ORIGINAL RESEARCH ARTICLE

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Woody plant diversity and carbon sequestration in fruit agroforestry systems in the Guinean high savannah zone of Adamawa, Cameroon

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ABSTRACT

Fruit agroforestry systems are important not only for improving human living conditions but also for natural resource management. The objective of this study was to assess the woody plant diversity and carbon stocks of fruit agroforestry systems in the Adamawa region. The methodological approach was based on floristic inventories. For this, plots measuring 50 metres long by 20 metres wide were explored. A total of 250 plots were set up, at a rate of 50 plots per division. Dendrometric parameters such as diameter at breast height, crown diameter, and tree height were measured. Carbon stocks were estimated using allometric equations. The study found that a total of 2986 individuals, grouped into 17 species, 14 genera, and 11 families, were recorded. The density of fruit trees varies from 60.8 stems/ha in the Faro-et-Deo division to 227 stems/ha in the Vina division. Fruit agrosystems show low diversity overall, but with higher diversity in Mayo-Banyo (H' = 0.81 bits). *M. indica* (IVIE=163.5%), *T. cacao* (IVIE=49.61%) and *P. americana* (IVIE=48.71%) are the most important species. The most important families are Anacardiaceae (FIVI=160.88%), Rutaceae (FIVI=68.43%) and Lauraceae (FIVI=48.43%). The vegetation stands are distributed in an L-shape and bell-shaped pattern. The carbon sequestration potential is 209.13±114.35 tCO$_2$eq/ha and the economic value is 2075043.42 CFA francs. Thus, fruit agrosystems are not very diverse but contribute to carbon storage in the fight against climate change. It would be necessary to encourage the establishment of fruit agrosystems to resolve environmental problems in Cameroon.

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INTRODUCTION

The Guinean high savanna zone is rich and diverse in terms of flora (Nyasiri *et al.*, 2019; Dongock *et al.*, 2022). This richness is mainly due to its contact between the predominantly tropical humid southern forest and the dry tropical north (Tchotsoua & Gonne, 2009). Unfortunately, the pressure of human activities undertaken to meet the socioeconomic needs of humans is eading to the disappearance of several plant species (Gnahoré *et al.*, 2020). The Adamawa region of Cameroon is not spared, as extensive agricultural practices are on the rise, as are tree fel-

ling, bush fires, and overgrazing (GTZ, 1994; Mapongmetsem *et al.*, 2011). In the face of these threats, agroforestry is now seen as a sustainable land use option which, through product diversification, optimizes the use of natural resources and reduces health, climate, and economic risks (Penot & Feintrenie, 2014). In the current context of food crisis, agroforestry systems in general and fruit agrosystems in particular provide important socio-economic services and offer an alternative for mitigating the effects of climate change through carbon sequestration (Masibo & He, 2008; Laflèche, 2017; Assanvo *et al.*, 2022, Fomekong *et al.*, 2023). Indeed, fruit trees in agrosystems are a

source of food and income for households. They constitute a source of subsistence for vulnerable populations in semi-arid sub-Saharan areas, provide shade, and act as carbon sinks by storing carbon dioxide (Kouebou *et al.*, 2013; Temgoua *et al.*, 2019; Etchike *et al.*, 2020). Work has been carried out in the forest zone of Cameroon on the carbon stock of agroforestry systems based on cocoa and coffee trees (Temgoua *et al.*, 2018; Fogaing *et al.*, 2021; Ndonmou *et al.*, 2022). In Guinea's high sa-vanna region, however, there has been little research on the assessment of floristic diversity and the carbon sequestration potential of fruit-based agroforestry systems. Existing studies have focused on *Persea americana* agrosystems (Dongock *et al.*, 2022) and mango agroforests (Noiha *et al.*, 2023). With a view to contributing to the sustainable management of woody resources in the Guinean high savannahs, it is essential to improve knowledge of fruit resources with socio-economic value in agroforestry systems. The objective of this research was to study the floristic diversity and carbon stock of fruit-based agroforestry systems in the Adamawa region.

MATERIALS AND METHODS

Description of the study area
The study was conducted in the Guinean high savannas of Ada-mawa, a transition zone between the Sudano-Sahelian north and the forested south of Cameroon. These high savannas stretch for about 400 km between Nigeria and the Central Afri-can Republic and reach an altitude of 2,460 m at the summit of Tchabal Mbabo (Tchotsoua & Gonne, 2009). They are divided into five Divisions: Djerem, Mayo-Banyo, Faro-et-Deo, Vina, and Mbere. Figure 1 shows the location of the study sites. The re-gion has a Sudano-Guinean mountain climate characterized by a rainy season that generally lasts seven months (from April to October) and a dry season that lasts five months (from Novem-ber to March) (Monnier & Piot, 1964). Annual rainfall is 1600 mm and the average annual temperature is 23°C (Piot, 1969). The soils are mainly composed of red ferralitic structures developed on ancient basalts (Yonkeu, 1993). The region is characterized by a fairly rugged terrain, marked by the presence of ancient volcanoes (Monnier & Piot, 1964). The vegetation observed is a shrubby savanna dominated by *Daniellia oliveri* and *Lophira lanceolata* (Letouzey, 1968). The herbaceous vegetation is mainly based on *Hyparrhenia* spp. (Piot, 1969).

Data collection and analysis

Data collection: Floristic inventories were carried out on 10 farms per Division, i.e., 50 farms in the Adamawa region. These inventories made it possible to identify fruit species and group them by family. The criteria for selecting farms were based on size (≥0.5 ha) and age (≥05 years). Plots measuring 50 meters long by 20 meters wide (1000 m²) were explored for each farm (Samb *et al.*, 2018). A total of 250 plots were set up, at a rate of 50 plots per Division, or five plots per farm. The geographical coordinates of each plot were recorded after installation using a GPS (Global Positioning System). The count was carried out in strips 5 m wide and 10 m long, one after the other (Figure 2), where all individuals in a productive state were systematically counted. For each individual, the following dendrometric mea-surements were taken as circumference (in cm), crown diame-ter, and height (in m). For small individuals, cocoa and coffee trees, the circumference was measured at 30 cm above the ground and at 1.30 m above the ground for those larger than chest height. In addition to living trees, standing dead wood and wood lying on the ground were also recorded. Species identifica-tion was carried out in situ. However, all plant species that could not be identified in the field were collected to create a herba-rium and identified at the Laboratory of Ecology and Sustainable Development at the University of Ngaoundere. The botanical nomenclature used is that of the Angiosperm Phylogeny Group (APG IV) classification.
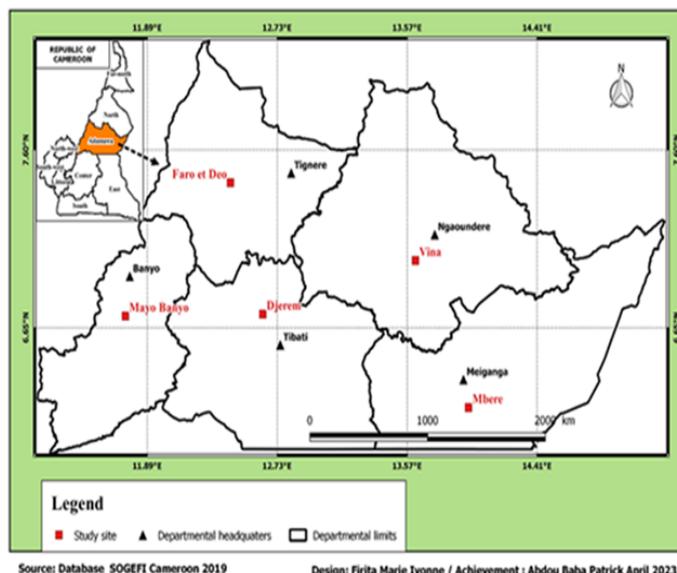

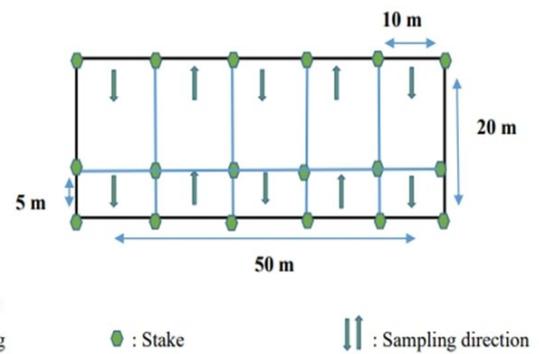Figure 1. *Map showing the location of the study sites.*

Figure 2. *Plan of the species inventory system applied in the field.*

Data processing and analysis

Vegetation parameters

Density (D): Density (D) is the number of individuals per hectare and is calculated using the following formula:

$$D = \frac{N}{S}$$

Where N= total number of individuals in the sample and S= surface area of the sample or plot in ha (Kent & Coker, 1992).

Basal area (Ba): The basal area (basal coverage) was expressed in square meters per hectare (m²/ha), denoted by Ba, and calculated using the following formula:

$$Ba = \sum \frac{\pi \left(\frac{D}{2}\right)^2}{S_E}$$

Where D is the diameter measured at 130 cm above the ground and S_E is the area of the sample considered in ha (Ngom *et al.*, 2018).

Aerial cover (Ac): Aerial cover (Ac) is obtained using the diameter of the canopy projection on the ground (Dh). It is calculated using the formula below (Ngom *et al.*, 2018):

$$Ac = \sum \frac{\pi \left(\frac{Dh}{2}\right)^2}{S_E}$$

Where Dh (m) is the average of the north/south and east/west diameters and S_E (ha) is the area of the sample considered.

Frequency (F): Frequency (F) is expressed by the formula:

$$F = \frac{n}{N} \times 100$$

Where n is the number of individuals of a species and N is the total number of fruit trees.

Relative frequency (Fr): Given by the ratio between the number of surveys where the taxon is present and the total number of surveys, expressed as a percentage (Nnanga *et al.*, 2023):

$$Fr = \frac{ni}{N} \times 100$$

Where ni represents the number of plots where species i is present and N is the total number of plots.

Relative dominance (Domr): Refers to the area occupied by a species (by its basal area or cover) in relation to the area occupied by all species in the sample. It is calculated using the following formula (Ndiaye, 2024):

$$Domr = \frac{Bai}{Bat} \times 100$$

Where Bai is the basal area occupied by species i and Bat is the total basal area of the species in the sample.

Relative density (Dr): Relative density (Dr) corresponds to the proportion of individuals of a species relative to individuals of all species. Its formula is (Ndiaye, 2024):

$$Dr = \frac{ni}{N} \times 100$$

Where ni is the number of individuals of species i in the sample and N is the total number of individuals in the sample.

Importance value index (IVIE): The species importance value index (IVIE) characterizes the importance of a species in an environment and is calculated using the formula below (Curtis & McIntosh, 1950):

$$IVIE = Fre_{espèce} + Domr_{espèce} + Dr_{espèce}$$

Where $Fre_{especie}$ = relative frequency of a species ; $Domr_{especie}$ = relative dominance of a species and $Dr_{especie}$ = relative density of a species

Family Importance Value Index (FIVI): The Family Importance Value Index (FIVI) assesses the diversity of a family and characterizes the importance of that family relative to others in a plant community (Mori *et al.*, 1983):

$$FIVI = Dr_{famille} + Fr_{famille} + Domr_{famille}$$

Where Dr_{family} is the relative density of a family; Fr_{family} is the relative frequency of a family and $Domr_{family}$ is the relative dominance of a family.

Diversity indices

The Shannon index (H') is given by the following formula:

$$H' = -\sum Pi \log_2 Pi$$

Where Pi = ni/N; with Pi: the relative proportion of the average cover of species i (values between 0 and 1); ni is the number of individuals for species i in the plant community surveys, N is the total number of individuals of all species in the plant community surveys, and log is the decimal logarithm (Shannon, 1948). The Shannon index expressed in bits generally varies between 0 and 0.5 bits.

Pielou's evenness (E): Pielou's evenness (E) provides information on how individuals are distributed within species (Piélou, 1966). It is obtained using the following formula:

$$E = \frac{H'}{\log_2 S}$$

Where H' is the Shannon specific diversity index of the plant group, S is the total specific richness or total number of species, and log is the decimal logarithm. It range between 0 and 1. E tends towards 0 when almost all individuals belong to a single species and tends towards 1 when all species have exactly the same coverage.

Determination of vegetation structure: This was assessed based on diameter classes according to diameter at breast height, crown diameter, and height of woody vegetation. For the horizontal distribution of the stand, the diameter classes were grouped into six categories : 0-20 m, 20-40 m, 40-60 m, 60-80 m, 80-100 m and >100 m. For the distribution taking into account crown diameter, the classes used were : <2 m, 2-4 m, 4-6m, 6-8m and ≥8 m. The vertical distribution of the stand took into account the following height classes: <5m, 5-10 m, 10-15 m, 15-20 m and ≥ 20 m.

Estimation of carbon stocks in phytomass: The estimation of phytomass or carbon quantity was carried out using a non-destructive method, taking into account dendrometric measurement data from floristic inventories.

Estimation of aboveground phytomass: The allometric equation of Mbow *et al.* (2014) was used to determine the aboveground biomass of fruit trees in agrosystems. It is expressed as follows:

$$EP = (1.929 \times D) + (0.116 \times D^2) + (0.013 \times D^3)$$

Where: EP: aboveground phytomass (t/ha) and D: diameter at 1.30 m above ground level (cm)
For palm trees, the equation of Pearson & Brown (2005) was used:

For H= 33 m, $EP = 6.666 + 12.826 \text{ x } H^{0.5}\ln H$

For H= 11 m, $EP = 23.487 + 41.851 \text{ x } (\ln(H))^2$

Where H is the height

For banana trees, the equation by Nyombi *et al.* (2009) was used:
$$EP = 0.325 \text{ x } e^{0.036 \text{ x } C}$$
Where C represents the circumference.

Estimation of hypogeous phytomass: Hypogeous phytomass (HP) was determined using the equation developed by Cairns *et al.* (1997) with the formula:

$$HP = \exp\left[-1.0587 + 0.8836 \times \ln(EP)\right]$$

Where HP is the hypogeous phytomass (kg) and EP is the epigeous phytomass (t/ha).

Phytomass of standing dead wood: The volume of standing dead wood was calculated using the given equation used by Ifo *et al.* (2017):

$$VSDW = \Pi \times h \times f \times \left(\frac{D}{2}\right)^2$$

Where VSDW= volume of standing dead wood (m3/ha); D=

diameter at breast height (m); h= height of standing dead wood (m); f = form factor (equivalent to 0.627).
The conversion to phytomass was made by multiplying the volume by the density of wood at 0.5 tmS/m^3 (Brown, 1997):

$$PSDW = VSDW \times 0.5$$

Phytomass of dead wood lying on the ground: The volume of dead wood lying on the ground was obtained using the formula developed by Warren & Olsen (1964):

$$VDWL = \frac{\pi^2(\sum Di^2)}{8L}$$

Where VDWL= volume of dead wood lying on the ground (m^3/ha); Di= diameter of each piece of woody debris sampled (m) and L= length of the transect (m).
The biomass of dead wood was estimated using the formula developed by Brown (1997):

$$PDWL = VDWL \times d$$

PDWL = phytomass of dead wood lying on the ground; VDWL= volume of dead wood lying on the ground and d= wood density. The wood density value used is 0.5 tmS/m^3 (Brown, 1997).

Total phytomass: The total phytomass (TP) of fruit trees was obtained by adding together the values of all estimated phytomasses. It is given by the following formula:

$$TP = EP + HP + PSDW + PDWL$$

Where EP= aboveground phytomass; PH= hypogeous phytomass; PSDW= standing dead wood phytomass and PDWL = lying dead wood phytomass.

Total carbon quantity: According to the IPCC (2006), the amount of carbon stored (C) is estimated by multiplying the total phytomass by the ratio 0.47, which represents the conversion factor.

$$C = TP \times 0.47$$

Where: TP is the total phytomass in t/ha.

Assessment of sequestered CO$_2$: The amount of carbon obtained was converted into the amount of atmospheric carbon dioxide (CO$_2$) using the ratio CO$_2$/C. This ratio corresponds to 44/12, or 03.67. Thus, the equivalent carbon stock is (IPCC, 2006):

$$ST_{(eqCO2)} = C \times 3.67$$

Where C is the total carbon stock.

Economic value: The economic value was assessed using the value of the atmospheric CO$_2$ stock obtained multiplied by the monetary value of a ton of CO$_2$eq according to the formula:

$$EV = ST_{(eqCO2)} \times MV$$

Where EV: ecological value; ST (eqCO$_2$): Atmospheric CO$_2$ stock; MV: Monetary value.

The average value of the ecological service was estimated based on three mechanisms: Reducing Emissions from Deforestation and Forest Degradation (REDD+); Voluntary Carbon Market (VCM) and Clean Development Mechanism (CDM) (Ecosystem Marketplace, 2016).

For REDD+ at $10/tCO_2$; For VCM at $4.7/tCO_2$; For CDM at $3/tCO_2$.

$1 = 560.58 CFA francs.

Statistical analysis

Microsoft Office Excel was used for calculations and graphing. Statgraphic 5.0 software was used for analysis of variance. A p-value=0.05 was used to show statistical significance.

RESULTS AND DISCUSSION

Floristic composition and diversity indices of fruit agrosystems

In fruit agrosystems, a total of 2986 individuals were recorded in the 250 plots, grouped into 17 species, 14 genera, and 11 families. Floristic richness varies from one agrosystem to another (Table 1). Table 1 shows that the agrosystems of Vina have the highest number of woody stems (1135 individuals), followed by Mayo-Banyo (800 individuals) and Mbere (393 individuals). The Division of Faro-et-Deo has the fewest individuals (304 individuals). In terms of species, Djerem and Mayo-Banyo are more diverse, with 12 species each. Vina (10 species) and Faro-et-Deo (10 species) come in second place. The agrosystems of the Mbere division, on the other hand, are very poorly diversified, with only three species. Temgoua *et al.* (2019) in the Loum district (Littoral) found 27 species belonging to 23 genera and 18 families. Manaye *et al.* (2021) in Ethiopia identified a total of 23 species, 21 genera, and 14 families in household gardens. The difference observed in fruit species diversity could be due to sampling and also to climate variability in these study areas. High diversity is found in wetlands in general and more particularly in cocoa/coffee agroforestry systems.

Fruit diversity varies across agrosystems (Table 1). Shannon indice and Pielou's Equitability show very low values in all divisions. They range from 0.31 bits in Mbere to 0.81 bits in Mayo-Banyo for the Shannon index. Pielou's Equitability is very low in the Mbere division (0.12). The highest values are found in the divisions of Faro-et-Deo (0.29), Mayo-Banyo (0.28), Djerem (0.26), and Vina (0.22). There is a significant difference between the Divisions in terms of the Shannon diversity index and Pielou's Equitability index (p<0.05). This reflects the low diversity of these areas and the fact that individuals in agrosystems have been grouped around a few species. The high Shannon index value in the Mayo-Banyo division can be explained by the fact that it is rich in coffee and cocoa production systems where trees are preserved for shade. These results are similar to those of Manaye *et al.* (2021) in Ethiopia, who found that the Shannon diversity index (0.93 bits) and Pielou's Equitability (0.76) were low in household gardens. However, in the Adamawa region of Cameroon, the work of Dongock *et al.* (2022) reveals that the Shannon index varies from 02.31 to 03.09 bits and the Pielou Equitability is equal to 01 in all sites. This difference in indices could be explained by the fact that the number of species obtained by Dongock *et al.* (2022) is much higher (61 species) than the number of species obtained in the present study.

Frequency of species

The frequencies of fruit species vary according to agrosystems (Table 2), from 0.08 for *C. sinensis* in Vina to 75.06 for *M. indica* in Mbere. Six fruit species are specific to one area, as they are only found in a single department. These are *A. muricata* and *C. nucifera* found in Djerem *C. arabica* and *T. cacao* in Mayo-Banyo and *C. acuminata* and *C. papaya* in Faro-et-Deo. *M. indica* and *P. americana* are species common to all Divisions studied. In Vina, *M. indica* (44.66%) and *C. limon* (17.7%) are the most common. *M. indica* (54.51%) and *P. americana* (17.51%) are more common in Djerem, while *M. indica* (75.06%) and *A. occidentale* (12.97%) are common in Mbere. In Mayo-Banyo, *T. cacao* is the most common (25.62%), followed by *M. indica* (19.87%). Faro-et-Deo, on the other hand, is dominated by *C. reticulata* (41.11%) and *C. sinensis* (21.71%). The abundance of these species is thought to be linked to the fact that they best meet the socio-economic needs of producers. In the agroforests of Ndikinimeki (Central Cameroon), Etchike *et al.* (2020) reveal that *D. edulis*, *M. indica*, *M.* spp. and *E. guineensis* are the most common species. According to Dasylva *et al.* (2023) in Senegal, the most common species are *A. occidentale* (38.67%), *P. guajava* (20%), *C.* sp. (16%) and *M. indica* (12%).

Table 1. Floristic richness and diversity indices of agrosystems in different divisions.

Division	Species	Genera	Families	Individuals	Shannon	Pielou
Vina	10	07	06	1135	0.68±0.016[b]	0.22±0.006[a]
Djerem	12	10	08	354	0.66±0.015[b]	0.26±0.006[a]
Mayo-Banyo	12	09	08	800	0.81±0.015[a]	0.28±0.006[a]
Mbere	03	03	02	393	0.31±0.03[ab]	0.12±0.01[b]
Faro-et-Deo	10	07	06	304	0.74±0.016[a]	0.29±0.007[a]
Total	17	14	11	2986		

Values with different letters are significantly different at the 5% level in columns.

Table 2. Frequency of fruit species in agrosystems.

Species	Divisions				
	Vina	Djerem	Mayo-Banyo	Mbere	Faro-et-Deo
Mangifera indica	44.66	54.51	19.87	75.06	17.1
Citrus limon	17.7	01.12	15.87	-	01.31
Persea americana	15.41	17.51	11.5	11.95	03.28
Citrus reticulata	13.56	0.28	-	-	41.11
Citrus maxima	04.75	-	0.37	-	06.25
Psidium guajava	02.55	02.54	04.25	-	03.94
Dacryodes edulis	0.35	02.54	0.12	-	-
Anacardium occidentale	0.26	02.54	0.25	12.97	-
Citrus sinensis	0.08	0.28	0.5	-	21.71
Musa balbisiana	01.4	09.32	02.37	-	-
Elaies guinensis	-	05.93	01.37	-	02.63
Cocos nucifera	-	01.45	-	-	-
Annona muricata	-	02.54	-	-	-
Theobroma cacao	-	-	25.62	-	-
Coffea arabica	-	-	18.12	-	-
Carica papaya	-	-	-	-	01.64
Cola acuminata	-	-	-	-	06.25

Note : - Species absent.

Table 3. Ecological parameters of fruit trees in different divisions.

Ecological parameters	Divisions					Mean	P-value
	Vina	Djerem	Mayo-banyo	Mbere	Faro-et-Deo		
Density (stem/ha)	227[ab]	70.8[b]	160[ab]	78.6[b]	60.8[a]	119.44	0.01
Basal area (m^2/ha)	14.8b	58.41ab	22.14ab	24.05ab	06.94a	25.26	0.006
Aerial coverage (m^2/ha)	01.92[a]	04.98[b]	01.27[a]	03[b]	01.33[a]	02.5	0.02

Values with different letters are significantly different at the 5% level online.

Floristic structure of agrosystems

The ecological parameters of fruit trees in the different Divisions are shown in Table 3. The density of trees in agrosystems varies from 60.8 stems/ha in the Faro-et-Deo Division t to 227 stems/ha in the Vina Division, giving a total density of 119.44 stems/ha in the Guinean high savannahs. Analysis of variance reveals a significant difference between Divisions (p<0.05). According to Samb *et al.* (2024), in cashew plantations in Senegal, the stand density is 93 individuals/ha for all species combined, and that of cashew plantations is 74 individuals/ha. The difference can be explained by the production objectives of each producer and the size of the trees. The cashew tree is a species that occupies a lot of space, which can limit the number of trees that can be introduced per hectare in an agroforestry system. In terms of basal area, the lowest value was observed in the Faro-et-Deo area (06.94 m²/ha) and the highest in Djerem (58.41 m²/ha). Analysis of variance reveals a significant difference between departments (P<0.05). The work of Ndonmou *et al.* (2022) in cocoa and coffee agroforests in the humid savannahs of Cameroon reveals that the basal area varies from 13.7 to 25.6 m²/ha depending on the agroforestry systems. The high values of basal area in the study Divisions in general, and more particularly in the Djerem Division, could be explained by the size of certain fruit trees such as *M. indica* and *P. americana*. The aerial coverage of all individuals in fruit agrosystems ranges from 01.27 m²/ha to 04.98 m²/ha. The lowest values are obtained in the Divisions of Mayo-Banyo (01.27 m²/ha) and Faro-et-Deo (01.33 m²/ha). The Divisions of Djerem and Mbere have the highest values, at 04.98 m²/ha and 03 m²/ha respectively. The high values in these two areas are due to the presence of trees with large crowns. The analysis of variance reveals a significant difference between the Divisions (p<0.05). Thiam *et al.* (2020) in Senegal present well-covered vegetation with rates ranging from 19.5% to 77.1%. The fact that our results are significantly lower than those of this study could be justified by the ecological zone. In our work, the environment has been modified by humans, with only individuals of interest being planted, spacing being respected, and branches being pruned. Thiam *et al.* (2020), however, worked in a forest whose main characteristic is high tree density. The higher the density, the greater the vegetation cover.

Species importance value index

Table 4 shows the ecological importance of species in the agro-systems of different areas. *M. indica* (IVIE=163.5%), *T. cacao* (IVIE=49.61%), and *P. americana* (IVIE=48.71%) are the most important species in the Guinean high savannas, as they have an IVIE>35.41%. Depending on each Division, *M. indica* is the most important species in Djerem (IVIE=179.93%), followed by *P. americana* (IVIE=56.73%) and *M. balbisiana* (IVIE=34.28%). In Mayo-Banyo, *M. indica* (IVIE=144.38%), *P. americana* (IVIE=50.47%), and *T. cacao* (IVIE=49.61%) are the most important. *M. indica* (IVIE=199.98%) and *P. americana* (IVIE=34.44%) are the species with high ecological importance in Mbere, while *C. reticulata* (IVIE=144.38%) and *C. sinensis* (IVIE=41.75%) are important in the Division of Faro-et-Deo. In the Division of Vina, *M. indica* (IVIE=206.96%) and *P. americana* (IVIE=206.96%) have the highest indices. The least important species are *C. sinensis* in Djerem (IVIE=02.36%), *C. limon* in Faro-et-Deo (IVIE=03.55%), *D. edulis* in Mayo-Banyo (IVIE=02.23%) and *A. occidentale* in Mbere (IVIE=25.57%) and Vina (IVIE=04.27%). The importance of certain species over others could be explained by the economic, nutritional, and even medicinal value they provide to producers. In the work of Fomekong *et al.* (2023), *D. edulis* (IVIE= 99.24%), *M. indica* (IVIE= 42.24%) and *E. guineensis* (IVIE = 41.73%) are the most important species in cocoa-based agroforestry systems in the savannah. In contrast, in agroforestry systems based on cocoa trees under forests, *D. edulis* (IVIE= 67.37%), *E. guineensis* (IVIE = 28.05%), *M. indica* (IVIE= 26.66%), *P. americana* (IVIE= 21.09%), and *C. sinensis* (IVIE = 15.19%) are the most important.

Importance value index of families

Of the 11 families identified, the most important families at the regional level are Anacardiaceae (FIVI=160.88%), Rutaceae (FIVI=68.43%), Lauraceae (FIVI=48.43%) and Malvaceae (FIVI=33.47%). In the Djerem Division, the Anacardiaceae (FIVI=187.34%), Lauraceae (FIVI=55.24%) and Musaceae (FIVI=34.28%) families have the highest importance indices. In Mayo-Banyo, Anacardiaceae (FIVI =55.37%), Rutaceae (FIVI =55.37%) and Lauraceae (FIVI =50.47%) are the most important. In Faro-et-Deo, the families with high ecological importance are Rutaceae (FIVI =131.31%) and Anacardiaceae (FIVI =86.22%). Anacardiaceae (FIVI=225.55%) occupy first place in Mbere, while in Vina, the most important families are Anacardiaceae (FIVI =161.87%), Lauraceae (FIVI =90.35%) and Rutaceae (FIVI =72.98%). In Central Cameroon, the work of Fomekong *et al.* (2023) showed that families such as Burseraceae (FIVI = 62.07%), followed by Moraceae (FIVI= 24.49%), Arecaceae (FIVI = 22.79%), Anacardiaceae (FIVI = 21.99%), Lauraceae (FIVI =15.08%), and Combretaceae (FIVI =13.22%) have the highest importance values in agroforestry systems based on cocoa trees under forests. For Diatta *et al.* (2018) in Senegal in mango orchards, the Anacardiaceae family is the most represented (48.28%) in mango orchards. This is followed by the Rutaceae (18.12%), Icacinaceae (17.48%), Arecaceae (04.20%), Annonaceae (02.17%), and Apocynaceae (01.54%) families.

Table 4. Ecological importance of species.

Species	Divisions					
	Djerem	Faro-et-Deo	Mayo-Banyo	Mbere	Vina	Mean
Coffea arabica	-	-	27.49	-	-	27.49
Theobroma cacao	-	-	02.13	-	-	02.13
Anacardium occidentale	05.40	-	02.29	25.57	04.27	09.38
Annona muricata	06.93	-	-	-	-	06.93
Carica papaya	-	04.3	-	-	-	04.30
Citrus limon	09.18	03.55	48.02	-	44.50	26.31
Citrus maxima	-	13.57	04.64	-	13.66	10.62
Citrus reticulata	02.48	74.43	-	-	24.53	33.81
Citrus sinensis	02.36	41.75	06.71	-	04.28	13.78
Cocos nucifera	05.80	-	-	-	-	05.8
Cola acuminata	-	15.20	-	-	-	15.2
Dacryodes edulis	15.88		02.23	-	06.62	08.24
Elaeis guineensis	26.14	06.63	09.38	-	-	14.05
Mangifera indica	179.93	86.22	144.38	199.98	206.96	163.5
Musa balbisiana	34.28	-	12.88	-	05.85	17.67
Persea americana	56.73	11.65	50.47	34.44	90.25	48.71
Psidium guajava	10.81	10.65	23.71	-	30.92	19.02
Theobroma cacao	-	-	49.61	-	-	49.61
Mean	29.66	26.8	29.53	86.66	43.18	35.41

Note: - Species absent

Structural characteristics of agrosystems

Diameter distribution

The diameter structure of fruit trees varies depending on the site (Figure 3). Overall, the stands have an L-shaped structure in all Divisions. This shape indicates that the number of individuals decreases as the diameter of the trees increases. In these areas, there is a high proportion of trees with a diameter between 0 and 20 cm, i.e., 68.72% in Vina 33.33% in Djerem 79% in Mayo-Banyo and 84.53% in Faro-et-Deo. In contrast, in the Mbere Division, the optimum distribution is in 20-40 cm diameter range (47.32%). The L-shaped curve indicates a young and healthy population. The high proportion of individuals with a diameter ≤ 40 cm could be due to the fact that the fruit farms are relatively young. Trees with small diameters reflect the restoration of agrosystems. These results are similar to those of Maryo *et al.* (2023) in northern Ethiopia and Ndiaye (2024) in Senegal, which show a predominance of individuals with small diameters.

Diameter distribution according to the diameter of fruit tree crowns

The distribution of fruit tree crown diameter in agroforestry systems shows that stands have an L-shaped structure in the Divisions of Vina, Mayo-Banyo, and Faro-et-Deo (Figure 4). As crown diameter increases, the number of individuals decreases. Individuals with a diameter of less than 0.2 m are predominant in Vina (58.5%) and Mayo-Banyo (52.62%). In contrast, in the Faro-et-Déo Division, the diameter class between 2-4 m is the largest (62.5%). The L-shaped structure indicates a promising population with good health status. The work of Dangai *et al.* (2020) in the *D. oliveri* agroforestry parklands (Sudano-Sahelian zone of Cameroon) reveals that the canopy diameter distribution of woody species is bell-shaped. In the Djerem and Mbere Divisions, the distribution of individuals is bell-shaped. The optimum values for this distribution are in 2-4 m class for Mbere (43%) and 4-6 m for Djerem (31.07%). The shape of the curves indicates a low representation of young and old individuals in agrosystems, reflecting vegetation degradation or a disturbed environment.
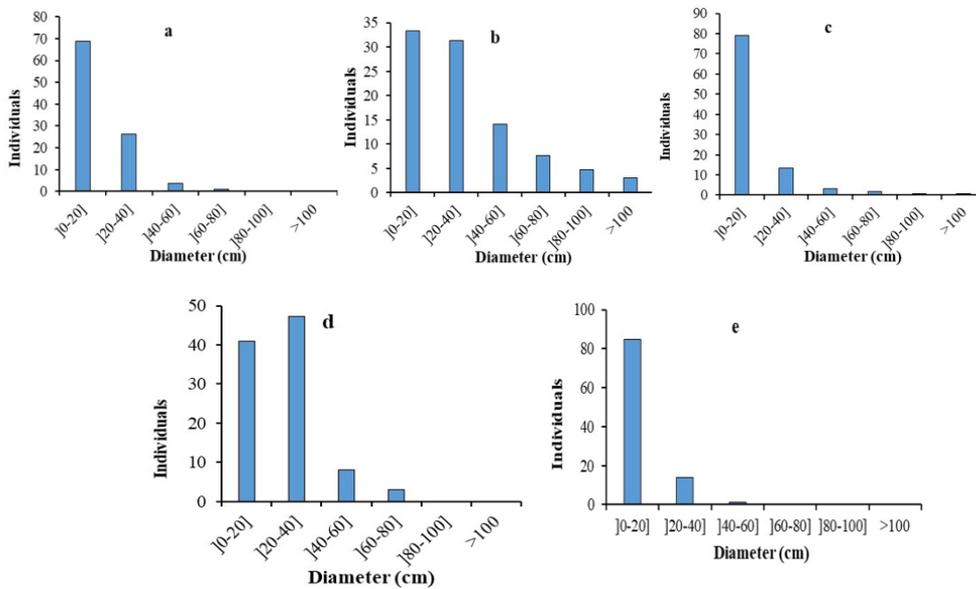

Figure 3. *Horizontal distribution of fruit trees in: Vina (a); Djerem (b); Mayo-Banyo (c); Mbere (d) and Faro-et-Deo (e).*
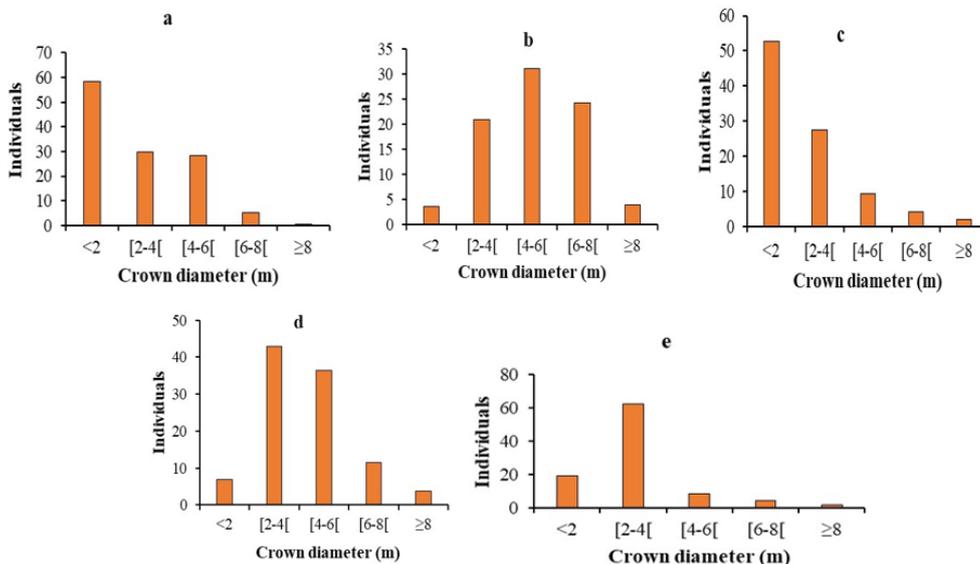

Figure 4. *Distribution of fruit tree canopy diameter in: Vina (a); Djerem (b); Mayo-Banyo (c); Mbere (d) and Faro-et-Deo (e).*

Vertical distribution of fruit trees

For the stands in Vina and Mayo-Banyo, the height structure is inverted J-shaped (Figure 5). Trees of low height (⬚ 5 m) are more prevalent (39.46%) than tall trees, accounting for 33.33% in Vina and 45.65% in Mayo-Banyo. This structure indicates a dominance of young trees and exploitation focused more on tall trees. Ndiaye (2024) in Casamance (Senegal) and Dangai *et al.* (2020) in Cameroon obtained a bell-shaped structure indicating a regeneration deficit. In the Divisions of Djerem, Mbere, Faro-et-Deo, the curve is bell-shaped (Figure 5). This shape reflects a good representation of the intermediate classes. It indicates a low representation of young and old individuals. This curve shape is a sign of agrosystem disturbance. In the Mbere and Djerem Divisions, the optimum tree distribution is in 10-15 m range, with 34.60% and 27.11% respectively. In contrast, in Faro-et-Deo, the 5-10 m range is the most represented (58.55%). These results contradict those found by Nnanga *et al.* (2023) in the Divisions of Pendé and Nya (Chad). According to these authors, the stands have an L-shaped structure, indicating that the plots have several promising individuals to ensure regeneration.

CO_2 sequestration potential

CO_2 equivalent ranges from 17.09±12.03 tCO$_2$eq/ha to 68.11±32.54 tCO$_2$eq/ha (Table 5). The Djerem and Mayo-Banyo areas have the highest values, at 68.11±32.54 tCO$_2$eq/ha and 66.97±27.73 tCO$_2$eq/ha, respectively. The total sequestration potential is 209.13±114.35 tCO$_2$eq/ha. The low carbon stock value in Vina, despite its large number of individuals, can be explained by the strong presence of Rutaceae, which generally have small diameters. According to Fogaing *et al.* (2021), a sys-

tem with dense vegetation tends to have trees with small diameters due to the phenomenon of phototropism. Although rich in individuals, this system will have a reduced carbon stock. However, according to Nair *et al.* (2009), the greater the number of individuals, the greater the biomass, carbon stock, and CO_2 equivalent. In the Adamaoua region, the work of Noiha *et al.* (2017) has shown that the carbon sequestration potential of mango tree agrosystems varies between 99.00±0.17 and 330.96±0.82 tCO$_2$eq/ha. Boukeng *et al.* (2023) in the homegardens in the Sudano-Sahelian zone of Cameroon estimated the equivalent amount of CO_2 at 112.3 t/ha. The difference in equivalent CO_2 quantity could be justified by the type of allometric equation used. According to Fogaing *et al.* (2021) the more large-diameter trees are represented in a system, the higher its carbon stock will be.

Economic value of fruit agrosystems

The economic value of agrosystems varies according to markets and Divisions. It is very low, at 551000.23 CFA francs for the Clean Development Mechanism. For REDD+, on the other hand, the carbon credit amounts to 1172340.93 CFA francs. The Divisions of Djerem and Mayo-Banyo record the highest carbon credit values regardless of the type of carbon market. The total economic value of the ecological services of agrosystems is therefore estimated at 2075043.42 CFA francs. In *P. americana* agrosystems, the work of Dongock *et al.* (2022) showed that the economic service varies from 66,918.54 to 4221851.58 CFA francs. The difference could be due to the density of individuals and the age of *P. americana* agrosystems. The species mentioned stored more carbon (712.66 t/ha) compared to the results in the study area.
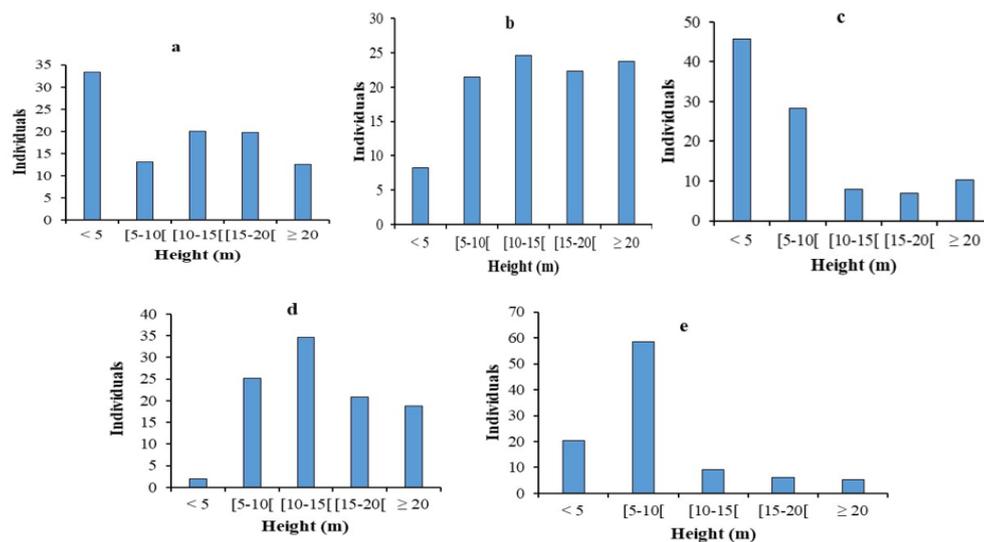

Figure 5. *Vertical distribution of fruit trees in: Vina (a); Djerem (b); Mayo-Banyo (c); Mbere (d) and Faro-et-Deo (e).*

Table 5. Amount of CO_2 equivalent.

CO_2eq	Divisions					
	Vina	**Djerem**	**Mayo-Banyo**	**Mbere**	**Faro-et-Deo**	**Total**
Epigeal	13.5±10.3	61.47±30.2	54.02±21.6	29.91±20.9	19.81±16.3	178.71±99.5
Hypogean	01.98±01.4	06.64±02.2	04.62±01.5	03.08±01.6	01.57±0.84	17.89±07.79
SDW	03.55±02.2	00±00	08.33±04.5	0.36±0.18	00±00	12.24±06.92
DWG	0.29±0.1	00±00	00±00	00±00	00±00	0.29±0.14
Total	19.32±14.1	68.11±32.5	66.97±27.7	33.35±22.7	21.38±17.2	209.13±114.3

Note : CO$_2$eq: CO_2 equivalent ; SDW: Standing dead wood ; DWG: Dead wood on the ground.

Conclusion

This study identified 17 species grouped in 14 genera and 11 families in fruit-based agroforestry systems in the Guinean high savannas of Cameroon. The most common species in the different divisions are *M. indica*, *T. cacao*, and *C. reticulata*. The total tree density in agrosystems is 119.44 stems/ha in the Guinean high savannas. Fruit agrosystems in the Guinean high savannas of Cameroon are not very diverse. The vegetation stands are distributed in an L-shape and bell-shape. The total carbon stock of the fruit agrosystems in the area is 209.13±114.35 tCO$_2$eq/ha and its economic value is estimated at 2075043.42 CFA francs. This economic value could contribute to improving fruit producers'incomes. Agroforestry systems based on fruit trees contribute to the conservation of species of significant socioeconomic value and to the storage of considerable amounts of carbon for sustainable development. It would be interesting to estimate the carbon stock of herbaceous plants, soil, and litter in fruit agrosystems for the sustainable management of these systems.

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DECLARATIONS

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