Open Journal of Forestry, 2024, 14, 42-66
https://www.scirp.org/journal/ojf
ISSN Online: 2163-0437
ISSN Print: 2163-0429

Typology and Agroecology of Agroecosystems in Vegetation Dynamics in the Ecotones of the Mbam and Inoubou

Alex Bruno Dong Etchike[1*], Lucie Félicité Temgoua[2], Bertine Tiokeng[1], Marie Caroline Momo Solefack[1], Martin Benoit Ngassoum[3], Pierre Marie Mapongmetsem[4]

[1]Laboratory of Applied Botany, Faculty of Sciences of the University of Dschang, Dschang, Cameroon
[2]Department of Forestry, Faculty of Agronomy and Agricultural Sciences, University of Dschang, Dschang, Cameroon
[3]National School of Agro-Industrial Sciences of the University of Ngaoundéré, Ngaoundéré, Cameroon
[4]Laboratory of Biodiversity and Sustainable Development of the University of Ngaoundéré, Ngaoundéré, Cameroon
Email: *etchikealex@yahoo.fr, bertiok@yahoo.fr, mcarofr@yahoo.fr, piermapong@yahoo.fr, ngassoum@yahoo.fr, temgoualucie@yahoo.fr

How to cite this paper: Dong Etchike, A. B., Temgoua, L. F., Tiokeng, B., Momo Solefack, C. M., Ngassoum, M. B., & Mapongmetsem, P. M. (2024). Typology and Agroecology of Agroecosystems in Vegetation Dynamics in the Ecotones of the Mbam and Inoubou. *Open Journal of Forestry, 14,* 42-66.
https://doi.org/10.4236/ojf.2024.141003

Received: August 14, 2023
Accepted: November 27, 2023
Published: November 30, 2023

Abstract

Agroforestry systems strongly characterize the Cameroonian agrarian landscape. Agroforests are among those structuring the ecotones of Mbam and Inoubou in the Central Cameroon region. Numerous works on agroecosystems of Central and South Cameroon, few have come out contribution of the structure of these traditional systems in the dynamics of the vegetation of these forest-savannah ecotones. The present contribution has the overall objective of demonstrating the structural efficiency of agroforests the dynamics of ecotone vegetation, but also in the conservation of biodiversity. To do this, a participatory analysis was carried out with 56 farmers distributed in the five villages of Makénéné. Botanical inventories supplemented socio-economic household surveys. The data collected was subjected to various analyzes (univariate test, analysis of variance, multivariate test, PCA, CAH). The results reveal that 55.2% of agroforests are less than 15 years old and those with an area greater than 1500 m^2 predominate (33%). They are mainly young with generally small surface areas. The horizontal structure reveals that the largest diameter classes are those of [20 - 30 cm[and [10 - 20 cm[with a very low rate of basal area. Agroforests with trees over 10 m high are dominant in five villages of Makénéné. Two types of structural profiles characterize the agroforestry flora of the area, namely intensive pluristratified home gardens on savannah and intensive pluristratified agroforests under forest-savannah transition vegetation. Principal Component Analysis (PCA) and Ascending Hierarchical Clustering (HAC) show three Agroforest Clusters each. The PCA distribution reveals that woody biomass (Y) is strongly correlated with tree diameter (DBH) and significantly with height (Cluster 2). The age (AAG)

(Cluster 1) of these agroforests, on the other hand, remains independent of the density (DST) of these trees (Cluster 3). The agroforests in the Nyokon, Carrière and Mocksud villages are the most effective in terms of conserving woody diversity while the agroforests of the Kinding ndé and Nyokon villages are more efficient in the reforestation processes. These results could be considered as effective and quantifiable tools for the certification of numerous cash crops such as cocoa and coffee, which will make it possible to valorize this local knowledge in terms of scientific and in the development of various programs and writing of technical notes.

Keywords

Agroforests, Agroecosystem, Center Cameroon, Dynamics, Agroecology, Typology

1. Introduction

In tropical areas, there is a significant reduction in global forest cover, from 4128 million hectares in 1990 to 3999 ha in 2015 (FAO, 2016). The African continent between 1900 and 2000 lost 52 million hectares of forests, representing 56% of the reduction in global forest cover (FAO, 2014). Unsustainable management practices, extensive forest conversion and agricultural intensification are generally identified as important drivers of land use change and biodiversity loss (Ballo et al., 2016; Temgoua et al., 2018). This change in land use is one of the main causes of global climate change (IPCC, 2014). The fight against Climate Change is now one of the priorities for governments and in particular that of Cameroon given the importance of its impact on the lives of populations (IUCN-PC, 2013).

In Cameroon, there is a decline in forest area of about 220,000 ha per year (FAO, 2010). Dense forests accounted for 71% of forest cover, or about 1,909,104 ha, compared to 29% of non-dense forests, or about 7,763,960 ha (Ciza et al., 2015). And as a major impact, the threat to the food security of the local populations who depend on it, given that agricultural production in the majority of these developing countries is growing more slowly than demography (Mapongmetsem et al., 2016). As the impact of climate change is felt over the years, especially through the perception of small local producers who report the decrease and/or increase in rainfall, as well as shifts in the rainy and dry seasons (Ogouwalé, 2006). These farmers also note the concentrations of rains in a short period, early breaks in these rains, high occurrence of violent winds and the increase in heat intensity and duration (Agossou, 2008). Furthermore, there is growing interest in combining adaptation and mitigation measures (Locatelli et al., 2008; Lasco et al., 2014). These climatic deteriorations are clearly evident in the forest-savannah ecotones of central Cameroon. Indeed, the removal of wood energy and bush fires in the forest or savannah cause a reduction in plant cover which leads to exposure of the soil to the sun, and can no longer fulfill its role of protection against the various environmental factors; erosion and leaching which results in the reduction of the reproductive capacity of the land (Jacquin, 2010). Lemoupa (2015) and Guillet et al. (1996) already reported that the central forest-savanna transition zone is a particular and complex ecosystem, made up of savannahs dotted with gallery forests along waterways as well as forests from human plantations and which is home to a great diversity of resources and particularly in agroecosystems.

Several studies have shown the effectiveness of these systems not only in food security, but also their carbon stock potential in the fight against climate change (Somarriba et al., 2013; Zapfack et al., 2013; Mapongmetsem et al., 2016; Temgoua et al., 2018, 2019; Etchike et al., 2017, 2020). Agroforestry systems therefore present themselves as both an alternative for the conservation of phytodiversity, local development and the fight against poverty through the provision of various products and other socio-economic needs of populations (Eboutou, 2009; Jagoret et al., 2011, 2012; Manfo et al., 2015; Abada Mbolo et al., 2016). Cocoa farming is a great source of income for central farmers, which allows them to introduce or retain many useful woody species (Saj et al., 2013; Temgoua et al., 2018). These agroforests indeed preserve a certain level of biodiversity, because it is similar to that of forests and can go up to a level close to that of secondary forest depending on the systems (Tayo, 2014; Saj et al., 2017). In this agrarian landscape of the forest-savannah ecotones of Mbam and Inoubou, the architecture of agroecosystems has not yet been the subject of scientific studies regarding their contributions to the dynamics of vegetation and their carbon stock potential in the fight against climate change.

2. Material and Methods

2.1. Location of the Study Site

The district of Makénéné in the region of central Cameroon, Department of Mbam and Inoubouis approximately 100 km from Bafia, the departmental capital, and extends between 4˚59'04" - 4˚55'60" north latitude and 10˚47'40" - 10˚52'60" East longitude (MINFOF, 2014; Ngon, 2016). There reigns a Bimodal equatorial climate with two rainy seasons interspersed with two dry seasons. Average temperatures are between 24˚C and 26˚C. The average annual rainfall is 1440 mm. Two sets of plateaus of high and low altitudes characterize the relief of the area as shown in **Figure 1**. In the center and east of the area meet the high plateaus whose altitude varies between 600 and 900 m, while the low plateau with altitudes below 500 meters occupies the western part of the area (PCDM, 2011; MINFOF, 2014). Red and yellow ferralitic type soils (clay-sandy soils) are the most common in this area. Secondary forests characterize the vegetation of this region and are represented on the one hand by large trees such as *Mansonia altissima*, *Sterculia oblonga*, *Celtis zenkeri*, *Celtis tessmanii*, *Ceiba pentadra*, *Albizia grandifolia*, *Musanga cecropioides*, *Adansonia digitata*, *Ricinodendron heudolotii*. There are also fallows dominated by *Chromolaena odorata*, *Pennisetum purpureum*, *Costus afer*, *Ageratum* sp. and *Imperata cylindrica* (MINFOF, 2016).

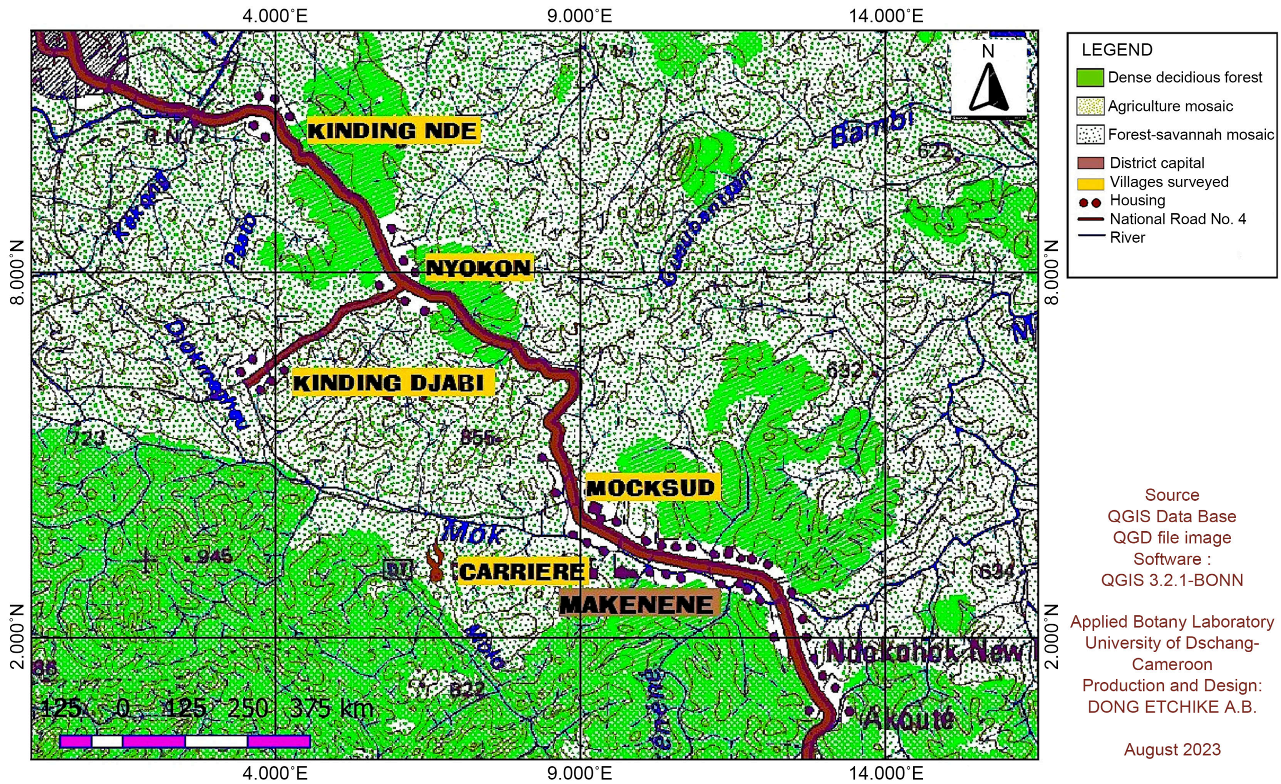


Figure 1. Location of the study site in the district of Makénéné (Center Cameroon).

2.2. Methodology

The methodology adopted involves ethnobotanical surveys and botanical inventories. A sampling rate of 9% was used for the sampling of surveyed households. Participatory and reiterative semi-structured interviews using a previously developed form were carried out (Mapongmetsem et al., 2016). A sample of 56 farmers was interviewed in five villages of the locality of Makénéné namely: Mocksud, Carrière, Nyokon, Kinding djabi and Kinding ndé, all on one total area of approximately 77.834 m^2, or 7.7834 ha. With regard to the botanical inventories, dendrological measurements were taken such as the dbh (diameter of the trunk at chest height) and the height of the trees. Indeed, all shrubs and trees whose dbh at 1.3 m from the ground for individuals without buttresses and without anomalies and which were greater than or equal to 5 cm were identified and measured (White & Edwards, 2001). The botanical nomenclature used is that adopted by Lebrun & Stork (1991-1997) in order to be able to compare our results with the bibliography. Various ecological indices and parameters were calculated such as age and area of farms, basal area, Jaccard proximity index, biomass and carbon stock to better understand the ecology, structure and complexity of these agroecosystems of the forest-savannah ecotones of the Makénéné zone (Ngueguim et al., 2015; Temgoua et al., 2018, 2019; Etchike et al., 2017, 2020).

- **Basal area**

The basal area provides information on the surface area occupied by the sections of the barrels at 1.30 m from the ground. It is expressed in square meter per hectare (m^2/ha). The total basal area corresponds to the sum of all the basal areas of the species on the inventoried area (Ngueguim et al., 2015). It is calculated by the following formula:

$$S = \Pi Di^2 / 4$$

With: S the basal surface area of the tree (m^2/ha) and Di the diameter of the woody tree

- **Jaccard proximity index**

The Jaccard index measures the similarity or proximity of farms.

$$J = \frac{C}{A + B - C}$$

A = number of species for site A, B = number of species for site B and C = number of species that site A and site B have in common.

- **The density**

$$\text{Density} = (\text{Number of individuals of the species/Total number of individuals}) * 100$$

- **Above-ground tree biomass**

The non-destructive method was adopted by the use of so-called "allometric" mathematical equations which consists of an evaluation of the biomass of the tree from its diameter, its height and/or its wood density (Brown, 1997). This biomass was estimated using allometric equations specific to Congo Basin forests. Among the existing models, one which takes into account the diameter and the density of the wood, chosen for the present study is that of Ngomanda et al. (2014). This model is written as follows:

$$Y = \exp\left[-4.0596 + 4.0624 \ln D - 0.228 (\ln D) 2 + 1.4307 \ln \rho\right]$$

where Y is expressed in kg or (t), D in cm, and ρ = 0.69826 g/cm.

The carbon fraction represents 47% of the tree's dry biomass. To obtain the accumulated carbon stock (Sc), the biomass (Y) was multiplied by 0.47 (IPCC, 2006; Tsoumou et al., 2016) according to the formula below:

$$Sc = 0.47 * Y$$

where Sc is expressed in tons of carbon (tC).

Palm tree biomass was calculated using the formula opposite (Winrock, 2005).

$$Y = 23.487 + 41.851 * \ln(H)^2$$

Architectural profiles have been illustrated on a two-axis plan (height and length) for a better appreciation of the landscape, structure and complexity of these agroecosystem characteristics of the study area (Flore et al., 2023). The method adapted from Sénécal and Saint-Laurent (2004) was used to assess the rate of cover of the agroforestry canopy. Indeed, the canopy is said to be "Open" when its rate of cover is inferior at 30%, "Shaded" when it varies from 30% to 60%, and finally "Closed" (>60%). Five structural and ecological parameters were used to develop the typology (ACP and CAH) of agroforests in the area, namely: age of agroforests (AAG), tree height (HTR), diameter at breast height (DBH), tree density (DST) and woody biomass (*Y*).

2.3. Data Analysis

The data obtained were subjected to various analyses. Several ecological parameters and ecological indices were used, namely: the Jaccard index, density and woody biomass. The Microsoft Office Excel spreadsheet was used to classify numerical data and to draw up various graphs. Univariate test (ANOVA) were performed on several parameters to determine their significance. When a significant difference is observed, the significant means are separated by Duncan's or Turkey's test (Etchike et al., 2020). Multidimensional analyzes (ACP, CAH) to a truncation of 0.0375 by the "Full Link" Aggregation Method via the Pearson correlation coefficient were carried out to highlight the typology of agroforests. The tools used for these analyses are, among others, the spreadsheets Numbers and Office Excel (Macintosh), R (4.3.1) and RStudio software. QGIS 3.2.1-BONN software was used to map the study area.

3. Results and Discussion

3.1. Biophysical Characteristics of Agroforests

3.1.1. Age and Area of Agroforests

Overall 55.2% of the agroforests in the area are young (less than 15 years old). This young slice is followed by that of mature and old agroforests (>45 years old) with a rate of 18%. The rate of agroforests whose age is between 31- 45 years and 16 - 30 years is respectively 14.2% and 12.6% as shown in Table 1. The analysis of variance shows a significant difference (0.003 < 0.01) between the age group under 15 and the three other age groups of agroforests. These structural characteristics of the agroforests of Makénéné are very varied ranging from the simplest structures to the most complex structures.

Table 1. Distribution of percentages by class of age and area of agroforests.

Villages (Nbr plots)	Ages of agroforests (year)				Areas of agroforests (m^2)				
	<15	16 - 30	31 - 45	>45	< 500	500 - 1000	1001 - 1500	>1500	Unknown
Mocksud (20)	50b	15a	10a	25a	35a	20a	25a	10a	10a
Carrière (10)	90b	10a	0a	0a	40a	30a	10a	20a	0a
Nyokon (10)	40b	20a	20a	20a	10a	40a	20a	30a	0a
Kinding djabi (5)	60b	0a	40a	0a	0a	40a	0a	60y	0a
Kinding ndé (11)	36b	18a	1a	45a	18a	9a	1a	45a	27a
Mean	55.2 ± 21.6	12.6 ± 8.0	14.2 ± 16.5	18 ± 18.9	20.6 ± 16.8	27.8 ± 13.4	11.2 ± 11.2	33 ± 19.9	7.4 ± 11.8
Probability	0.003***				0.067^{ns}				

Legend: Mean ± standard deviations (SD). Numbers with different letters are statistically different after performing Tukey's test at the 5% level. *** level of significance; ns: not significant.

3.1.2. Stratification of Agroforests

1) Horizontal stratification

Measurements of trunk diameters and basal surface area of local species recorded in these agroecosystems were considered for the study of horizontal structure. The histogram of distribution of the diameter classes of these trees in the Makénéné agroforests shows a predominance of individuals in the classes [20 - 30 cm[(84 stems) and [10 - 20 cm[(68 stems) with higher values of individuals in the Mocksud agroforests. The class (>10 cm) is the least represented with only 11 individuals as shown in Figure 2. The average diameteris 32.40 cm and varies from 29.87 cm to 33.96 cm between the five villages. The analysis of variance with the Duncan test reveals a significant effect (0.004 < 0.05) between the diameters of the trees in these different villages.

The basal areas vary from 0.23 m^2/ha to Kinding djabi has 3 m^2/ha to Mocksud with an average total basal area of 4.89 m^2/ha over a total area of 77.834 m^2, or 7.7834 ha as shown in Figure 3, which represents only 0.0062% of the entire area. The Duncan test carried out on these basal areas of trees between the villages shows a significant difference (0.004 < 0.05).

These basal area values show their effectiveness in stimulating the natural regeneration of both introduced and conserved species.

2) Vertical stratification

The tree height distribution histogram in the agroforests of Makénéné shows a predominance of the first height class (<10 m) in all five villages. The distribution level of this class is more or less uniform, which is not the case for the class of height [10 - 20 m [which has a slightly concave profile. This "concave" appearance shows that the stands in this section are unstable in the area. The height class [>30 m[displays an almost uniform plateau but remains very insignificant as shown in Figure 4. The two largest height classes are totally absent in the Kinding djabi village and practically non-existent in Kinding ndé.

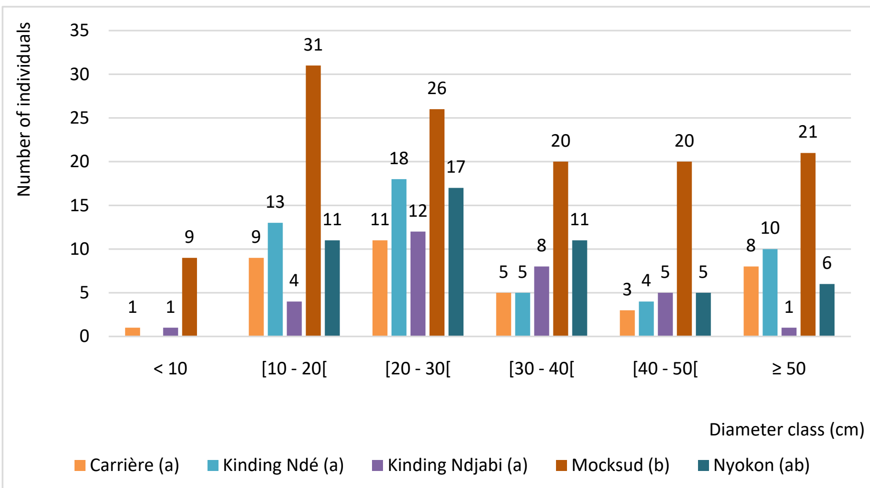


Figure 2. Distribution of tree diameter classes in Makénéné. Legend: Numbers with different letters are statistically different after performing Duncan's test at the 5% level.

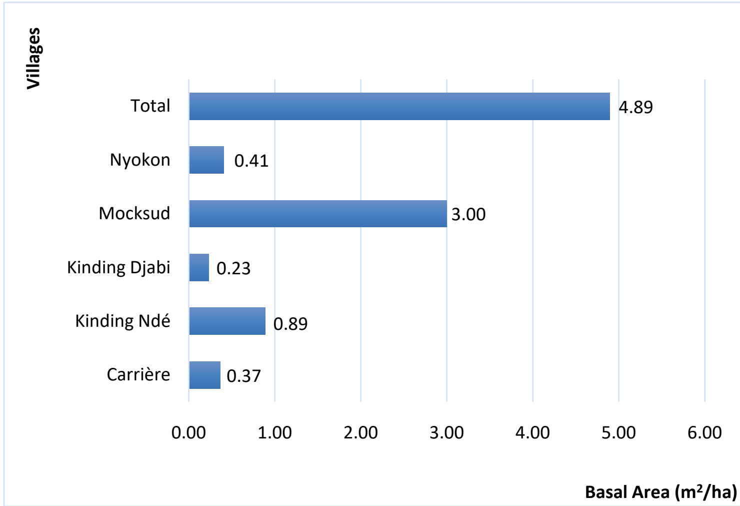


Figure 3. Basal area (m²/ha) of trees in Makénéné agroforests. Legend: Numbers with different letters are statistically different after performing Duncan's test at the 5% level.

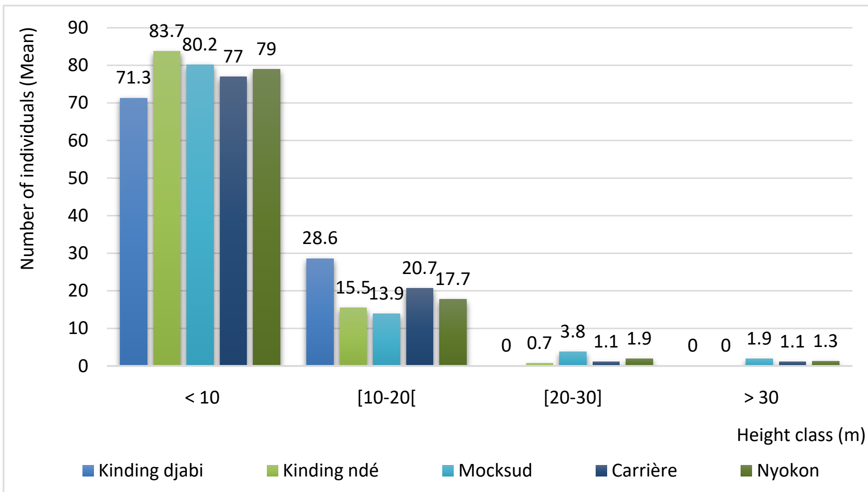


Figure 4. Distribution of tree height classes in Makénéné.

3.1.3. Gradient of Complexity Agroforests

Simple type agroforests (58.4%) characterize the agrarian landscape of Makénéné as shown in **Table 2**. In this type, the number of components and wood density are reduced. Their physiognomy is almost monostrate with woody plants of low height (<8 m) and open canopies (coverage rate < 30%). The medium type (32.6%) comes in second place with agroforests with greater woody density and shade (coverage rate between 30% and 60%). They are at least bi- or multi-layered with a greater number of trees of average height (between 8 and 14 m). Agroforests with a complex structure (9%) are the least represented with a high density of multistratified trees. They have a closed canopy (coverage rate > 60%) and are found only in the locality of Mocksud (5% closed and 45% complex). The analysis of variance indicates on the one hand a significant difference between the levels of complexity of the agroforests (0.003 < 0.01), and on the other hand between their canopy state (0.0001 < 0.01).

Table 2. Complexity gradient (%) of agroforests.

villages	Level of complexity			Canopy condition		
	Simple	Medium	Complex	Opened	shaded	Closed
Mocksud	30b	25a	45a	0b	95c	5a
Carrière	50b	50y	0a	10b	90c	0a
Nyokon	70b	30a	0a	40b	60c	0a
Kinding djabi	60b	40a	0a	40b	60c	0a
Kinding ndé	82b	18a	0a	18b	82c	0a
Mean	**58.4 ± 19.82**	**32.6 ± 12.60**	**9 ± 20.12**	**21.6 ± 17.97**	**77.4 ± 16.55**	**1 ± 2.24**
Probability	**0.003*** **			**0.0001*** **		

Legend: Mean ± standard deviations (SD). Numbers with different letters are statistically different after performing Tukey's test at the 5% level. *** level of significance.

As for the rate of cover of the agroforestry canopy, on average 77.4% of the agroforests explored in the area are of the "Shaded" type, 21.6% are of the "Open" type and 1% of the "Closed" type.

3.1.4. Level of Proximity to Agroforests

The proximity index of Jaccard reveals that there is a significant proximity between the floristic components of the different agroforests of the localities of the zone in view of the values almost all above 0.50 as shown in Table 3. The agroforests of Nyokon and Kinding djabi localities are those with the strongest floristic similarity (J = 0.65), followed by those of Carrière and Kinding djabi (J = 0.63) and finally those of Kinding djabi and Kinding ndé (J = 0.60) as shown in Figure 5. This result suggests that the agroforests of these localities share respectively 65.1%, 63.9% and 60.5% of common species.

Local agroforests Mocksud and Kinding ndé have the least similar floristic compositions. They share the fewest species in common with others (J = 0.48). The proximity index of Jaccard reveals rates above 50% between the agroforests of the area. On the other hand, the correlation matrix reveals a strong correlation between the floristic components of the agroforests of the Mocksud and Carrière localities (0.95), Kinding ndé and Carrière (0.90) and between Mocksud and Nyokon (0.89).

3.2. Agroecology of Agroforests

The forest-savannah ecotones of Mbam and Inoubou give a very particular aspect to the agroforestry exploitations of the district of Makénéné in view of their complex plant formations. The relevant agroecology of its agroforestry systems is essentially due to the fact that they are all created either under savannah vegetation or in a transition zone (zone of forest invasion), which imprints on the architectural profiles of its farms particular. There are two main architectural profiles of agroforests in the area, namely as shown in Figure 6.

Table 3. Jaccard proximity index between agroforests of different localities.

Localities	Mocksouth	Career	Nyokon	Kinding djabi	Kinding ndé
Mocksud	0				
Carrière	0.548	0			
Nyokon	0.542	0.568	0		
Kinding djabi	0.596	**0.639**	**0.651**	0	
Kinding ndé	0.488	0.588	0.575	**0.605**	0

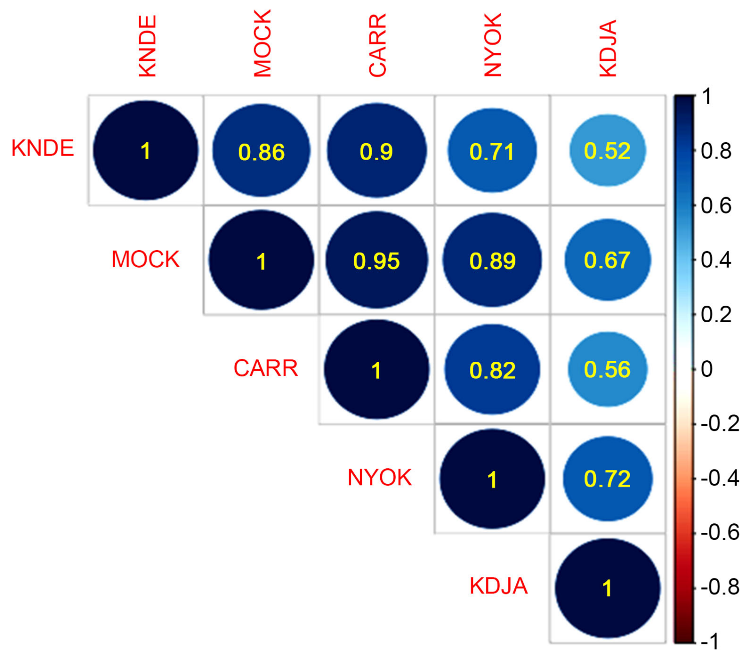
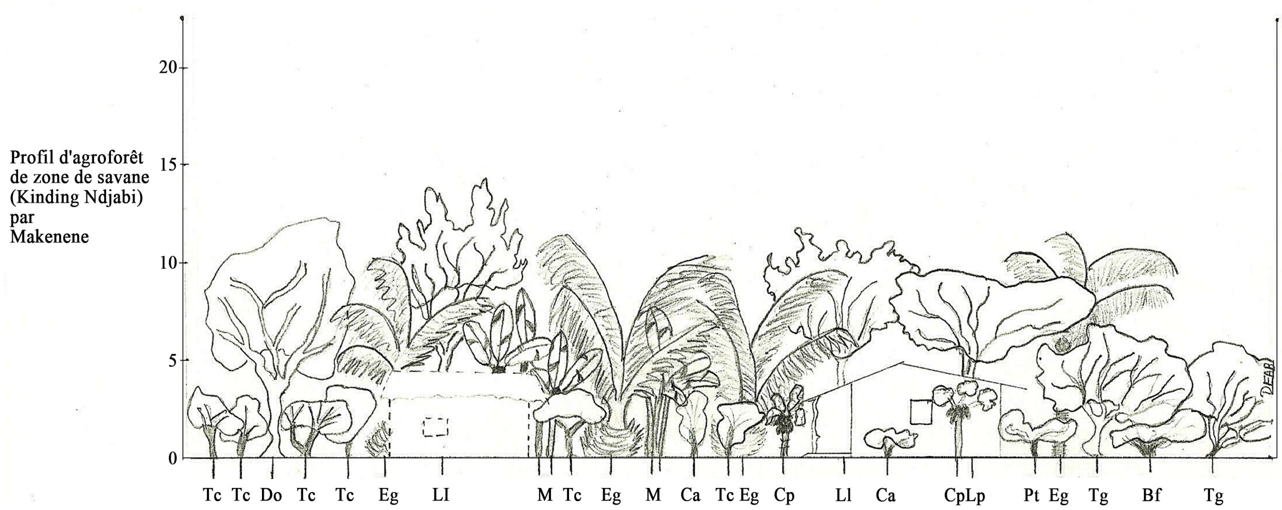


Figure 5. Correlation matrix between the agroforests of the different localities of the Makénéné area.

P1



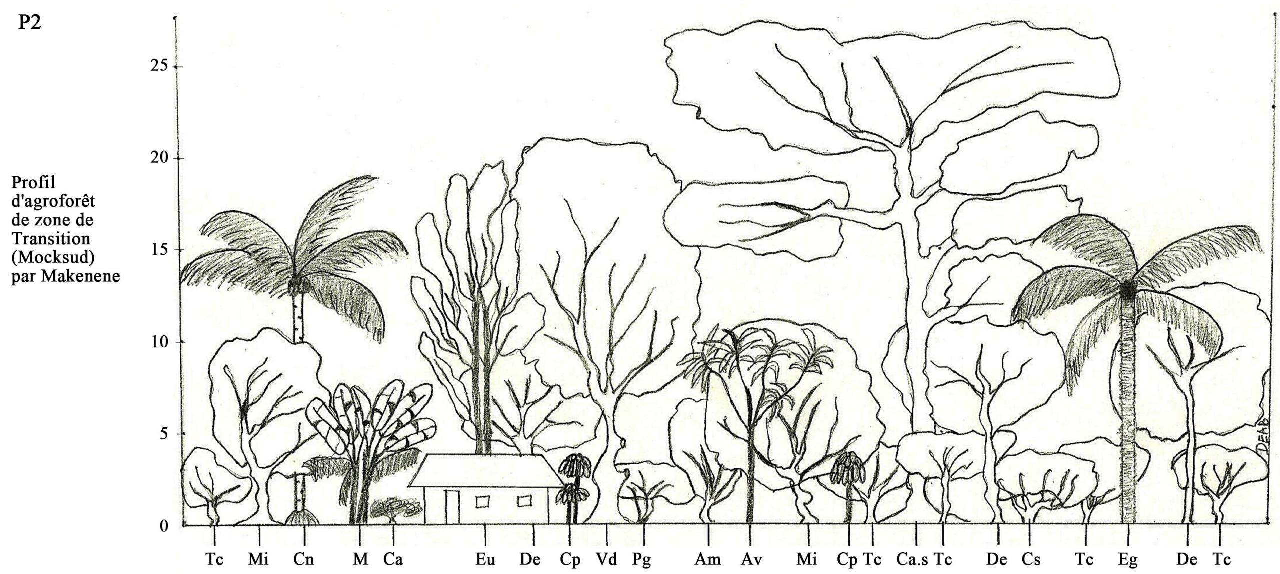


Figure 6. Architectural profiles (height in m) of agroforests in the forest-savannah mosaics of Makenéné. Legend: Theobroma cacao (Tc), Dacryodes edulis (De), Elaeis guineensis (Eg), Lophira lanceolata (Ll), Musa sp (M), Citrus aurantifolia (Ca), Carica papaya (Cp), (Lp) Piliostigma thonningii (Pt), Bridelia ferruginea (Bf), Terminalia glaucescens (Tg). Mangifera indica (Mi), Cocos nucifera (Cn), Eucalyptus sp. (Eu), Vitex doniana (Vd), Psidium guajava (Pg), Annona muricata (Am), Anthocleista vogelii (Av), Canarium schweinfurthii (Ca.s). Citrus sinensis (Cs). Pachira insignis (Pi), Citrus reticulata (Cr), Ricinodendron heudelotii (Re), Persea americana (Per), Coffea robusta (Caf), Albizia zygia (Az), Cola acuminata (Co.a), Fagara heitzii (Fe), Voacanga africana (Va).

- **multi-layered intensive home gardens** (Profile 1) having the singularity of having been "built" under savannah vegetation;
- **intensive multi-stratified agroforests** (Profile 2) under transition vegetation.

1) Pluristratified intensive home garden on savannah

Home gardens are characterized by different crops associated with tree components, mainly shrubs and fruit trees most often exotic or preserved premises. Here they are the genders Citrus, *Annona*, *Psidium*, *Voacanga* and *Vitex* who is the most encountered. This type very often presents an appearance of continuous crowns with little difference in the level of the crowns between the individuals which leads to a low penetration of light to the ground thus favoring numerous negative interactions on the one hand on the phenology of the undergrowth species, on the one hand elsewhere on regeneration (Jagoret et al., 2017; Flore et al., 2023). They are mainly found in the localities of Kinding djabi, Kinding ndé and Nyokon.

2) Intensive pluristratified agroforest under transition vegetation

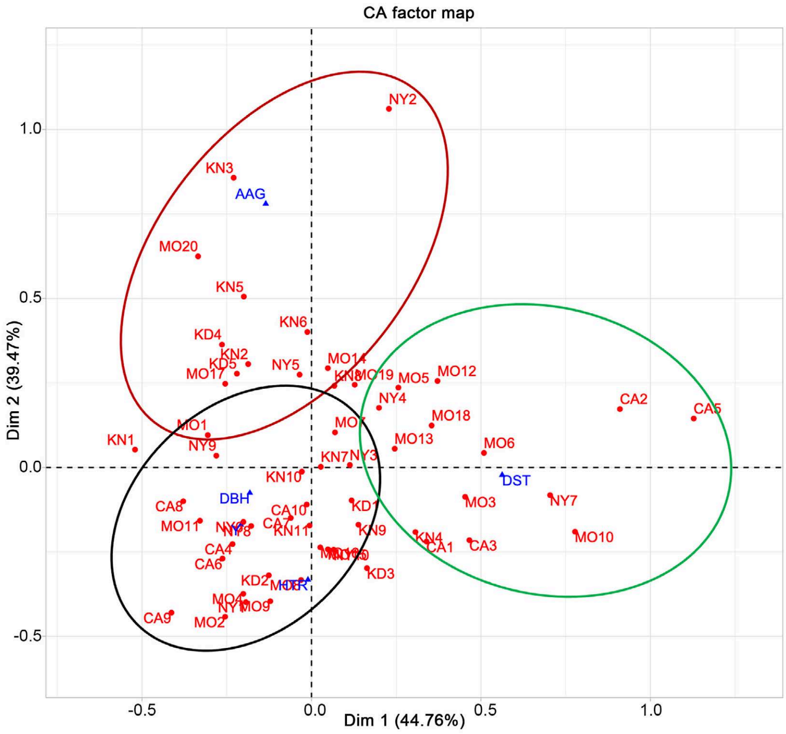
This type of agroforest is characterized by a very important ecological plasticity linked to their strong extension. They have the particularity of having been built in a forest-savannah contact zone, which often appears as a crumbling or fragmentation of the two plant formations with re-entrants from savannahs or open formations within the forest massifs. This situation explains the complex ambiguity of the presence of species typical of one or other of the formations in these agroforests. They meet on the outskirts of Makénéné in the villages Mocksud, Carrière. The genera "*Albizia*, *Terminalia* and *Bridelia*" are quite diversified and very characteristic of the flora of this forest-savannah ecotone, hence the additions of a second or even third level of tree height. The progressive installations of this type of exploitation combined with the conservation or intensive introduction of native or fruit species create on the one hand and ombrophile temperament of the exploitation reminiscent of that of the forest, on the other hand a local microclimate favorable to the installation of sciaphilous species characteristic of forests which in the long term leads to a real transgression of forests into savannahs (Sonké, 1998; Lemoupa, 2015).

3.3. Typology of Agroforests

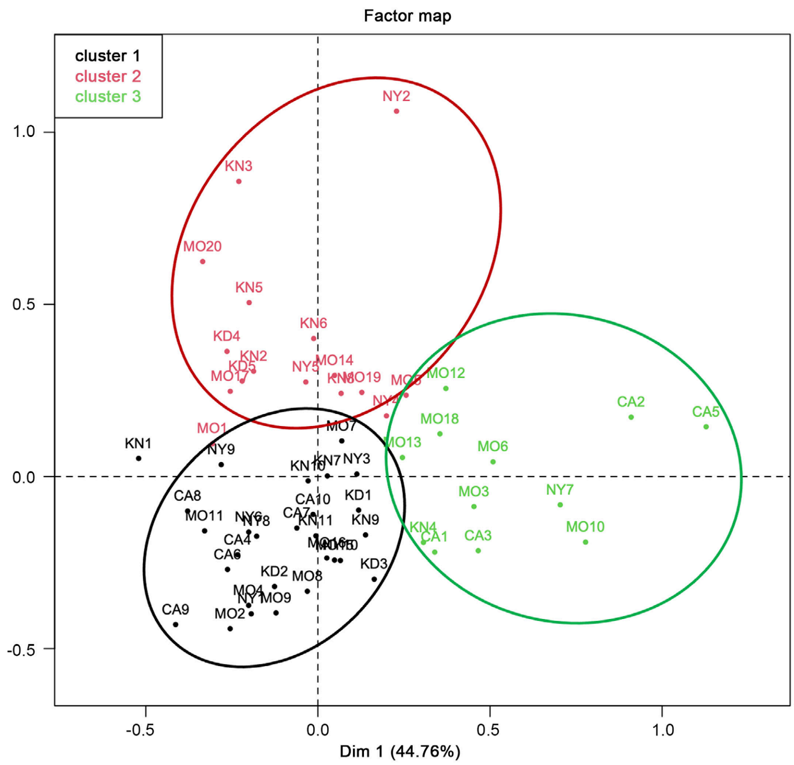
Three groups or "Cluster" of agroforests are distinguished according to the plan of dimensions D1-D2 of the PCA carried out on the 56 agroforests of the Makénéné zone. These two axes represent 84.23% of the distributional variance of agroforests and show the levels of correlations existing between the five structural parameters considered. It emerges from this correlation matrix that the woody biomass (Y) is strongly correlated with the diameter (DBH) of the trees (the two factors closest to the PCA) and to a lesser extent with their height (HTR) (a little closer to the Y and DBH factors). On the other hand, the age of agroforests (AAG) and the density of trees (DST) (the most distant factor in the PCA) are fairly independent of each other and of the three other correlated factors as shown in **Figure 7(a)**. These three parameters, which appear to be interrelated variables, therefore do not influence the age and density of agroforests. The inertia of the biomass factor (Y) on the distribution of these agroforests shows that these are the species *Mangifera indica* (829.5 t), *Dacryodes edulis* (438.2 t), *Ficus exasperata* (239.5 t), *Canarium schweinfurthii* (223.6 t), *Vitex doniana* (216.3 t), *Ricinodendron heudelotii* (147.6 t), *Persea americana* (95.6 t), *Cordia platythyrsa* (78.4 t), *Spondias cytherea* (71.7 t) and *Albizia zygia* (70.9 t) which have the biomasses and the stock most important carbon.

Cluster 1 (black colored circle) located on the negative side of axis 1 and 2 includes 28 agroforests or 50% as shown in **Figure 7(b)**. These agroforests are on the influence of the inertia of the factors Y, DBH and HTR and are mainly encountered in the villages Mocksud (28.57%), Carrière and Nyokon with 21.42% each. They are characterized by an average age of 13 years and an average tree height of 8.74 m. They have an average dbh of 60.81 cm, an average density of 36.9 feet and an average woody biomass of 83.05 t.

It is individualized above the D2 axis, Cluster 2 (red colored circle) composed of 16 agroforests (28.57%) and is concentrated around the correlated AAG parameters. Most of the agroforests of this Cluster are located particularly in the villages Mocksud (37.5%) and Kinding ndé (31.25%). They are characterized by agroforests with an average age of 40 years and have an average tree height of 6.85 m. The trees in these agroforests have an average dbh of 55.08 cm, an average density of 45.53 trees and an average woody biomass of 75.11 t.



(a)



(b)

Figure 7. Factorial map of the principal component analysis of agroforests. Correlation of factors and individuals (a); Inertia of individuals per group (b). Legend: Codes of agroforests in localities: MO = Mocksud, CA = Carrière, NY = Nyokon, KD = Kinding djabi and KN = Kinding ndé.

On the positive side of axis D1 is identified Cluster 3 (green circle) composed of 12 agroforests (21.42%). The latter are influenced by the inertia of the DST parameters, which turns out to be the most important factor inertia. The agroforests concerned in this Cluster are found in the Mocksud village (50%). They are 35 years old on average and an average tree height of 5.29 m. In these agroforests the trees have an average dbh of 42.37 cm, an average density of 61.41 trees and an average woody biomass of 54.03 t.

A more detailed analysis of the distribution of these agroecosystems by means of an ascending hierarchical classification (CAH) allowed us to highlight the strength of the links, namely the similarities and dissimilarities between them. Also to better appreciate the relief of the proximity tree of these agroecosystems according to their distances on two and three factorial planes at a truncation of 0.0375 by the "Full Link" aggregation method carried out on R software as shown in Figure 8.

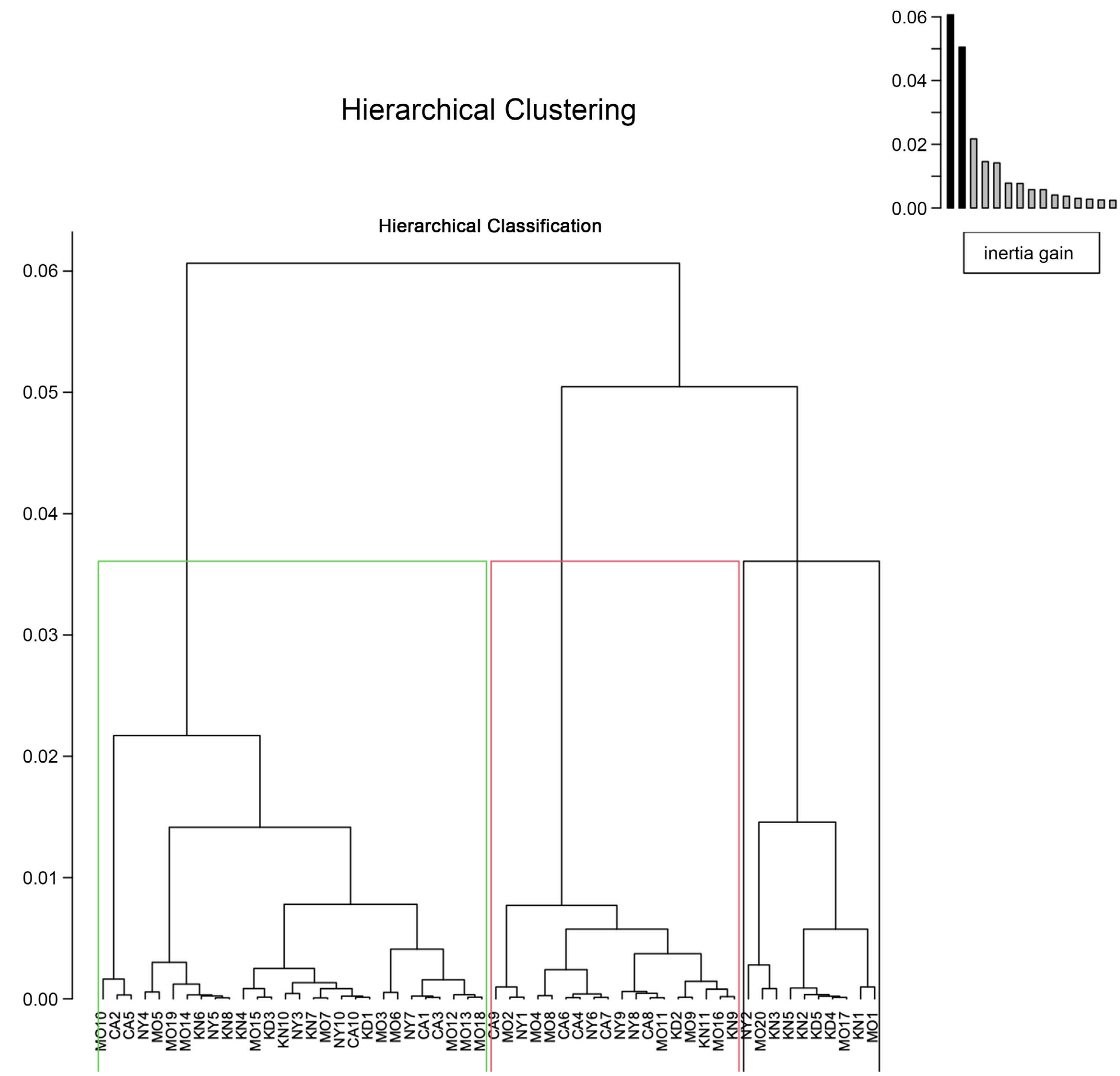


Figure 8. Dendrogram. Hierarchical classification of agroforests.

This dendrogram reveals from the right (of the y-axis) to the left three "Clusters":

- The first "Cluster 3" (green frame) is the one with the largest number of agroforests with strong biophysical similarity (*i.e.* 28 agroforests for a rate of 50%). They are mainly found in the Mocksud village (39.28%). This class is the most heterogeneous of the three (highest node value). These characteristic agroforests are the most distributed in the other "Clusters" 1 and 2 of the ACP. These are both intensive pluristratified home gardens and intensive pluristratified agroforests under transitional vegetation. AgroforestsCA10, NY8, KD2, CA7 and KN10 are the most characteristic of this class with distances (from the center of gravity of the class) of 0.13, 0.15, 0.19, 0.20 and 0 respectively, 20.
- The second "Cluster 2" (red frame) comes with a rate of 32.15% of agroforests with strong biophysical similarity, *i.e.* 18 agroforests. They are mainly encountered in the Mocksud (33.33%) and Carrière (27.77%) villages. This class is the most homogeneous (lowest node value). These are pluristratified intensive agroforests under transition vegetation and little under savannah, with the existence of several levels of stratification of the agroforestry vegetation. Agroforests KN6 (0.06), NY5 (0.12), KN5 (0.19), KD4 (0.19) and KD5 (0.19) are the most characteristic of this "Cluster 2".
- Finally, the third "Cluster 1" (black box) with only 10 agroforests having a strong biophysical similarity, *i.e.* 17.85%. The latter are found in the Kinding ndé (40%) and Mocksud (30%) villages, *i.e.* a total of 70%. This class is moderately heterogeneous (mean node value) and has the oldest agroforests (59 years) and therefore the largest woody biomass (87.33 t). These are more intensive multi-stratified home gardens and few intensive multi-stratified agroforests under transition vegetation. Agroforests MO6 (0.18), CA3 (0.30), MO3 (0.31), NY7 (0.31) and MO18 (0.32) are the most characteristic of this class.

3.4. Interactions and Agroecological Importance

A more complex analysis in the form of a classification map was carried out to better highlight the interactions between these agroecosystems. This heat map presents us with simultaneous dendrograms of the agroecosystems of the different localities and that of the richness of the types of species present according to the Jacquard proximity index (**Figure 9**). These two dendrograms (A and B) each present two groups of trees (1 and 2). Dendrogram A presents two trees or groups of species divided into three species types, namely: species of high-density socio-economic interest (tree 1: EIS1), species of low-density socio-economic interest (EIS2) and local species and pioneers of reforestation (ELPR) (tree 2). Dendrogram B presents two trees or groups of agroecosystems depending on the localities and reveals a strong proximity between the agroecosystems of the Kinding ndé (KNDE), Mocksud (MOCK) and Carrière (CARR) localities (tree B1), and between the agroecosystems localities Nyokon (NYOK) and Kinding djabi (KDJA)(tree B2).

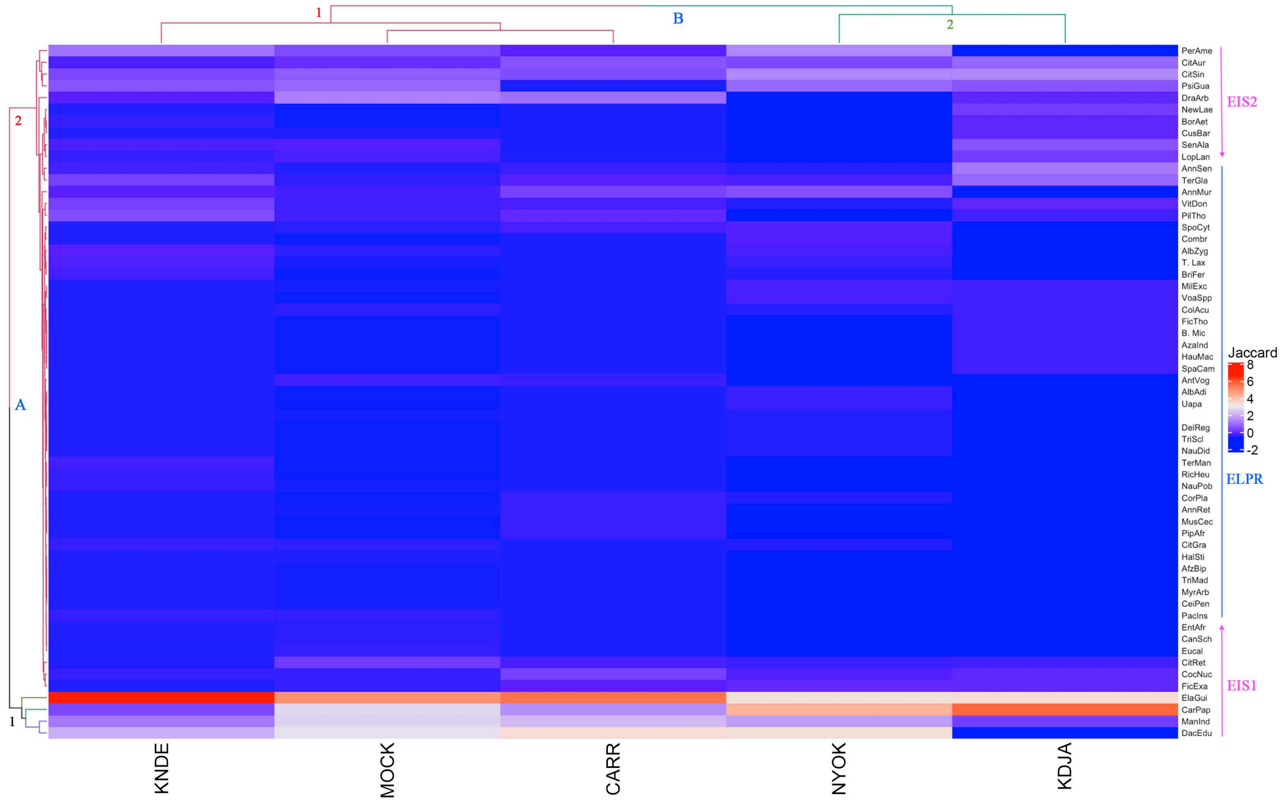


Figure 9. Classification map of agroecosystem dendrograms and the richness of the types of species present. Legend: EIS1: represents high density species of socio-economic interest; EIS2: represents species of socio-economic interest of medium density; ELPR: represents local species and pioneers of reforestation, Kinding ndé (KNDE), Mocksud (MOCK), Carrière (CARR), Nyokon (NYOK), Kinding djabi (KDJA).

The high-density species of socio-economic interest (EIS1) are *Dacryodes edulis*, *Mangifera indica*, *Carica papaya*, *Elaeis guineensis*, *Ficus exasperata* and *Cocos nucifera*. On the other hand, *Persea americana*, *Citrus aurantifolia*, *Citrus sinensis*, *Psidium guajava*, *Dracaena arborea*, *Newbouldia laevis*, *Borassus aethiopum*, *Cussonia barterie* and *Senna alata* are the low-density species of socio-economic interest (EIS2). The third type of species is made up of fruit and local shrubs associated with pioneer species of reforestation, namely: *Annona reticulata*, *Annona muricata*, *Voacanga spp*, *Vitex doniana*, *Piliostigma thonningii*, *Myrianthus arboreus*, *Anthocleista vogelii*, *Ficus exasperata*, *Albizia zygia*, *Milicia excelsa*, *Musanga cecropioides*, *Entada africana*, *Terminalia glaucescens*, *Terminalia laxiflora*, *Bridelia ferruginea Bridelia micrantha Albizia adianthifolia* and *Lophira lanceolata*. This floristic structuring of agroforests creates an ecological atmosphere favorable to the installation of indigenous or native species of the dense forest, which promotes reforestation mechanisms. The distribution of the color bands reveals that 68% of the agroforests in the Nyokon, Carrière and Mocksud villages are the most effective in terms of conserving woody diversity in the area with 72.87% of average architectural profile with shaded canopy. On the other hand, the agroforests of the Kinding ndé and Nyokon villages are more efficient in the reforestation processes of the adjacent savannahs in this

Makénéné ecotone given their potential as pioneer species of reforestation.

4. Discussion

4.1. Age and Area of Agroforests

The young age group turns out to be very significant compared to the other three age groups. These results are in agreement with those of the works of Temgoua et al. (2018, 2019) and Etchike et al. (2020) respectively carried out in the Department of Lom and Djerem in the East region, the Arrondissements of Loum in the neighboring Littoral and that of Ndikiniméki in central Cameroon. Etchike (2010) and Mapongmetsem et al. (2016) obtained opposite results in the district of Bafia where mature agroforests over 45 years old dominate the agrarian landscape with 40.92%. This difference can be explained by the financial, material and human capacities (manpower, ingenuity) of the operators to initiate or not the renewal of their operations. Also due to the rural exodus of local youth who are increasingly educated in large cities. These young people do not stay long in rural areas to help parents who are already elderly in renewing and maintaining these farms. Regarding the area of agroforests in the area, there is a clear predominance of those with more than 1500 m^2 with 33% followed by the class between 500 and 1000 m^2 with 27.8%. In third place are agroforests with a rate of 20.6% for areas less than 500 m^2. Class 1001 to 1500 m^2 agroforests are the least represented with 11.2%. However, it is important to note the non-negligible rate (7.4%) of farms of unknown surface area whose limits of their operator. The analysis of variance does not show a significant difference (0.067 > 0.05) between the 4 slices of agroforest area (columns). These results are in agreement with those reported by Temgoua et al. (2018) and Etchike et al. (2020) in the districts of Loum and Ndikiniméki. The average area of these agroforestry systems is estimated at 3.5 ha by Temgoua et al. (2018). The purchasing power and the enthusiasm of farmers to own increasingly large plots explain these results, questions for them to increase their annual and long-term income. These farms are either nested or in continuity with the natural forests near the houses, or located further in the bush (Jiofack et al., 2013; Etchike et al., 2020). With the growing demography and the high rate of urbanization in the city of Makénéné, it can be seen that the further these villages and farms are from the urban center, the older these agroforests are and their floristic composition is richer, denser and more diversified in large local trees preserved mostly from the old forest.

4.2. Stratification of Agroforests

This distribution quite irregular or erratic individuals in these diameter classes demonstrates the complexity of the floristic mosaic of the agroforests of this forest-savannah ecotone of the Makénéné zone. This observation corroborates those made by Lemoupa (2015) and (Flore et al., 2023) respectively on the importance of living hedges in the dynamics of forest-savannah contacts in Yambassa country in the region of central Cameroon and structure of robusta coffee agroforests (*Coffea canephora var. robusta*) in the Moungo production basin in coastal Cameroon. The low rate of basal area in these agroecosystems of the Makénéné zone is explained by the high number of small-diameter individuals of both introduced fruit species and conserved forest species. The genus *Citrus*, *Annona* and *Carica* are the most represented and dominate the shrub layer as shown by the work of Mapongmetsem et al. (2016) and Etchike et al. (2017) respectively in the agroecosystems of Bafia and Makénéné in central Cameroon. Grillot and Asaël (2015) showed that in a pine forest as soon as $S < 18$ m^2/ha, the light on the ground becomes sufficient to initiate natural regeneration. This ecological indicator that is basal area is correlated with tree cover and reflects thus the degree of competition within the population, what constitutes an indirect measure of the lighting conditions on the ground. It is a descriptor of the different stages of development of trees of these agroecosystems.

The stratification of these agroforests reveals that the species emerging from these farms have a height greater than 10 m. The progressive occupation of savannah plots by food and perennial crops (palm groves, banana plantations, pineapple plantations, coffee trees, cocoa trees) is gradually causing the savannahs to be colonized by the forest, crops always associated with fruit trees introduced by man to create groves and forest islands forming firebreaks and corridors for the dispersal of forest species. This result corroborates that of Lemoupa (2015) in the forest-savannah ecotones of central Cameroon. Indeed, the cessation of fires leads to an expansion of dense forest and/or agroforests in the savannah in the medium and long term, which explains the importance of this agroforestry stratification in contributing to the current trend of forest transgression on savannas (Jacquin, 2010). Ouédraogo (2009, 2010) and Noiha Noumi et al. (2015) also affirm these high densities of species in these same classes, respectively in savanna and forest stands from Senegal, Burkina Faso and in cocoa-based agroforests in Pendiki in the department of Sanaga Maritime, Littoral region (Cameroon).

4.3. Gradient of Complexity Agroforests

Gradient evaluation complexity of agroforests shows a clear predominance (58.4%) of "Simple" type agroforests and a canopy cover rate of 77.4% for the "Shaded" type. This situation therefore creates favorable conditions for the establishment of pioneer species of the dense forest in the savannah, as also confirmed by the work of Lemoupa (2015) in "Yambassa" country still in Mbam and Inoubou. Nasi et al. (2008) already pointed out that deforestation in a given country is a reduction in canopy cover below the threshold defined by that country. The proximity index of Jaccard reveals rates above 50% between the agroforests of the area. This suggests that the agroforests in all these localities share more than halfof plant species. These results do not corroborate those of Temgoua et al. (2019, 2020) in the cocoa agroforestry systems of Loum in the Littoral and Kekem, in Haut-Nkam in western Cameroon with indices of proximity of Jaccard not exceeding 0.50. This difference is mainly due to the structure of the farms and the technical itinerary used by the farmers (divergence of appreciation and selection of trees). Moreover, the great variability in the floristic composition of the dense evergreen Atlantic forests of the Littoral and the high-altitude vegetation of the western region compared to the semi-deciduous forests that characterize the forest-savannah ecotones of central Cameroon (Sonké, 2004).

4.4. Agroecology of Agroforests

On the agroecological level, two main architectural profiles characterize the agroforests of Makénéné, namely; multi-stratified intensive home gardens and multi-stratified intensive agroforests. The first profile has the particularity of having been "built" under savannah vegetation and the second is an adapted technical itinerary under transition vegetation (with a strong forest physiognomy). These intensive profiles are also confirmed in the work of Flore et al. (2023) in robusta coffee agroforests (*Coffea canephora* var. *robusta*) in the Moungo production basin (Melong, Nkongsamba, Malantouen and Ayos). Our findings are similar to those of these authors for whom the large trees are also found in the high strata of 12 to 20 m and >20 m, do not prevent the penetration of light into the lower strata. Unlike them, these are the genera *Musa* and *Elaeis*, which present high densities in the sites of Nkongsamba and Melong. These models of stable, intensive, multi-stratified and permanent production systems located around houses and where the emphasis is placed on the domestic species according to the socio-economic objectives of the farmer are found in the tropical world, ranging from Sahelian shrub savannahs to forests. passing through the Sudano-Guinean savannahs. These systems aim to use the immediate surroundings of homes to continually produce food for family consumption (Mapongmetsem et al., 2011, 2016; Etchike et al., 2017, 2020).

4.5. Typology of Agroforests

Three groups or "Clusters" of agroforests and three species types can be distinguished according to the analyzes of the PCA, the CAH and the heat map carried out on the 56 agroforests in the Makénéné zone. These results do not corroborate those of Jagoret et al. (2008, 2009) and Etchike (2010) who worked respectively on the diversity of cocoa farming systems and on the agroforests of Bafia in central Cameroon. These authors claim to have respectively obtained five classes of farms according to five variables considered (among which yield, the age of the cocoa farm and the age of the operator), and four types of agroforests in the peri-urban area of the city of Bafia according to six factors. Jagoret et al. (2008, 2009) show that the yield of cocoa plantations is strongly correlated with the level of labor intensification and the level of input intensification of the farmers' technical itinerary. This difference in results for constructing the typology of these agroforests is explained by the difference in the parameters considered and the truncation index (cutting of the tree structure) chosen to determine the classes or "Clusters". Noiha Noumi et al. (2017a, 2017b) carried out in the agroecosystems of Yagoua, Ngong, Ngaoundéré and Mbandjock a factorial analysis of correspondences rather on the distribution of agroforestry species according to their carbon stock potential (single factor considered). Of the four groups obtained, *Eucalyptus camaldulensis*, *Daniellia oliveri*, *Terminalia albida*, *Balanites aegyptiaca*, *Terminalia schimperiana*, *Burkea africana*, *Azadirachta indica*, *Lannea schimperi*, *Gardenia aqualla*, *Acacia sieberiana*, *Hexalobus monopetalus* and *Combretum adenogonium* were the most represented species in terms of potential of carbon stock. Zapfack et al. (2016) also obtained four floristic groups in ACP distributed under the influence of eight agroecological factors in the agroecosystems of Mengomo in the district of Ambam, Department of the Ntem Valley in southern Cameroon. Mapongmetsem et al. (2016) on the other hand obtained four classes of agroforests according to the HAC according to six variables considered in the agroforests of Bafia in central Cameroon, and whose classification was carried out according to the binary Bray-Curtis dissimilarity index.

All this work and results obtained increasingly show the importance and relevance of modeling and simulation of plant architecture, the structure and diversity of plant covers, landscapes and tropical agroecosystems. They thus contribute to the emergence of bioinformatics and biomathematics of phytodiversity which is placed in a perspective of sustainable development of territories. The purpose of our work aims to contribute to the construction of models for understanding complex agroforestry systems in order to arrive at political orientations for the management of resources, the environment and the integrated management of territories via the policies of REDD++ mechanisms. . This progressive spatialization of phytodiversity will allow us to better understand the dynamics, interactions and consequences in terms of policy support for the sustainable management of tropical territories.

5. Conclusion

The agroforests of Makénéné present a varied structure ranging from the simplest to the most complex structures. They are mainly young with generally small surface areas. The horizontal structure reveals that the largest diameter classes are those of [20 - 30 cm[and [10 - 20 cm[with a very low rate of basal area. Their stratification reveals that they are in full recovery and constitute an important factor of forest transgression on the savannahs in the ecotones of Mbam and Inoubou. The gradual occupation of savannah plots by agroecosystems is gradually causing the savannahs to be colonized by the forest given its richness in pioneer species. The complexity gradient of these agro-ecosystems shows that the “Simple” and “Shaded” types characterize these farms, which in the long run creates favorable conditions for the establishment of pioneer species in reforestation. of their plant species and present two main characteristic profiles of the agrarian landscapes of Makénéné. Three agroforest “clusters” and three species types are distinguished around five agroecological parameters considered with a strong correlation of woody biomass and tree diameter and to a lesser extent the height of these trees. We note that the age of these agroforests and their floristic density do not influence the woody biomass (Y), diameter (DBH) and height (HTR) of the trees. The agroforests in the Nyokon, Carrière and Mocksud villages are the most effective in terms of conserving woody diversity while the agroforests of the Kinding ndé and Nyokon villages are more efficient in the reforestation processes. These different indicators, which are basal area, architectural profiles and the typology of associated species, could be considered as effective and quantifiable tools not only for the certification of numerous cash crops such as cocoa and coffee, but also in the mechanisms of reforestation of the forest-savannah ecotones of this area of central Cameroon. In short, all this information will make it possible to promote this local knowledge scientifically and in the development of various programs and drafting of technical notes.

Acknowledgements

The authors thank the Laboratory of Biodiversity and Sustainable Development of the University of Ngaoundéré as well as the Laboratory of Applied Botany of the University of Dschang for their contributions to the realization of several activities of this work, the specific bibliography and the exploitation of the data collected. We would also like to thank the anonymous reviewers for their edifying comments which have improved the quality of this manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Abada Mbolo, M. M., Zekeng, J. C., Mala, W. A., Fobane, J. L., Chimi, D. C., Nyako, M. C., & Tamandjong, V. (2016). The Role of Cocoa Agroforestry in Conserving Forest Tree Diversity in Central Region of Cameroon. *Agroforestry System, 90,* 577-590. https://doi.org/10.1007/s10457-016-9945-8

Agossou, S. (2008). *Adaptation to Climate Change: Perceptions, Local Knowledge and Adaptation Strategies of Producers in the Communes of Glazoué and Savalou in Central Benin*. Thesis, The University of Abomey-Calavi, 173 p.

Ballo, A., Traoré, S. S., Coulibaly, B., Diakité, C. H., Diawara, M., & Traoré, A. (2016). Anthropogenic Pressures and Dynamics of Land Occupation in the Ziguéna Region, Cotton-Growing Area of Mali. *European Scientific Journal, 12,* 90-99. https://doi.org/10.19044/esj.2016.v12n5p90

Brown, S. (1997). *Estimating Biomass and Biomass Change of Tropical Forests: A Primer.* FAO Forestry Paper, FAO, 134 p.

Ciza, S. K., Milwa, J. F., Malekezi, A. C., Gond, V., & Bosela, F. B. (2015). Identification of Drivers of Deforestation in the Isangi Region. Democratic Republic of Congo. *Woods and Forests of the Tropics, 324,* 29-38. https://doi.org/10.19182/bft2015.324.a31264

Eboutou, L. Y. (2009). *Financial Profitability of Cocoa-Based Agroforests Enriched by*

Domestic Trees in the Central Production Basin, Cameroon. MSc Thesis, University of Dschang.

Etchike, D. A. B. (2010). Biophysical Characterization of Agroforests in the Peri-Urban Area of Bafia (Centre Cameroon). Master's Thesis, University of Ngaoundéré, 68 p.

Etchike, D. A. B., Mapongmetsem, P. M., & Ngassoum, M. B. (2017). Phytodiversity and Carbon Stock in the Agroforests of Mbam and Noubou in Cameroon. *Cameroon Forum for Biological Sciences, 11,* 17.

Etchike, D. A. B., Ngassoum, M. B., & Mapongmetsem, P. M. (2020). Potentialities of Agroforests against Climate Change in the Forest-Savannah Ecotone Zone of Cameroon. *European Scientific Journal, ESJ, 16,* 319.

FAO (2010). *Impact of the Global Forest Industry on Atmospheric Greenhouse Gases*. Study: Forests 159, 159 p.

FAO (2014). *Methodology Proposed for the Analysis of the Agents and Causes of Deforestation in the Component 4 Pilot Sites of the FFEM Project* (p. 365). Working Paper.

FAO (2016). *Global Forest Resource Assessment 2015. How Are the World's Forests Changing?* (2nd ed.). Food and Agricultural Organization of the United Nations.

Flore, N., Cédric, C., Roger, K., Félicité, T., Louise, A., Martin, T., & Emmanuel, B. (2023). Plant Biodiversity and Structure of Robusta Coffee (*Coffea canephora* var. *robusta*) Agroforests in Cameroon. *Open Journal of Forestry, 13,* 225-241. https://doi.org/10.4236/ojf.2023.132014

Grillot, M. F. & Asaël, S. (2015). *Trees and Forests: Basal Surface Area: A Very Down-to-Earth Measurement*. Zimmer, Forestry Expertise, 5p.

Guillet, B., Achoundong, G., Bonvallot, J., Desjardins, T., Happi, Y., Kamgang, B.V., Mariotti, A., Namur, C., & Schwartz, D. (1996). The Forest-Savanna Boundaries in West Central Africa: Structure and Recent Dynamics of the Forest. *Ecofit Symposium Long-Term Dynamics of Intertropical Forest Ecosystems* (pp. 145-147). ORSTOM-CNRS.

IPCC (2006). *Guidance for the National Inventory of Greenhouse Gases Agriculture, Forestry and Other Land Use*. Institute for Global Environmental Strategies, 6 p.

IPCC (2014). Summary for Policymakers. In C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, & R. C. Genova (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability*. Cambridge University Press.

IUCN-PC (2013). *How to Approach REDD+ in Cameroon: Context, Challenges and Options for a National Strategy*. IUCN, 103 p.

Jacquin, A. (2010). *Dynamique de la végétation des savanes en lien avec l'usage des feux à Madagascar*. Thèse de Doctorat, Université de Toulouse, 146 p.

Jagoret, P., Bouambi, E., Menimo, T., Irénée, Domkam, I., & Batomen, F. (2008). Analysis of the Diversity of Practice Systems in Cocoa Farming. Case of the Cameroon Center. *Biotechnology, Agronomy and Society and Environment, 12,* 367-377.

Jagoret, P., Michel-Dounias, I., & Malézieux, E. (2011). Long-Term Dynamics of Cocoa Agroforests: A Case Study in Central Cameroon. *Agroforestry Systems, 81,* 267-278. https://doi.org/10.1007/s10457-010-9368-x

Jagoret, P., Michel-Dounias, I., Snoeck, D., Ngnogué, T., & Malézieux, E. (2012). Afforestation of Savannah with Cocoa Agroforestry Systems: A Small-Farmer Innovation in Central Cameroon. *Agroforestry Systems, 86,* 493-504. https://doi.org/10.1007/s10457-012-9513-9

Jagoret, P., Ngogue, H. T., Bouambi, E., & Battini J. (2009). Diversification of Cocoa-Based Farms in Central Cameroon: Myth or Reality. *Biotechnology, Agronomy and Society and Environment, 13,* 271-280.

Jagoret, P., Snoeck, D., Bouambi, E., Todem Ngnogue, H., Nyassé, S. & Saj, S. (2017). Key Management Practices to Maintain the Effectiveness of Cocoa Agroforestry Systems in the Very Long Term: Evidence Provided by Perennial Plantations in Central Cameroon. *Agroforestry Systems,* 1-15.

Jiofack, T., Guedje, N. M., Tchoundjeu, Z., Fokunang, C., Lejoly, J., & Kemeuze, V. (2013). Agroforestry Typology of Some Cocoa Based Agroforests in the Mbam and Inoubou Division: The Importance for Local Population Livelihoods*. Journal of Ecology and the Natural Environment, 5,* 378-386. https://doi.org/10.5897/JENE12.085

Lasco, R. D., Delfino, R. J. P., & Espaldon, M. L. O. (2014). Agroforestry Systems: Helping Smallholders Adapt to Climate Risks While Mitigating Climate Change. *Wiley Interdisciplinary Reviews: Climate Change, 5,* 825-833. https://doi.org/10.1002/wcc.301

Lebrun, J. P., & Stork, A. L. (1991, 1992, 1995, 1997). *Enumeration of Flowering Plants in Tropical Africa, 4 Vols*. Conservatory and Botanical Garden of the city of Geneva.

Lemoupa, F. C. (2015). *Hedgerows in the Dynamics of Forest-Savanna Contacts in Yambassa, Central Region of Cameroon*. Master's Thesis, University of Yaoundé I, 135 p.

Locatelli, B., Kanninen, M., Brockhaus, M., Colfer, C. J. P., Murdiyarso, D., & Santoso, H. (2008). *Facing an Uncertain Future: How Forests and People Can Adapt to Climate Change*. Insights into CIFOR Forest No. 5, Bogor.

Manfo, D. A., Tchindjang, M., & Youta, H. J. (2015). Agroforestry Systems and Biodiversity Conservation in a Heavily Anthropized Environment: The Case of Obala. *Scientific and Technical Journal Forest and Environment of the Congo Basin, 5,* 22-34.

Mapongmetsem, P. M., Etchiké, D., & Ngassoum, M. B. (2016). Conservation and Enhancement of Biodiversity in the Agroforests of the Peri-Urban Area of the City of Bafia (Central Region in Cameroon)*. Scientific and Technical Review Forest and Environment of the Congo Basin, 6,* 60-69.s

Mapongmetsem, P. M., Nkongmeneck, A. B., Rongoumi, G., Dongock, N. D., & Dongmo, B. (2011). Impact of Land Use Systems on the Conservation of *Vitellaria paradoxa* Gaertn. f. (*Sapotaceae*) in the Sudano-Guinean Savanna Region. *International Journal of Environmental Studies, 68,* 51-72. https://doi.org/10.1080/00207233.2011.587259

MINFOF (2014). *Bases de données du Système Informatique de Gestion d'Informations Forestières.* SIGIF.

MINFOF (2016). *Secteur forestier et faunique du Cameroun: Faits et chiffres*. MINFOF, 47 p.

Nasi, R., Mayaux, P., Devers, D., Bayol, N., Eba'a Atyi, R., Mugnier, A., Cassagne, B., Billand, A., & Sonwa, D. (2008). *An Overview of Carbon Stocks and Their Variations in the Congo Basin Forests*. Sourcebook (GOFC-GOLD, 2008).

Ngomanda, A., Laurier, N., Lebamba, J., Moundounga, Q., Gomat, H., Mankou, G., Loumeto, J., Midoko, D., Ditsouga, F., Koumba, R., Henga, K., Okouyi, C., Nyangadouma, R., Lépengué, N., Mbatchi, B., & Picard, N. (2014). Site-Specific versus Pantropical Allometric Equations: Which Option to Estimate the Biomass of a Moist Central African Forest? *Forest Ecology and Management, 312,* 1-9. https://doi.org/10.1016/j.foreco.2013.10.029

Ngon, O. A. L. (2016). *Potentiel touristique et stratégies de développement socio-économique dans la commune de Makénéné*. Mémoire pour l'obtention du Diplôme de Professeur de l'Enseignement Secondaire Deuxième Grade (DIPES II), 129 p.

Ngueguim, J. R., Zapfack, L., Noiha, N. V., Onana, D., Betti, J. L., & Riera, B. (2015).

Expériences sylvicoles au Cameroun: Croissance, mortalité et adaptabilité des espèces de bois d'œuvre dans la station forestière de Mangombé (1964-2010). *Journal International des Sciences Biologiques et Chimiques, 9,* 2789-2807. https://doi.org/10.4314/ijbcs.v9i6.22

Noiha Noumi, V., Awe Djongmo, V., Nyeck, B., Tabue Mbobda, R. B., & Zapfack, L. (2017b). Vegetation Structure, Carbon Sequestration Potential and Species Conservation in Four Agroforestry Systems in Cameroon (Tropical Africa). *Acta Botanica Brasilica, 32,* 212-221. https://doi.org/10.1590/0102-33062017abb0279

Noiha Noumi, V., Zapfack, L., & Tabue Mbobda, L. F. (2015). Biodiversity Management and Plant Dynamics in a Cocoa Agroforests (Cameroon). *International Journal of Plant and Soil Science, 6,* 101-108. https://doi.org/10.9734/IJPSS/2015/10347

Noiha Noumi, V., Zapfack, L., Awe Djongmo, V., Witanou, N., Nyeck, B., Ngossomo, J. D., Hamadou, M. R., Chimi, C. D., & Tabue Mbobda, R. B. (2017a). Floristic Structure and Sequestration Potential of Cashew Agroecosystems in Africa: A Case Study from Cameroon. *Journal of Sustainable Forestry, 36,* 277-288. https://doi.org/10.1080/10549811.2017.1296776

Ogouwalé, E. (2006). *Climate Change in Southern and Central Benin: Indicators, Scenarios and Prospects for Food Security.* Doctoral Thesis, LECREDE/FLASH/EDP/UAC, 302 p.

Ouédraogo, I. (2010). *Functions and Services of the Phytocenoses of the Pama-Nord Partial Faunal Reserve and the Riparian Zones.* DEA Thesis, University of Ouagadougou, 50 p.

Ouédraogo, O. (2009). *Phytosociology, Dynamics and Productivity of Vegetation in Arly National Park (South-Eastern Burkina Faso).* Doctoral Thesis, Ouagadougou University, 132 p.

Plan Communal de Développement de Makénéné (PCDM) (2011). *Plan communal de développement de Makénéné.* Réalisé avec l'appui du Programme National de Développement (PNDP), 174 p.

Saj, S., Durot, C., Mvondo-Sakouma, K., Tayo Gamo, K., & Avana Tientcheu, M. L. (2017). Contribution of Companion Trees to Long-Term Tree Conservation, Carbon Storage and Agroforest Sustainability: A Functional Analysis of the Diversity in Cocoa Plantations of Central Cameroon. *International Journal of Agricultural Sustainability, 15,* 282-302. https://doi.org/10.1080/14735903.2017.1311764

Saj, S., Jagoret, P., & Ngogue, H. T. (2013). Carbon Storage and Density Dynamics of Associated Trees in Three Contrasting *Theobroma cacao* Agroforests of Central Cameroon. *Agroforestry Systems, 87,* 1309-1320. https://doi.org/10.1007/s10457-013-9639-4

Sénécal, G., & Saint-Laurent, D. (2004). The Urban Forest, a Vulnerable Ecosystem, a Forgotten Resource and an Urban Issue. In M. Boisvert (Ed.), *The Urban, an Environmental Issue* (pp. 9-27). Presses de the University of Quebec.

Somarriba, E., Cerda, R., Orozco, L., Cifuences, M., Davila, H., Espin, T. et al. (2013). Carbon Stocks and Cocoa Yields in Agroforestry Systems of Central America. *Agriculture, Ecosystems and Environment, 173,* 46-57. https://doi.org/10.1016/j.agee.2013.04.013

Sonké, B. (1998). *Floristic and Structural Studies of the Forests of the Dja Faunal Reserve (Cameroon).* Doctoral Thesis, Free University of Brussels, 267p.

Sonké, B. (2004). *Biological Environment of the Nkamouna Site; Biodiversity—Flora.* Environmental Impact Study of the GEOVIC Mining Project in Nkamouna. Rainbow Environment Consult.

Tayo, G. K. Y. (2014). *Dynamics of Woody Biodiversity and Carbon Stocks in Co-*

coa-Based Agroforestry Systems in Central Cameroon: The Case of Ngomedzap. Professional Master in Forestry, FASA, 77 p.

Temgoua, L. F., Ajonina, G., & Woyu, H. B. (2018). Land Use and Land Cover Change Analysis in Ajei Upland Waterched Community Forest, North West Region, Cameroon. *Journal of Geoscience and Environment Protection, 6,* 83-99. https://doi.org/10.4236/gep.2018.69007

Temgoua, L. F., Dong Etchike, A. B., Tumenta, P., Solefack, M. C. M., & Nkwelle, J. (2020). Woody Species Diversity Conservation and Carbon Sequestration Potential of Coffee Agroforestry Systems in the Western Region of Cameroon. *Journal of Horticulture and Forestry, 12,* 35-48. https://doi.org/10.5897/JHF2020.0627

Temgoua, L. F., Momo, S. M. C., & Boucheké, R. K. (2019). Floristic Diversity of Woody Cocoa Agroforestry Systems in Coastal Cameroon: Case of the Loum District. *European Scientific Journal, 15,* 62-83.

Tsoumou, B. R., Lumandé, K. J., Kampé, J. P., & Nzila, J. D. (2016). Estimation of the Amount of Carbon Sequestered by the Dimonika Model Forest (South-West of the Republic of Congo). *Scientific and Technical Review Forests and Environment of the Congo Basin (RIFFEAC), 6,* 39-45.

White, L., & Edwards, A. (2001). *African Rainforest Conservation: Methods and Research*. Wildlife Conservation Society, 444 p.

Winrock (2005). *Guide to Measuring and Monitoring Carbon in Forests and Grasslands*. Winrock International.

Zapfack, L., Djomo, C. C., Noumi, V. N., Zekeng, J. C., Daghela, G. R. M., & Mbobda, R. B. T. (2016). Correlation between Associated Trees, Cocoa Trees and Carbon Stocks Potential in Cocoa Agroforests of Southern Cameroon. *Sustainability in Environment, 1,* 71-84. https://doi.org/10.22158/se.v1n2p71

Zapfack, L., Noiha, N. V., Dziedjou, K. P. J., Zemagho, L., & Fomete, N. T. (2013). Deforestation and Carbon Stocks in the Surroundings of Lobéké National Parc (Cameroon) in Congo Basin. *Environment and Natural Resources Research, 3,* 78-86. https://doi.org/10.5539/enrr.v3n2p78