7.91 (± 7.86)	40.41 (± 36.25)	3.41 (± 3.27)	53.25 (± 44.85)	20.3 (± 14.85)	
[30—45]	1805.26 (± 1116.63)	14.6 (± 11.82)	47.95 (± 45.3)	18.64 (± 16.52)	28.35 (± 27.82)	3.38 (± 3.25)	93.28 (± 27.31)	17.95 (± 14.88)	
≥ 45	1276.92 (± 840.58)	7.71 (± 4.65)	23.63 (± 20.98)	14.48 (± 10.91)	31.97 (± 21.46)	1.77 (± 1.51)	80.51 (± 64.85)	36.09 (± 27.85)	
Average	1343.35 (± 815.27)	9.44 (± 7.74)	28.49 (± 33.48)	13.99 (± 15.63)	36.44 (± 33.22)	2.66 (± 3.94)	97.55 (± 67.96)	21.12 (± 14.75)	42.08 (± 27.99)

D, density (stem/ha); ST, basal area (m²/ha)

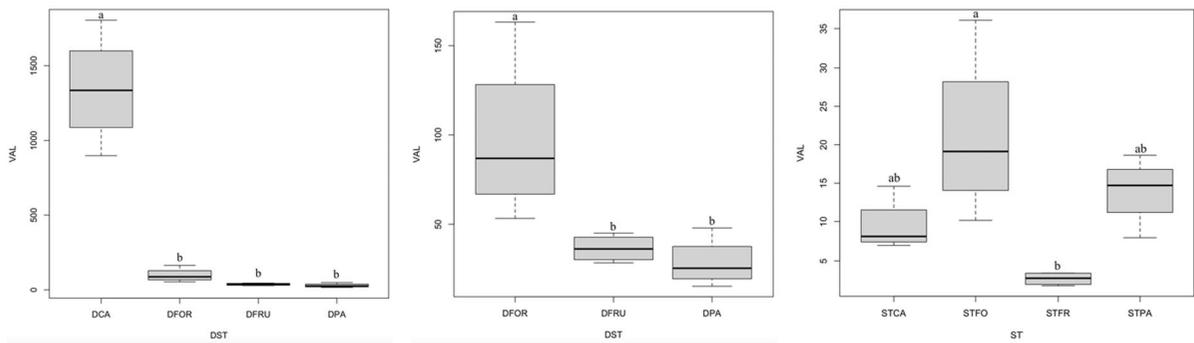


Fig. 5 Boxplot of density (stem/ha) and basal area (m²/ha) of woody types. Separation of means by Tukey test (P -value = 0.05). Means followed by the same letters are not significantly different ($p > 0.05$). DCA =Cocoa density; DFOR

=Forest species density; DFRU =Fruit species density; DPA =Palm density; STCA =Cocoa basal area; STFO =Forest species basal area; STFR =Fruit species basal area; STPA =Palm basal area; VAL = Value

density of associated species (fruit and forest) of large sizes (Fig. 6C).

Two types of architectural profiles of different stratification characterize the palm agroforest of the area.

Three-layer profile

The first profile has three layers A, B and C at heights that vary respectively from 0 to 2 m, from 2 to 4 m and from 4 to 12 m. Layers A and B are dominated by the presence of woody plants of small diameters, generally fruit shrubs and young stems of planted forest

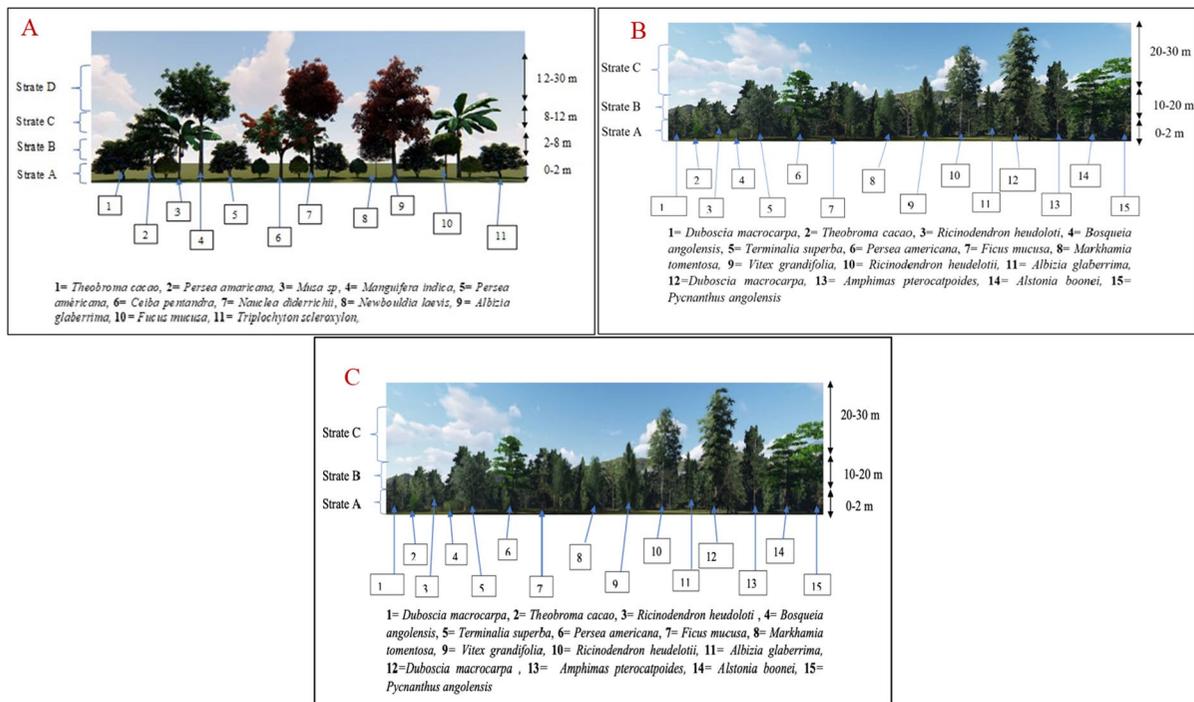


Fig. 6 Architectural profile of cocoa agroforests (young, adult and old)

species. Layer C, for its part, has a height of 4 to 12 m and is mainly made up of young palm trees and sometimes medium-sized palm trees whose leaves limit the arrival of light at ground level (Fig. 7A). This lack of sufficient light on the ground considerably slows down the growth of the underlying species of the system.

The second model of the observed three-layer architectural profile concerns older palm agroforest (over 45 years old). The three layers, namely A, B and C, here have heights that vary respectively from 0 to 2 m, from 2 to 6 m and finally from 8 to 15 m (Fig. 7B). Here, mature palm trees over 15 m high dominate the upper layer, sometimes mixed with associated large species.

Agroecological interactions and typology of SAFs

A more complex analysis of ecological interactions based on four factors (parameters) observed in SAFs allowed us to identify their typology. The factors considered in this classification are: age of the SAFs, the woody type, the level of complexity of association of the components in these SAFs and their proximity to the UFA. Four groups of significantly correlated factors emerge from Fig. 7 and allow us to identify three groups of land use types (LUTs). This typology presented in Fig. 8 shows us two dendrograms “A” and “B” which correspond respectively to the factors or parameters correlated according to the woody types and the land use types (LUTs) following a color density interaction gradient (calibrated from -4 to 4). These dendrograms made at a truncation of 1.15 are accompanied by some basic graphs (histogram, density, violin and box plot) to show the distribution of

the data in each branch of the tree. Dendrogram “A” shows us four (1 to 4) groups of positively correlated factors, namely:

Group 1

It exclusively groups together the cocoa SAFs of the class 2 of the dendrogram “B” and are characterized by adult SAFs of complex structure with an intermediate layer much more marked by the density and height of cash crops (more important color palettes). These more homogeneous farms are mainly found in zone 2 located between 3 and 4 km from the UFA and are the only type of land use in this group.

Group 2

The SAFs in this group are very heterogeneous and include all types of land use, namely cocoa agroforests (more than 78% of plots), palm agroforest (100%) and control forests (100%). It corresponds to a part of the class 1 and 2 of the dendrogram “B” and are characterized by old SAFs of average structure and whose intermediate and upper strata are marked by the density and height of native or preserved species of the old forest. These exploitations are mainly found in zone 1 located between 2 and 3 km from the UFA.

Group 3

It is very heterogeneous and only includes cocoa agroforests. It corresponds to the most important part (larger color palettes) of the class 1 of the dendrogram “B” and are characterized by young SAFs

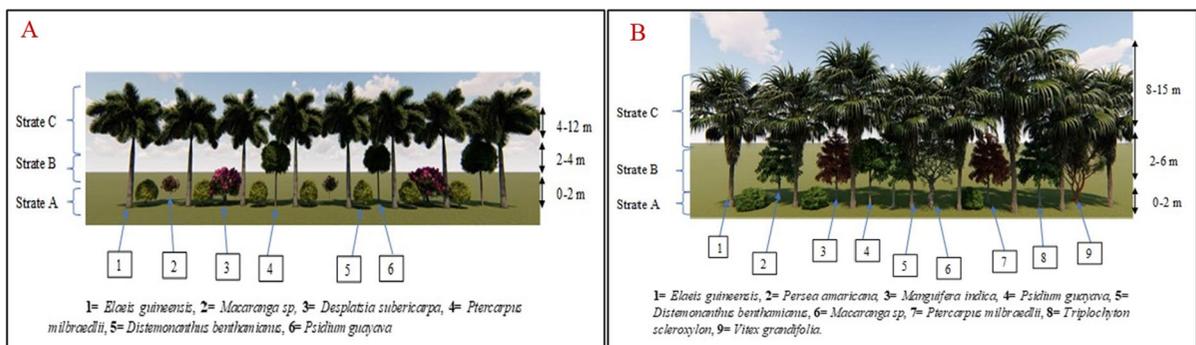


Fig. 7 Architectural profile of adult and old palm agroforest

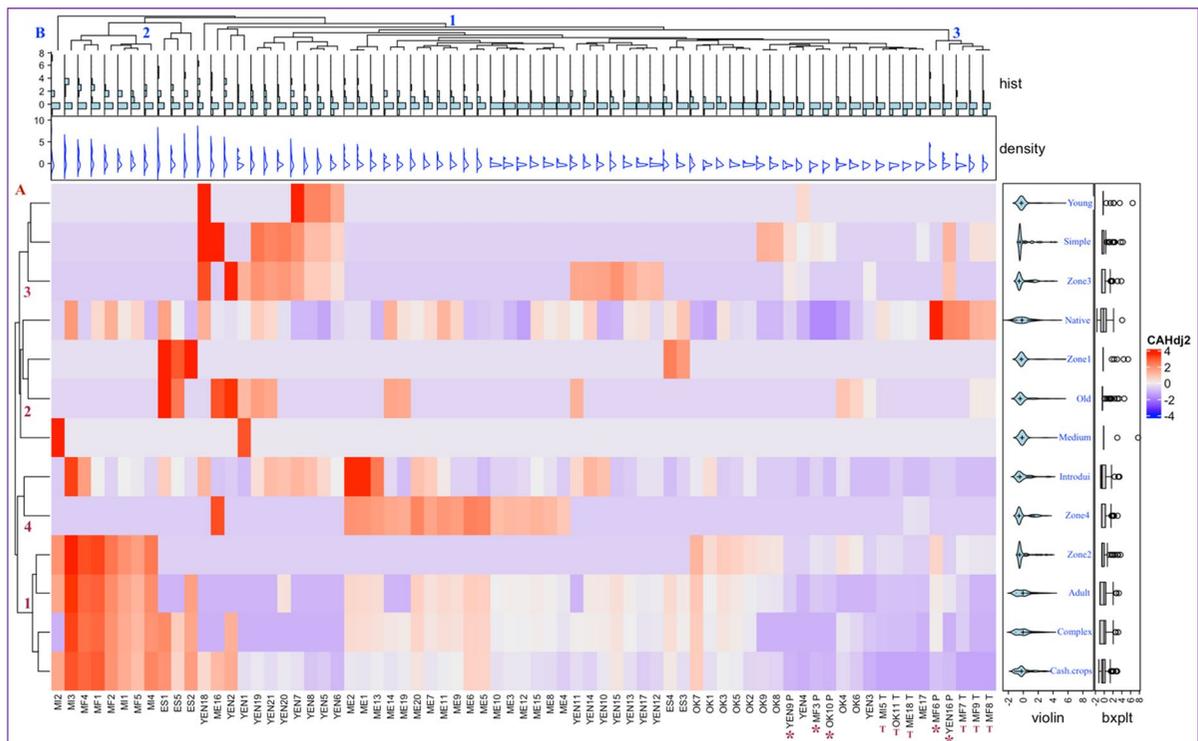


Fig. 8 Classification map of ecological interactions of woody type associations and SAF typology. T = Witness forest; * = Palm grove

with a simple structure and whose lower and intermediate strata are not marked by any particular woody type. These farms are mainly found in zone 3 located between 4 and 5 km from the UFA.

Group 4

This is a poorly represented homogeneous group that only includes cocoa agroforests. It corresponds to a significant part (more important color palettes) of the class 1 and 2 of the dendrogram “B” and are characterized by SAFs of very variable ages and structures but whose intermediate and upper strata are marked by fruit species most often introduced. These farms are mainly found in zone 4 (≥ 5 km) of the UFA.

We note from this analysis that two categories of woody plants are associated with food and/or perennial crops according to the type of SAF, namely: forest or native species and introduced fruit species. presents the contribution of these categories of woody plants in the configuration of architectural profiles

and the classification of agroforests. The diversity and density of these woody types contribute significantly to the architecture of SAF profiles in the region.

Carbon stock

Carbon stocks of cocoa trees and associated trees in different types of system

Overall, our results show that forests are the type of land use that stores the most carbon with a value of 115.81 (tC/ha) compared to 93.54 (tC/ha) for palm agroforest and 58.8 (tC/ha) for cocoa agroforests. Depending on the age of the agroforestry systems, we note that it is the adult plots that store the most carbon in cocoa agroforests with 99.24 (tC/ha) compared to 93.54 (tC/ha) in adult palm agroforest (Table 5). This adult class is followed by old cocoa agroforests with 60.58 (tC/ha) and only 14.41 (tC/ha) for young cocoa agroforests. Overall, it is therefore the forests which store the most carbon dioxide (CO₂) with 425.04

(tCO₂/ha) followed by palm agroforest 343.3 (tCO₂/ha) and finally cocoa agroforests 213.15 (tCO₂/ha).

Concerning woody types, our results show that it is the associated species that store the most carbon and CO₂ with 67.71 (tC/ha), followed by palm trees 18.64 (tC/ha) and at the end of cocoa trees 7.27 (tC/ha). Depending on the age of the agroforestry systems, it shows that it is the associated species of old agroforestry systems that store the most carbon with 97.29 (tC/ha) followed by adult systems with 95.41 (tC/ha) and at the end of young systems with 10.43 (tC/ha). This observation is not the same for perennial crops, namely cocoa trees and palm trees, where the highest values are observed in adult systems with respectively 26.23 (tC/ha) for palm trees and 11.18 (tC/ha) for cocoa trees (Table 6).

Discussion

The SAFs of the Djoum area have remarkable potential and floristic diversity. From our results, 8355 individuals were inventoried and are divided into 177 species, 153 genera and 47 families with an average Shannon diversity index of 2.95 bits. Forests are the most diverse land use type with 3.9 bits, followed by

cocoa SAFs (2.81 bits) and finally palm SAFs (2.15 bits). These results are in agreement with those of Temgoua et al. (2020) and Fomekong et al (2023) which show a greater diversity of forests compared to SAFs. Temgoua et al. (2020) found Shannon diversity indices ranging from 0.48 to 2.16 bits in coffee SAFs and 3.08 bits in neighboring forests while Fomekong et al (2023) found Shannon diversity indices of 3.47 bits and Simpson of 0.96 in forests. In young cocoa-based agroforests in the Bokito locality, Jagoret et al. (2011, 2012) showed that the Shannon index increased significantly from 2.35 to 2.90 for those over 40 years old. On the other hand, Eyoho Ewane (2012) obtained 3 bits in the South-West zone, which attests that the latter are as diverse as those in the Djoum zone.

On the other hand, different results are obtained on floristic and specific richness. Temgoua et al. (2020) and Fomekong et al (2023) obtain lower values respectively in coffee-based agroforestry systems in Kekem in Haut Nkam (West Cameroon region) and in cocoa-based agroforestry systems in Makénéne in Mbam and Inoubou (Central Cameroon region). Fomekong et al. (2023) worked in four land use types and found 85 species in forests, 44 species in cocoa-based SAFs under forest, 27 species in cocoa-based

Table 5 Carbon stock (tC/ha), CO₂ stock (tCO₂/ha) of TUTs and woody types in SAFs and their ecological value

Setting	Carbon stock (tC/ha)				SC Average (tC/ha)	SCO ₂ Average (tCO ₂ /ha)	Ecological value (\$)
	Young (< 15)	Adult [15–45]	Old (≥ 45)				
TUT	Cocoa agroforest	14.41 (± 8.83)	99.24 (± 85.37)	60.58 (± 58.2)	58.08 (± 42.47)	213.15 (± 174.87)	15,986.65
	Palm grove	0	93.54 (± 40.22)	0	93.54 (± 0)	343.3 (± 287.43)	25,748.12
	Witness	115.81 (± 119.23)			115.81 (± 0)	425.04 (± 359.72)	31,878.35
Average		37.37 (± 27.67)	14.41 (± 8.83)	102.86 (± 81.61)	60.58 (± 58.2)	89.14 (± 42.47)	327.16 (± 274)
Woody type	Cocoa tree	2.91 (± 1.62)	11.18 (± 9.09)	7.72 (± 4.61)	7.27 (± 5.11)	26.69 (± 17.6)	2002.25
	Palm	6.34 (± 0)	26.23 (± 37.28)	23.34 (± 19.05)	18.64 (± 28.16)	68.41 (± 122.76)	5131.34
	Associate Esp.	10.43 (± 7.68)	95.41 (± 107.27)	97.29 (± 61.38)	67.71 (± 58.78)	248.51 (± 238.33)	18,638.78
Average		17.74 (± 12.33)	6.56 (± 4.65)	44.27 (± 51.21)	42.78 (± 28.35)	31.21 (± 30.68)	114.54 (± 126.23)

In the same column, values followed by the same letter are not significantly different (*p* > 0.05). SAF under savannahs: agroforestry systems based on cocoa trees under savannah and SAF under forests: agroforestry systems based on cocoa trees under forests
 SC, Carbon Stock; SCO₂, Carbon dioxide stock

Table 6 Carbon stock (tC/ha), CO₂ stock (tCO₂/ha) of the main species in the TUT and their ecological value

TUT	Species	Young	Adult	Old	SC(tC/ha)	SCO ₂ (tCO ₂ /ha)	Ecological value (\$)
Cocoa agroforest	<i>Theobroma cacao</i>	0.39	21.35	33.55	18.43	67.64	5073.20
	<i>Terminalia superba</i>	0.00	21.58	32.64	18.07	66.32	4974.03
	<i>Desbordesia glaucescens</i>	0.00	29.89	4.94	11.61	42.62	3196.38
	<i>Triplochiton scleroxylon</i>	0.00	20.93	11.47	10.80	39.63	2972.48
	<i>Alstonia boonei</i>	0.00	11.49	16.27	9.25	33.96	2547.00
	<i>Pycnanthus angolensis</i>	0.00	4.03	16.85	6.96	25.54	1915.87
	<i>Musanga cecropioides</i>	0.00	19.89	0.04	6.64	24.38	1828.81
	<i>Petersianthus macrocarpus</i>	0.01	4.95	13.15	6.03	22.14	1660.58
	<i>Ceiba pentandra</i>	0.00	0.00	17.79	5.93	21.76	1632.23
	<i>Albizia ferruginea</i>	0.18	15.11	0.44	5.25	19.25	1443.69
	<i>Ricinodendron heudelotii</i>	0.00	15.63	0.00	5.21	19.13	1434.45
<i>Pericopsis elata</i>	1.71	7.12	6.44	5.09	18.67	1400.60	
Palm agroforest	<i>Uapaca vanhouttei</i>		8.13		8.13	29.83	2237.53
	<i>Mangifera indica</i>		5.20		5.20	19.10	1432.53
	<i>Elaeis guineensis</i>		3.35		3.35	12.28	920.72
	<i>Memecylon breteleranum</i>		1.91		1.91	7.01	525.59
	<i>Pycnanthus angolensis</i>		1.12		1.12	4.13	309.51
	<i>Macaranga burifolia</i>		0.96		0.96	3.54	265.47
	<i>Macaranga saccifera</i>		0.88		0.88	3.24	242.87
	<i>Pterocarpus soyauxii</i>		0.56		0.56	2.05	153.89
	<i>Albizia zygia</i>		0.49		0.49	1.80	135.24
	<i>Persea americana</i>		0.42		0.42	1.55	116.16
	<i>Vernonia conferta</i>		0.41		0.41	1.49	111.69
<i>Tetrapleura tetraptera</i>		0.17		0.17	0.63	47.29	
Forest	<i>Terminalia superba</i>		62.92		62.92	230.93	17,319.89
	<i>Triplochiton scleroxylon</i>		47.22		47.22	173.30	12,997.25
	<i>Piptadeniastrum africanum</i>		45.42		45.42	166.71	12,502.89
	<i>Excellent Militia</i>			21.22	21.22	77.87	5840.29
	<i>Funtumia elastica</i>		20.06	3.15	11.61	42.60	3194.76
	<i>Albizia laurentii</i>		10.03		10.03	36.82	2761.72
	<i>Annonidium manni</i>		14.90	5.05	9.98	36.62	2746.66
	<i>Entandrophragma cylindricum</i>		7.88		7.88	28.91	2168.50
	<i>Duboscia macrocarpa</i>		7.37		7.37	27.03	2027.36
	<i>Memecylon breteleranum</i>		6.59		6.59	24.18	1813.56
	<i>Alstonia boonei</i>		6.56		6.56	24.09	1806.72
	<i>Erythrophleum ivorense</i>		3.38	8.77	6.08	22.30	1672.25

SC, Carbon stock; SCO₂, Carbon dioxide stock; VaEc, Ecological value

SAFs under savannah and 7 species in savannahs. Temgoua et al. (2020) on the other hand obtained in coffee-based SAFs in five prospected villages, 1066 individuals divided into 30 species and 19 families, while in the surrounding secondary forests they found 184 individuals divided into 30 species and 15 families. This difference is mainly explained by the size

of the sampling, the difference in vegetation in the areas studied and the technical itinerary adopted by producers for SAFs. Fomekong et al. (2023) also presents a different approach to the increase in diversity following the gradient of establishment of SAFs from savannahs to forests while it was noted in our study that this diversity increases following the gradient

of distance from the UFA. This situation in our case is explained by the fact that SAFs are increasingly enriched with fruit species with distance from the UFA and the proximity of SAFs near villages while a contrary observation is observed for forest species especially of forestry interest which are illegally cut and removed in the most peripheral SAFs of the UFA and which on the other hand are preserved longer in SAFs near villages sometimes well beyond the average exploitation diameter (DME).

The most ecologically important species (EIS) are respectively *Elaeis guineensis* (13.08%), *Persea americana* (12.29%), *Musa* sp. (7.87%), *Terminalia superba* (6.19%) and *Funtumia elastica* (5.01%). These results are similar to those obtained by Jiofack et al. (2013), Mapongmetsem et al. (2016) and Temgoua et al. (2020) in the SAFs and agroforests of several localities identified as important cocoa and coffee production basins of Mbam and Inoubou in the central and western regions of Cameroon. For Jiofack et al. (2013) for example, *Mangifera indica* (122.14), *Dacryodes edulis* (104.86), *Elaeis guineensis* (98.95) and *Persea americana* (94.23) are identified as the most ecologically important species with much higher values. In the multi-storey agroforests of Bafia these are *Elaeis guineensis* (25.02), *Mangifera indica* (21.07) and *Dacryodes edulis* (17.84) which are identified as the most ecologically important species by Mapongmetsem et al. (2016). This finding reflects the fact that producers have a particular preference for fruit species as cover species associated with cocoa and coffee trees, most often with high socio-economic value mainly for the sale of fruits (palm nuts, mangoes, avocados). Fabaceae (38.99%), Arecaceae (27.34%), Phyllanthaceae (24.20%), Malvaceae (22.88%) and Apocynaceae (15.89%) are the most ecologically important families in the SAFs of the Djoum area. This result is different from those obtained by Etchike et al. (2017) and Ndonmou et al. (2022) respectively in the agroforests of Makénéne in Mbam and Inoubou and in the SAFs of western Cameroon. Fabaceae-Caesalpinioideae (31.59%), Agavaceae (28.53%), Combretaceae (27.87%) and Moraceae (26.25%) were the most ecologically important families noted by Etchike et al. (2017) while Burseraceae (15.2%), Moraceae (13.1%), Arecaceae (11.3%), Malvaceae (10.6%) and Fabaceae (10.4%) were the most dominant families in the SAFs of western Cameroon highlighted in the work of

Ndonmou et al. (2022). This difference is explained by the type of vegetation encountered in these different study areas. The characteristic vegetation of the areas in which the work of these authors took place are respectively humid savannahs of the western highlands and forest-savannah mosaics of the Mbam and Inoubou plain, vegetation dominated by shrubs and trees of savannahs, open forests and semi-deciduous forests. These families are full of many deciduous species and pioneer species of reforestation and whose seeds are mainly disseminated by the wind (anemochory), animals (zoochory), man (anthropochory) and birds (ornithochory). Unlike the forest area where our work was carried out, here the most predominant families are mainly made up of species belonging to anthropized secondary forests, often mature and young primary forests.

The Jaccard proximity index shows that cocoa forests and SAFs share 66.7% of forest species conserved in these SAFs compared to only 6.34% of forest species conserved in oil palm SAFs, which clearly illustrates the effectiveness of these SAFs, especially cocoa, in providing this ecosystem service of biodiversity conservation. These results do not corroborate those of Temgoua et al. (2019, 2020) and Etchike et al. (2025) respectively in the cocoa agroforestry systems of Loum and Kekem in the Littoral and Haut-Nkam (west Cameroon) and in the Ndikiniméki area (central Cameroon). Temgoua et al. (2019, 2020) obtain Jaccard proximity indices not exceeding 0.50 while Etchike et al. (2025) obtain on average 69% floristic similarity between agroecosystems. The structure of the farms and the technical itinerary used by the producers in this case in the divergence of assessment and selection of associated trees explains this difference. Furthermore, the great variability of the floristic composition of the dense evergreen Atlantic forests of the Littoral and the high-altitude vegetation of the western region compared to the humid tropical forests that characterize the Djoum area. Etchike et al. (2024) note, however, that this Jaccard proximity index has rates higher than 50% in the multi-level agroforests encountered in the forest-savannah ecotones of the Makénéne area, simultaneously sharing species characteristic of savannahs and those characteristics of the surrounding semi-deciduous secondary forests, most often anthropized.

The rarefaction curve of species richness as a function of the number of individuals for each TUT shows

that a small number of species (17.02% Fr > 10 and 11.34% Fr [5–10]) are frequent in SAFs while a large number (71.63% Fr < 5) of species are infrequent or rare in these SAFs. Several situations explain this rarity, for example they can result naturally from competition between the species present and their differences in temperament on the one hand, but also result from historical phenomena. Our results confirm what was observed by Pascal (2003) in his work on the dynamics of tropical rainforests and by Omatoko et al. (2015) who worked on the structure of *Pericopsis elata* and *Julbernardia seretii* stands in the lowland forest in the Democratic Republic of Congo. Etchike et al. (2020) illustrated this rarefaction on the families encountered in the multi-storey agroforests of the Ndikiniméki district. The rarest species (*Heisteria trillesiana*, *Celtis* sp, *Petersiantus macrocarpus* and *Syzygium guineense*) belong respectively to the families Olacaceae, Ulmaceae, Lecythidaceae and Myrtaceae.

The distribution of histograms in diameter class of the species associated in the SAFs has a generally bell-shaped appearance for all woody types in the different TUTs while that of the height strata has rather an “L” shaped appearance. The diameter classes which show the highest number of stems per hectare are the species classes in the UFA forests which vary from 44 to 4 stems/ha monitoring of forest species classes in the palm agroforest (between 18 and 13 stems/ha) and cocoa agroforests (between 24 and 8 stems/ha). Concerning the height strata, the most important strata in number of stems per hectare are found in the forests of the UFA (vary from 43 to 15 stems/ha) followed by those of cocoa agroforests which vary from 23 to 5 stems/ha for fruit and vegetable species 19 to 13 stems/ha for conserved forest species. Similar results were noted in the work of Madountsap et al. (2017), Temgoua et al. (2020) and Ngomeni et al. (2023) respectively in the SAFs for cocoa trees from SODECAO in the locality of Talba (central region of Cameroon), the SAFs based on coffee trees in Kekem in Haut Nkam (western region of Cameroon) and in the SAFs to *Coffea canephora* var. *robusta* in the Mounjo production basin (Melong, Nkongsamba, Malantouen and Ayos). The diameter class [10–20] cm also had the highest abundance at all sites, then decreased as the diameter classes increased, giving an inverted “J” curve (Ngomeni et al. 2023). A slight shift in the peaks is observed

in the work of Temgoua et al. (2020) for classes [35–45], [45–55] and [55–65] cm with 20%, 40% and 22% respectively. Etchike et al. (2025) found, however, different results in the agroecosystems of the different villages in the Ndikiniméki area in Mbam and Inoubou (central Cameroon). For these authors, the diameter and height classes are very heterogeneous and present respective peaks in the classes of [30–40 cm] and [≥ 50 cm] and higher values in the height classes [< 10 m], proof of good regeneration and good reconstitution of the agroforestry vegetation and local flora.

The average density of cocoa trees in the SAFs of the locality of Djoum is 1343.35 stems/ha against 28.49 stems/ha for palm trees. Those of fruit and forest trees are respectively 36.44 stems/ha and 97.55 stems/ha for an average density of associated species of 67 stems/ha while it is 110.51 stems/ha in the forests of the UFA. The basal area of cocoa agroforests is 9.44 m²/ha against 13.99 m²/ha for palm trees. In the SAFs the average basal area of forest trees is 21.12 m²/ha compared to only 2.66 m²/ha for fruit trees, which gives us an average basal area of associated species of 11.89 m²/ha, while it is 42.08 m²/ha in the UFA forests. Very variable results were obtained in cocoa-based SAFs in similar areas from central and southern Cameroon. The works of Michel et al. (2021) highlight the great variability in the density of associated species in SAFs of Talba (43 stems/ha) in central Cameroon to 163.1 stems/ha in the SAFs of Mintom in southern Cameroon via Akongo (102.3 stems/ha) in Mbam and Kim and Obala (139.8 stems/ha) in Lékié. Different basal area values of associated species were recorded between 9 and 46 m²/ha in the work of Bisseleua and Vidal (2008), 17.6 m²/ha, average obtained by Jagoret et al. (2017) and 30.5 m²/ha, average indicated by Sonwa et al. (2017). Michel et al. (2021) find average basal areas of 14.5 m²/ha in the SAFs of Talba, 19.1 m²/ha in Akongo, 16.8 in Obala and 35.5 m²/ha in Mintom. These differences observed in these values are explained not only by the endogenous knowledge and technical itineraries used by the farmers, but also by the type of flora and vegetation encountered in these different areas. It is important to emphasize that the direct involvement of these low basal areas obtained in the Djoum SAFs are favorable to good light penetration on the ground for good productivity of the

system, especially for underlying species. This rate of light on the ground therefore becomes sufficient to initiate the natural regeneration of many undergrowth species (Grillot and Asaël 2015).

Three types of architectural profiles are identified in cocoa-based SAFs against two types of profiles for oil palm-based SAFs in the Djoum area. The four-layer profile is found in young cocoa agroforests aged between 0 and 15 years while the three-layer profile characterizes adult cocoa agroforests (15 to 45 years) and old cocoa agroforests (over 45 years). Concerning oil palm-based SAFs, the three-layer architectural profile at heights between 0–2 m, 2–4 m and 4–12 m. The second three-layer architectural profile model observed concerns older palm agroforests (over 45 years). These results are slightly different from the intensive profiles observed in the work of Ngomeni et al. (2023) and Etchike et al. (2024, 2025) respectively in the *robusta* coffee agroforests (*Coffea canephora* var. *robusta*) in the Moungo production basin (Melong, Nkongsamba, Malantouen and Ayos) and in the Makénééné and Ndikiniméki agroforests (central Cameroon). For Ngomeni et al. (2023) it is the *Musa* and *Elaeis* genera that present high densities in the Nkongsamba and Melong sites while it is the *Citrus* and *Annona* genera that dominate the intermediate shrub layer in the Bafia agroforests (Mapongmetsem et al. 2016) and of Makenene (Etchike et al. 2024). These authors show overall that large trees are also found in the upper strata of 12 to 20 m and > 20 m, most often with open canopies which do not prevent the penetration of light into the lower strata. Etchike et al. (2024, 2025) specifies that these SAFs related to multi-stratified intensive family gardens have the particularity of having been “built” under savannah vegetation (mostly found in Makénééné) while Intensive multi-stratified SAFs are built under transitional vegetation between forest and savannah and under forest vegetation cover (partly encountered in Makénééné and more frequent in Ndikiniméki).

A typology of agroecological interactions of these SAFs according to the age of SAFs, woody type, level of complexity of association of components and their proximity to the UFA shows 4 groups of SAFs ranging from the most homogeneous to the most heterogeneous, from the simplest to the most complex structures. These results are different from those obtained by Michel et al. (2021) and Etchike et al. (2024) respectively in the SAFs of Talba, Akongo, Obala

and Mintom and agroforests of Makénééné in Mbam and Inoubou. This typology of complexity of SAFs based on cocoa trees for Michel et al. (2021) based on the basal area values of associated species. For these authors, the SAF is called “simple” if the basal area value is less than 8 m²/ha; it is called “medium” for a value between 8 and 16 m²/ha; “complex” for a value between 16 and 35 m²/ha; and “very complex” for a value greater than 35 m²/ha.

Ngomeni et al. (2023) define this typology of architectural profiles on the basis of five strata (1 to 5) of heights observed in the SAFs with *Coffea canephora* var. *robusta* of Nkongsamba, Melong, Ayos and Malantouen respectively in Moungo (Littoral), central and western Cameroon. For these authors, stratum 2 (3–6 m) is the most dominant of the five strata regardless of the study site. Etchike et al. (2024) consider five parameters for this classification namely the age of agroforests, (AAG), height (HTR), diameter (DBH), tree density (DST) and woody biomass (Y). This typology is presented in the form of a Principal Component Analysis (PCA), a Hierarchical Ascending Classification (HAC) and a heat gradient map. These three classifications show a significant contribution of three categories of woody plants that configure the architecture of these SAFs, namely high-density species of socio-economic interest (EIS1), medium-density species of socio-economic interest (EIS2) and local species and for the most part pioneer species of reforestation (ELPR) (Etchike et al. 2024, 2025). These classification maps (heat) lay the foundation for a new innovative analytical approach to understanding the ecological and biological interactions of tropical plant types and components for concrete ecological implications in sustainable and recommendable SAF types.

Forests are the land use type that stores the most carbon (115.81 tC/ha) compared to 93.54 tC/ha for palm agroforest and 58.8 tC/ha for cocoa agroforests. Depending on the age of the agroforestry systems, it is noted that it is the adult plots that store the most carbon in cocoa agroforests with 99.24 tC/ha compared to 93.54 tC/ha in adult palm agroforest. It is noted that Cocoa trees store less carbon than palm trees and related species. These results are similar to those of Fomekong et al. (2023) and Temgoua et al. (2018) respectively in SAFs and Makénééné forests in central Cameroon and in the SAFs of eastern Cameroon. For Fomekong et al. (2023) Forests also

store more carbon (135.95 tC/ha) compared to other systems. They also note that the total amount of carbon stored in cocoa-based SAF under forests is 55.81 tC/ha and is significantly higher than that of cocoa-based SAF under savannahs (22.81 tC/ha). In Eastern Cameroon, Temgoua et al. (2018) note that Cocoa trees store less carbon than associated trees with an average of 2.25 tC/ha and that this amount of carbon sequestered by cocoa trees increases with the age of the cocoa agroforest. The amount of carbon stored by associated trees varies from 89 tC/ha for SAFs aged 5 to 10 years to 127 tC/ha for those aged less than or equal to 5 years. Zapfack et al. (2017) obtained different results in the SODECAO SAFs in Mbam and Kim. For them, it is the old SAFs that store the most carbon with 38.72 MgC/ha for cocoa trees and 80.73 MgC/ha for associated species. They found that cocoa trees had lower basal areas than those of associated trees. This difference is linked to the smaller diameter and basal area of cocoa trees compared to those of associated trees.

Conclusion

The peripheral agroforestry systems of the forest concessions of the Djoum area in southern Cameroon show not only great wealth (8355 individuals) and specific diversity (177 species), but also a strong potential for the conservation of local plant resources with 66.7% of forest species preserved in cocoa agroforests. Among the land use types, forests are more diverse than SAFs with a Shannon index of 3.9 bits, compared to 2.81 bits for cocoa agroforests and 2.15 bits for palm agroforest. The Shannon diversity index is highest for forest species in the proximity zones to UFA 2 and 3 with 4.21 bits and 3.99 bits respectively, while it is highest for fruit species in zones 4 and 1 with 1.37 bits and 1.36 bits respectively. Species like *Elaeis guineensis*, *Persea americana* and *Musa* sp. have the highest ecological importance values while the Fabaceae, Arecaceae and Phyllanthaceae are the most predominant botanical families. UFA forests and peripheral SAFs share 42 forest species out of 63 inventoried species, i.e. 66.7% of forest species conserved in cocoa agroforests, proof of the effectiveness of the conservation potential of these SAFs in the region. The horizontal and vertical structures of the inventoried population are very variable, ranging

from the simplest to the most complex structures with “bell” shaped shapes for tree diameters and “L” shaped shapes for heights. These shapes respectively reflect the importance of individuals with medium diameter with some notable peaks of individuals with large diameter for certain woody types (forest species in SAFs and in forests) and an abundance of small individuals (< 15 m). Three types of architectural profiles emerge for cocoa-based SAFs versus two types of architectural profiles for oil palm-based SAFs. A typology of land use types based on relevant ecological interactions shows 4 distinct groups. Forests are the type of land use that stores the most carbon (115.81 tC/ha) compared to 93.54 tC/ha for palm agroforest and 58.8 tC/ha for cocoa agroforests. These different results show that the gradients of diversity, density and complexity of SAFs vary not only with the proximity to the forest concession but also with the woody type predominating in the system. These data could be considered as reliable, effective and quantifiable references for the certification of many cash crops such as cocoa and oil palm, which will allow to valorize this endogenous knowledge on the scientific level and in the development of various development programs.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Competing interests The authors declare no competing interests.

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