

Biodiversity Management under Cashew Agro-ecosystems in Central Africa: A case study from Cameroon

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Abstract: This study aimed to assess the floristic composition, vegetation structure and species associations of Cashew agro-ecosystems in the North region of Cameroon. The data were collected in 100 m x 20 m transect methods. An analysis of the data collected in the field was conducted around the diversity and richness of the flora, but also the structure of Cashew agro-ecosystems. For the analyzes of vegetation structure, tree density, basal area and biovolume were calculated. The inventory included trees with a dbh greater than or equal to 5 cm on an area of 1 ha per plot. The experimental device installed is a complete random Fisher block with five repetitions. A total of 7849 individuals in 17 families, 20 genera and 38 species were recorded. Species Important value of vegetation cover indicated that *Diospyros mespiliformis*, *Anogeissus leiocarpus*, *Annona senegalensis* and *Terminalia laxiflora* are the most represented. Combretaceae are the most ecologically important families. Additionally, the grouping of species into four subdivisions showed that the Shannon diversity index varies from 2.18 ± 0.09 - 3.47 ± 0.17 bits, Pielou index vary from 0.98 ± 0.01 - 0.99 ± 0.01 , Simpson's index ranges from 0.70 ± 0.18 - 0.93 ± 0.11 , density ranges from 102 ± 1.92 - 128 ± 6.36 indiv/ha, basal area ranges from 2.02 ± 0.31 - 12.68 ± 2.01 m²/ha, biovolume ranges from 11.58 ± 1.29 - 68.03 ± 13.21 m³/ha. The Sørensen similarity index is very high with floristic affinities greater than or equal to 90%. The diameters and heights structure show a predominance of young individuals for the diameter and height classes on all plots. The most represented species associations are legumes (*Arachis hypogaea*: 40.54%) and native fruit trees (*Vitellaria paradoxa*: 15%). These results show the contribution of Cashew agro-ecosystems in biodiversity conservation.

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1. Introduction

Forest ecosystems of Central Africa in general and those of Cameroon in particular, are rich in natural resources [1]. They offer many opportunities to people for their livelihoods. However, faced with the implementation of the socio-economic development process, this environment is faced many threats, in particular, deforestation, degradation, poaching, pollution, overexploitation of biotic and abiotic resources, etc. Forest inventory and monitoring are key tools for understanding the structure, composition, diversity of different types of vegetation and habitats, and are also essential for achieving the goals of international agreements [1]. However, one of the most worrying environmental issues of the 21st century immediately after the climate change is deforestation [2]. The combined effects of this increasing human activity on natural resources in synergy with severe climatic factors continue to upset the natural balance within terrestrial ecosystems [2]. The

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degradation of forest ecosystems is a cause of the reduction in biodiversity in the world [2, 3, 4]. The Changes in the floristic composition and vegetation structure show this degradation [5]. These ecological disturbances, which affect the biological resources and the potentialities of the land, result in the deterioration of the standard of living of the populations.

Cashew (*Anacardium occidentale* L.) plantations occupy about 7.5 million hectares worldwide and are distributed in 32 countries [6,7]. The cashew nut-based agroforestry system in Tanzania, Mozambique, Nigeria, Guinea Bissau, Ivory Coast, Benin and Cameroon help solve the environmental and socio-economic problems of producers [8]. Indeed, the cashew is an economic crop grown on small farms because of the ease of cultivation [9,10]. Additionally, at the end of each nut-marketing year, the income obtained allows producers to organize ceremonies, acquire goods, services and the construction of housing [11,12]. According to the same authors, the presence of cashew tree plantations on farms contributes to the reduction of atmospheric carbon levels and promotes a healthy environment conducive to human development. From an ecological viewpoint, [11] has shown that agroforestry, especially cashew nut-based agroforestry developed by peasant populations in Northern Cameroon, is one of the most adequate solutions to mitigate the effects of environmental degradation. In this context, it has a positive impact on the dynamics of land use and is of ecological interest in the study area. However, beyond socio-economic interests, cashew nut-based agroforestry, like other types, also offers ecological benefits in that it contributes to the reforestation of agricultural areas and reduces the roaming of producers in search of new land [13].

Additionally, cashew trees co-exist with other natural or planted plant species. Cashew agro-ecosystems can be places of refuge for plant biodiversity [11,14]. It is therefore important to study plant diversity within these ecosystems to better understand their power to conserve plant biodiversity. From a scientific viewpoint, the knowledge of the companion plant species of the cashew tree and the functioning of these agro-ecosystems constitutes a new line of research to be explored concerning the importance and rapid spread of this species in Cameroon. Thus, this study was initiated for the realization of the baseline study on the plant biodiversity of cashew agro-ecosystems in the North region of Cameroon, to lay the foundations for the sustainable management of these particular ecosystems. The cardinal point of this research is to appreciate the diversity of plant species evolving in the cashew nut based agroforestry.

2. Materials and Methods

2.1. Study area

The study occurred in Central Africa, more precisely in Cameroon, in the North region of Cameroon. This region is located between 8° 00.0'N to 10°00.0'N latitude and 13° 00.0'E to 15°00.0 'E longitude (Awé *et al.*, 2021) (Figure 1). [15]. **The relief is a vast plain between the Mandara Mountains (1442 m) in the North and Adamawa plateau in the South** [16]. The climate is of the Sudano-Sahelian type with two seasons: a dry season lasting six months (November-May) and a rainy season lasting six months (June-October) [11]. The average monthly temperature varies from 26°C in August to 40°C in March (extreme temperatures: 17°C to 40°C) [17]. **The soil is of the ferruginous type characterized by acidity (pH = 5.5 to 6) and low cation exchange capacity** [11]. The vegetation is a shrubby Sudanian savannah with a clear and degraded Savannah appearance around the villages [11]. Agriculture is the main activity of the people of the region. The population practices subsistence agriculture (corn, peanuts and millet) [11]. The administrative region

of Northern Cameroon comprises four subdivisions, namely, Bénoué, Faro, Mayo Louti, and Mayo Rey (Figure 1).

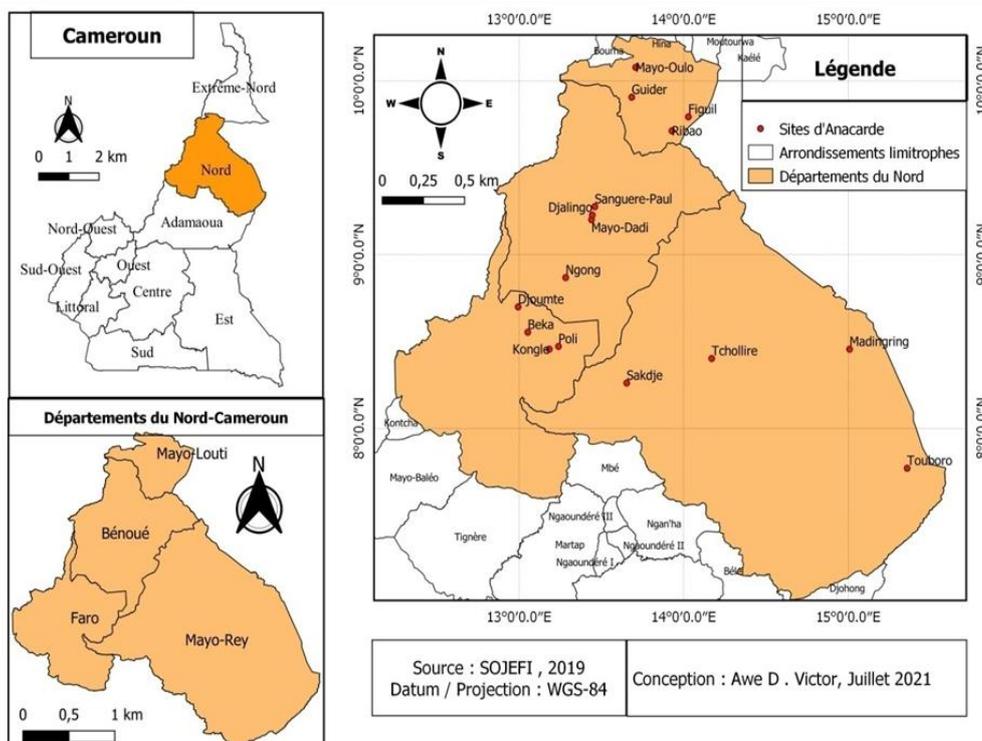


Figure 1. The geographic location of the study area in the North Region of Cameroon

2.2. Choice of study sites and experimental design

The choice of study station was based on the availability, age and area of cashew plantations. Three cashew plantations were selected according to age classes (0–10 years; 10–20 years and over 20 years). The survey was conducted among cashew producers. The IRAD fruit production subdivision in Garoua during the agricultural seasons from 2010 to 2018 records the targeted planters. The use of the report from IRAD in Garoua made it possible to get an idea of the situation in the areas. The choice of planters surveyed was made randomly among those with at least 1.5 hectares of agro-ecosystems. Thus, the investigation concerned 20 producers. The survey was conducted with a tool of the active method of participatory research and planning (the semi-structured interview). It occurred at home and/or in the field at the convenience of each planter. The purpose of the survey was to obtain information on the age of cashew agro-ecosystems in the study area. The experimental device installed is a complete random Fisher block with five repetitions. The four subdivisions (Bénoué, Faro, Mayo-Louti, Mayo-Rey) are considered main treatments. Three cashew plantations were selected according to age classes (0–10 years; 10–20 years and over 20 years) chosen in each subdivision are considered secondary treatments. The five plots of 100 m x 20 m as repetitions.

2.3. Data collection

Sampling methods consist of transects ranging from 100 m long to 20 m wide. The transects were installed in cashew plantations of three age groups at the end of making a comparison. A total of 5 transects were installed, representing a total sampling area of 1

ha per site. The sampling bands were established using the compass, measuring tape, GPS and strings. At the ends of each strip, the stakes were planted equidistant from 20 m (Figure 2). Sampling is done in each 200 m² strip to reduce counting errors. Along the transect, all woody species have been inventoried. The inventories of trees and shrubs were conducted by measuring their circumference with a tape measure. A transect corresponding to a survey, 60 surveys were conducted in the 12 plots of cashew trees sampled. As part of this work, the IUCN Red List has provided us with information on the status of the species inventoried. All the trees were systematically counted and measured. Dendrometric data focused on the measurement of the diameter at breast height (dbh) on bark using a tape measure and heightening a clinometer. Thus, the circumferences of the ligneous plants were measured using a tape measure at 1.30 m from the ground. The values of the circumference were then converted into diameter (dbh) according to the formula: $dbh = C / \pi$, with C = circumference, dbh = diameter at breast height, and $\pi = 3.14$. Several authors have used this sampling method [11,18,19].

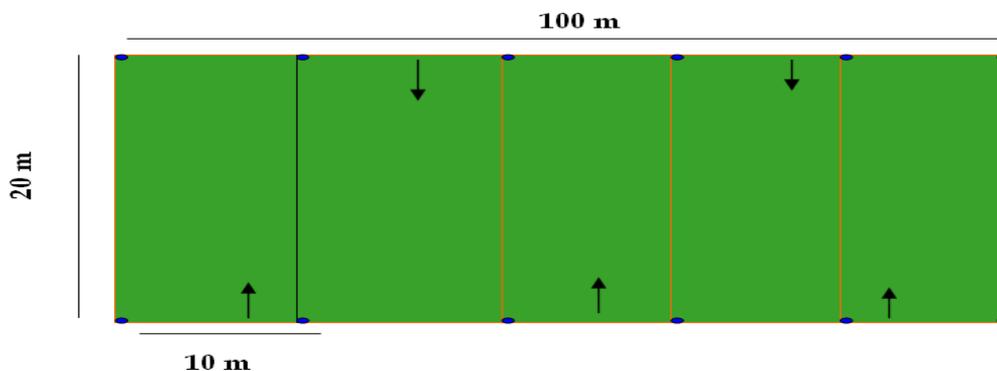


Figure 2. Illustration of the sampling method (100 m x 20 m transect for wood inventory in the 20 m x 10 m strips). ● = Picket).

2.4. Data analyses

The data have been encoded in the Excel software and then analyzed thanks to software Statgraphics Plus 5.0. Testing the significance was achieved thanks to ANOVA and Duncan test at 0.05.

The analysis of plant diversity focused on

Species richness (N): $N = 2^H$; 2 is the basis of the logarithm used to calculate the Shannon-Wiener's index (H).

Shannon-Wiener's Index (H): $= -\sum (ni/Ni) * \log_2 (ni/Ni)$ with ni = number of individuals of the species, Ni = total number of individuals; H is expressed in bit.

Pielou index (E): $= H / \log_2 N$.

Sørensen similarity index: $S = (2c) / (a + b) \times 100$ with a = number of species in survey 1, b = number of species in survey 2, c = number of species common to both surveys.

Simpson's diversity index (Ds) $= 1 - [(ni (ni - 1)) / (N (N - 1))]$.

Density (D): $D = n/S$ where D = Density (stems/ha), n = total of individuals in a sample plot; S = area of the sample plot (ha).

The Basal area (Ba) of individual trees

$$BA = \frac{\pi}{4} D^2 \quad \text{Where } Ba = \text{basal area (m}^2/\text{ha)}, D = \text{dbh (cm)} \text{ and } \pi = 3.142 \text{ (constant)}$$

Biovolume is defined as the volume of wood provided by vegetation in a given area. It makes it possible to estimate the wood potential of plant formation. It is given by the formula of [37]: Biovolume (V) $= 0.53 \sum Ba \times h \times n$ with Ba : Basal area (m²/ha). h : the height

of the barrel (m); n: total number of individuals; V: biovolume (m^3/ha). According to [37], the biovolume is high when it is greater than $250 \text{ m}^3 / \text{ha}$, medium when it is between 50 and $250 \text{ m}^3 / \text{ha}$, and low, when it is less than $50 \text{ m}^3 / \text{ha}$.

With $\sum \text{Ba}_i$: sum of basal area of individuals (m^2/ha); $\sum h_i$: sum of heights of individuals (m); $\sum n_i$: sum total of individuals; V: biovolume (m^3/ha).

Relative frequency (RFi) was determined using the formula: $\text{RFi} = \text{AFi} / \text{TF} \times 100$

Where AFi=Absolute frequency of species and TF = Total Frequency (Sum of AFi).

Relative density (RDi) was determined using the formula: $\text{RDi} = \text{ADi} / \text{AD} \times 100$

Where ADi = Absolute density of species and AD = Absolute density.

Relative Dominance or Cover (RCi) was determined using the formula:

$\text{RCi} = \text{BAi} / \text{TBA} \times 100$.

Where BAi = Basal area of species and TBA = Total basal area.

Species Importance Value (SIV) of a species was calculated by adding the Relative frequency (RFi), Relative density (RDi) and Relative dominance (RCi).

The Family Importance Value Index (FIV) for botanical families was calculated by adding the IVI for different species of the same family.

Vertical structure

The distribution of woody individuals in diameter and height classes was conducted. Five diameter classes with amplitude equal to 15 cm have been established. Based on the results of height measurements, the individuals were grouped into 4 cm amplitude classes. All 5 classes were then simplified into large classes: regeneration, future stems, medium and large trees.

3. Results

3.1. Species richness

Within the four subdivisions, 7849 individuals were counted in all plots studied in this study. They are divided into 17 families represented by 20 genera and 38 species. Among the four subdivisions, cashew plantations in Bénoué subdivision have the greatest specific richness of undergrowth (24 species) (Table 1).

Table 1. Specific richness of the undergrowth in cashew agro-ecosystems.

Subdivision	Ages (Years)	Species	Gen- era	Families	Number of individu- als
Bénoué	0–10	16	12	8	761
	10–20	20	15	8	880
	+20	25	17	13	932
	Total	24	18	10	2573
Faro	0–10	16	10	7	500
	10–20	18	12	8	593
	+20	21	15	10	705
	Total	20	16	9	1798
Mayo-Loutii	0–10	17	11	7	493
	10–20	20	16	9	555
	+20	22	18	10	634
	Total	23	17	10	1682
Mayo-Rey	0–10	13	9	6	508
	10–20	14	12	9	601
	+20	19	10	11	687
	Total	19	13	8	1796
General total		38	20	17	7849

3.2. Species importance value (SIV)

The woody undergrowth of cashew plantations that have a high value index (SIV) are *Diospyros mespiliformis* in Bénoué (SIV = 70.71%), *Anogeissus leiocarpus* in the Faro (SIV = 49.57%), *Annona senegalensis* in the Mayo-Loutii (SIV = 61.28%) and *Terminalia laxiflora* in the Mayo-Rey (SIV = 101.76%) subdivisions (Table 2).

Table 2. Species importance Value.

Subdivision	Species	RCi (%)	RD _i (%)	RF _i (%)	SIV(%)
Bénoué	<i>Piliostigma thonningii</i>	1.12	6.39	8.39	15.91
	<i>Terminalia schimperiana</i>	0.59	6.72	4.60	11.92
	<i>Phyllanthus muellerianus</i>	0.43	5.66	5.66	11.76
	<i>Detarium microcarpum</i>	13.81	20.71	34.71	69.23
	<i>Diospyros mespiliformis</i>	18.40	23.10	29.20	70.71
	<i>Annona senegalensis</i>	6.19	12.66	10.60	29.45
	<i>Terminalia albida</i>	4.56	10.05	6.05	20.66
	<i>Combretum adenogonium</i>	6.17	5.66	3.60	15.45
	<i>Gardenia aqualla</i>	2.79	2.82	6.82	12.44
	<i>Terminalia laxiflora</i>	3.75	1.63	5.62	11.00
	Other species	1.47	10	20	31.47
Faro	<i>Combretum collinum</i>	8.45	14.25	16.15	38.85
	<i>Vitellaria paradoxa</i>	8.26	10.47	12.47	31.21
	<i>Piliostigma thonningii</i>	4.78	9.90	7.50	22.19
	<i>Faidherbia albida</i>	11.22	4.14	2.10	17.48
	<i>Balanites aegyptiaca</i>	5.82	10.00	8.06	23.89
	<i>Burkea africana</i>	10.38	1.27	3.27	14.94
	<i>Sterculia setigera</i>	10.52	0.30	0.30	11.13
	<i>Anogeissus leiocarpus</i>	44.08	0.20	0.28	49.57
	<i>Guiera senegalensis</i>	8.18	4.50	2.46	15.16
	<i>Prosopis africana</i>	34.31	0.62	0.60	35.53
	Other species	30.05	6.6	8.4	40.05
Mayo-Loutii	<i>Acacia seyal</i>	21.49	11.61	9.55	42.67
	<i>Lannea schimperi</i>	5.16	18.88	16.80	40.85
	<i>Annona senegalensis</i>	44.65	7.24	9.30	61.28
	<i>Albizia zygia</i>	36.67	6.96	8.80	52.43
	<i>Vitex domiana</i>	4.38	14.70	10.70	29.79
	<i>Khaya senegalensis</i>	7.72	8.40	5.46	20.59
	<i>Detarium microcarpum</i>	3.05	5.80	7.88	16.73
	Other species	5.00	13.36	17.30	35.66
Mayo-Rey	<i>Terminalia laxiflora</i>	36	36.96	28.8	101.76
	<i>Sterculia setigera</i>	14.38	24.7	20.7	59.78
	<i>Faidherbia albida</i>	10.45	17.05	16	43.5
	<i>Piliostigma reticulatum</i>	16.07	10.12	13.6	39.79
	<i>Sclerocarya birrea</i>	11.79	2.82	10.7	25.31
	<i>Ximenia americana</i>	10	1.63	5.6	17.23
	Other species	1.31	6.72	4.6	12.63

Note: RF_i: Relative frequency; RD_i: Relative density; RC_i: Relative Dominance or Cover; SIV: Species Importance Value

3.3. Species importance value (SIV)

Combretaceae have the highest family importance values in all four subdivisions: Bénoué (FIV=89.35 %), Faro (FIV=79.98 %), Mayo-Loutii (FIV= 77.09 %) and Mayo-Rey (71.53 %) (Table 3).

Table 3. Families Importance Value (FIV).

Subdivision	Families	RFi (%)	RD _i (%)	RC _i (%)	FIV (%)
Bénoué	Combretaceae	29.21	32.03	28.09	89.35
	Euphorbiaceae	0.43	4.60	6.72	11.76
	Caesalpiniaceae	1.500	20.58	14.50	36.59
	Rhamnaceae	2.59	4.70	2.74	10.04
	Sapotaceae	0.39	2.20	8.24	10.85
	Anacardiaceae	6.03	9.32	5.30	20.66
	Annonaceae	10.74	17.10	11.14	38.98
	Mimosaceae	16.15	16.60	10.62	43.38
	Burseraceae	4.66	10.53	4.49	19.70
	Other families	5.61	8.50	3.58	18.69
Faro	Combretaceae	24.62	30.74	24.60	79.98
	Euphorbiaceae	18.42	10.73	16.53	45.70
	Caesalpiniaceae	18.65	4.40	6.59	29.64
	Annonaceae	9.01	0.42	4.30	13.75
	Rubiaceae	16.44	8.60	6.72	31.76
	Mimosaceae	28.06	10.00	16.20	54.27
	Ebenaceae	11.60	0.90	0.74	13.26
	Sapotaceae	2.85	1.62	5.80	10.29
	Other families	9.35	8.00	4.00	21.35
Mayo-Loutii	Mimosaceae	17.36	10.04	6.00	33.41
	Caesalpiniaceae	4.42	3.04	9.04	16.50
	Euphorbiaceae	4.42	10.00	2.08	16.50
	Combretaceae	12.06	32.00	33.02	77.09
	Burseraceae	10.76	4.00	0.06	14.83
	Verbenaceae	4.38	12.60	8.80	25.79
	Malvaceae	17.72	4.33	7.53	30.59
	Meliaceae	10.05	13.04	7.20	30.31
Other families	24.50	10.28	20.10	54.98	
Mayo-Rey	Combretaceae	21.09	30.2	20.24	71.53
	Anacardiaceae	16.6	20.32	18.3	55.22
	Annonaceae	16.03	15.3	18.3	49.63
	Euphorbiaceae	3.06	9.1	17.15	29.31
	Burseraceae	10.06	5	12.06	27.12
	Verbenaceae	4.38	12	6.4	22.78
	Malvaceae	16.72	4.33	4.53	25.58
Other families	12.06	3.75	3.02	18.83	

Note: RFi: Relative frequency; RD_i: Relative density; RC_i: Relative Dominance or Cover; FIV: Families Importance Value Index

3.4. Index of diversity in the undergrowth with cashew agroecosystems

Shannon-Wiener's Index: The highest value of the Shannon-Wiener's Index was recorded in Cashew agro-ecosystems (2.93 ± 0.50 bits) of Mayo-Loutii subdivision. The analysis of variance shows that there are no significant differences in the Shannon-Wiener's Index between the age groups ($F=0.22$; $P=0.8138 > 0.05$) and between the subdivisions ($F=0.24$; $p=0.8643 > 0.05$) (Table 4).

Pielou index: There is a Pielou index within species with a maximum value equal to 1. The analysis of variance shows that there are no significant differences in the Pielou index between the age groups ($F=0.32$; $P=0.7138 > 0.05$) and between the subdivisions ($F=0.34$; $p=0.7043 > 0.05$) (Table 4).

Simpson's index: There is a Simpson index within species with a maximum value tending to 1. Analysis of variance shows that there are no significant differences in the Simpson index between the age groups ($F=0.164$; $P=0.213 > 0.05$) and between the subdivisions ($F=1.31$; $P=0.3370 > 0.05$) (Table 4).

Importance Value Index: There is an Importance Value Index within species with a maximum value equal to 300 ± 57.47 . The analysis of variance shows that there are no significant differences in the Importance Value Index between the age groups ($F=0.164$; $P=0.286 > 0.05$) and between the subdivisions ($F=0.31$; $P=0.3370 > 0.05$) (Table 4).

Table 4. The index of diversity in Cashew agroecosystems.

Subdivision	Ages (Years)	ISH	EQ	DS	IVI
Bénoué	0–10	$2.28 \pm 0.07a$	$0.98 \pm 0.01a$	$0.75 \pm 0.15a$	$300 \pm 57.47a$
	10–20	$2.95 \pm 0.06a$	$0.99 \pm 0.01a$	$0.86 \pm 0.12a$	$300 \pm 57.47a$
	+20	$3.47 \pm 0.17a$	$0.98 \pm 0.01a$	$0.93 \pm 0.11a$	$300 \pm 57.47a$
	Mean	$2.90 \pm 0.59A$	$0.98 \pm 0.05A$	$0.84 \pm 0.09A$	$300 \pm 57.47A$
Faro	0–10	$2.29 \pm 0.06a$	$0.98 \pm 0.01a$	$0.75 \pm 0.15a$	$300 \pm 57.47a$
	10–20	$2.70 \pm 0.06a$	$0.99 \pm 0.01a$	$0.80 \pm 0.10a$	$300 \pm 57.47a$
	+20	$3.42 \pm 0.06a$	$0.98 \pm 0.01a$	$0.88 \pm 0.14a$	$300 \pm 57.47a$
	Mean	$2.80 \pm 0.57A$	$0.98 \pm 0.05A$	$0.81 \pm 0.06A$	$300 \pm 57.47A$
Mayo-Loutii	0–10	$2.43 \pm 0.05a$	$0.98 \pm 0.01a$	$0.78 \pm 0.15a$	$300 \pm 57.47a$
	10–20	$2.95 \pm 0.09a$	$0.99 \pm 0.01a$	$0.86 \pm 0.12a$	$300 \pm 57.47a$
	+20	$3.43 \pm 0.16a$	$0.98 \pm 0.01a$	$0.90 \pm 0.17a$	$300 \pm 57.47a$
	Mean	$2.93 \pm 0.50A$	$0.98 \pm 0.05A$	$0.84 \pm 0.06A$	$300 \pm 57.47A$
Mayo-Rey	0–10	$2.18 \pm 0.09a$	$0.98 \pm 0.01a$	$0.70 \pm 0.18a$	$300 \pm 57.47a$
	10–20	$2.25 \pm 0.09a$	$0.99 \pm 0.01a$	$0.72 \pm 0.12a$	$300 \pm 57.47a$
	+20	$3.29 \pm 0.06a$	$0.98 \pm 0.01a$	$0.82 \pm 0.15a$	$300 \pm 57.47a$
	Mean	$2.57 \pm 0.62A$	$0.98 \pm 0.05A$	$0.74 \pm 0.06A$	$300 \pm 57.47A$

Note: ISH: Shannon's Index; EQ: Pielou index; DS: Simpson's Index; IVI: Importance Value Index. The assigned values of the same letter are not statistically different ($p > 0.05$, Duncan's test).

3.5. Floristic similarity

The Sørensen similarity index is very high with floristic affinities greater than or equal to 90% (Table 5).

Table 5. Similarity Coefficients.

Subdivision	Parcelles	Bénoué			Faro			Mayo-Loutii			Mayo-Rey		
		PA1	PA2	PA3	PA1	PA2	PA3	PA1	PA2	PA3	PA1	PA2	PA3
Bénoué	PA1	100											
	PA2	93.98	100										
	PA3	90.54	96.64	100									
Faro	PA1	97.33	90.84	95.54	100								
	PA2	90.54	97.88	93.80	95.71	100							
	PA3	95.5	96.96	97.50	91.04	95.54	100						
Mayo-Loutii	PA1	91.82	93.34	90.76	90.73	90.76	93.98	100					
	PA2	93.03	97.62	94.59	95.92	94.59	90.54	96.12	100				
	PA3	90.44	93.78	98.94	93.32	98.94	97.33	98.98	95.74	100			
Mayo-Rey	PA1	97.98	97.04	90.06	94.03	90.06	90.54	96.93	95.08	90.92	100		
	PA2	94.55	98.09	96.67	97.04	96.67	93.34	95.54	96.14	94.84	93.54	100	
	PA3	91.27	94.03	97.96	92.04	97.96	97.62	93.74	90.92	98.44	94.03	96.08	100

Note: **PA1**: 0–10 years old; **PA2**: 10–20 years old; **PA3**: + 20 years old

3.6. Vegetation structure index

Density: The highest value of the density was recorded in Cashew agro-ecosystems (125 ± 2.64 indiv/ha) of Bénoué subdivision. The analysis of variance shows that there is no significant difference in the density of plantations within the four subdivisions ($F = 3.73$; $P = 0.0606 > 0.05$) (Table 6).

Basal area: The highest value of the basal area was recorded in Cashew agro-ecosystems (8.43 ± 4.91 m²/ha) of Bénoué subdivision. The analysis of variance shows that there is no significant difference in the average basal area of plantations between the four subdivisions ($F = 0.19$; $P = 0.9035 > 0.05$) (Table 6).

Biovolume: The highest value of the biovolume was recorded in Cashew agro-ecosystems (8.43 ± 4.91 m³/ha) of Bénoué subdivision. The analysis of variance shows that there is no significant difference in the average biovolume of the plantations within the four subdivisions ($F = 0.08$; $P = 0.9688 > 0.05$) (Table 6).

Table 6. The vegetation structure index.

Subdivision	Ages (Years)	Density (indiv/ha)	Basal area (m ² /ha)	Biovolume (m ³ /ha)
Bénoué	0–10	$128 \pm 6.36e$	$3.05 \pm 0.84b$	$16.70 \pm 3.41c$
	10–20	$124 \pm 1.78d$	$9.58 \pm 0.99f$	$43.69 \pm 5.09f$
	+ 20	$123 \pm 1.81d$	$12.68 \pm 2.01h$	$68.03 \pm 13.21h$
	Mean	$125 \pm 2.64B$	$8.43 \pm 4.91A$	$42.80 \pm 25.67A$
Faro	0–10	$119 \pm 4.32c$	$2.17 \pm 0.20a$	$13.94 \pm 0.74b$
	10–20	$112 \pm 4.69b$	$5.91 \pm 0.90 cd$	$26.08 \pm 6.01d$
	+ 20	$102 \pm 2.82a$	$10.11 \pm 1.31 fg$	$59.88 \pm 20.39g$
	Mean	$111 \pm 8.54A$	$6.06 \pm 3.97A$	$33.30 \pm 23.80A$
Mayo-Loutii	0–10	$114 \pm 1.87b$	$2.02 \pm 0.31a$	$11.58 \pm 1.29a$
	10–20	$102 \pm 1.92a$	$5.06 \pm 0.37c$	$25.56 \pm 1.74d$
	+ 20	$111 \pm 1.64b$	$11.34 \pm 2.72g$	$67.85 \pm 19.18h$
	Mean	$109 \pm 6.24A$	$6.14 \pm 4.75A$	$34.99 \pm 29.29A$
Mayo-Rey	0–10	$122 \pm 1.30 cd$	$2.85 \pm 0.14ab$	$14.30 \pm 0.47b$
	10–20	$111 \pm 0.83b$	$7.09 \pm 1.89e$	$33.13 \pm 11.44e$

	+ 20	110 ± 2.86b	10.86 ± 2.90g	60.00 ± 20.80g
Mean		114 ± 6.65AB	6.93 ± 4.00A	35.91 ± 22.96A

The assigned values of the same letter are not statistically different ($p > 0.05$, Duncan's test).

3.7. Distribution by diameter class

The analysis of this figure shows that all distributions have a bell shape and fit better to a polynomial function of degree three. These four distributions have determination coefficients (R^2) ranging from 0.930 to 0.968. The distribution is then asymmetric positive or asymmetric right, characteristic of monospecific stands with a predominance of young or small-diameter individuals, centered on the class]15–25 cm]. The analysis of variance shows that there is a highly significant difference ($p < 0.01 < 0.05$) in the diameter class. Indeed, in all four subdivisions, most populations are made up of individuals between 15 and 25 cm in diameter (60.55 %). The classes 5 to 15 cm; 25 to 35 cm and 35 to 45 cm represent 17.15%, 10 % and 7.82% of the population, respectively, while individuals larger than 45 cm in diameter are poorly represented (4.48 %) (Figure 3).

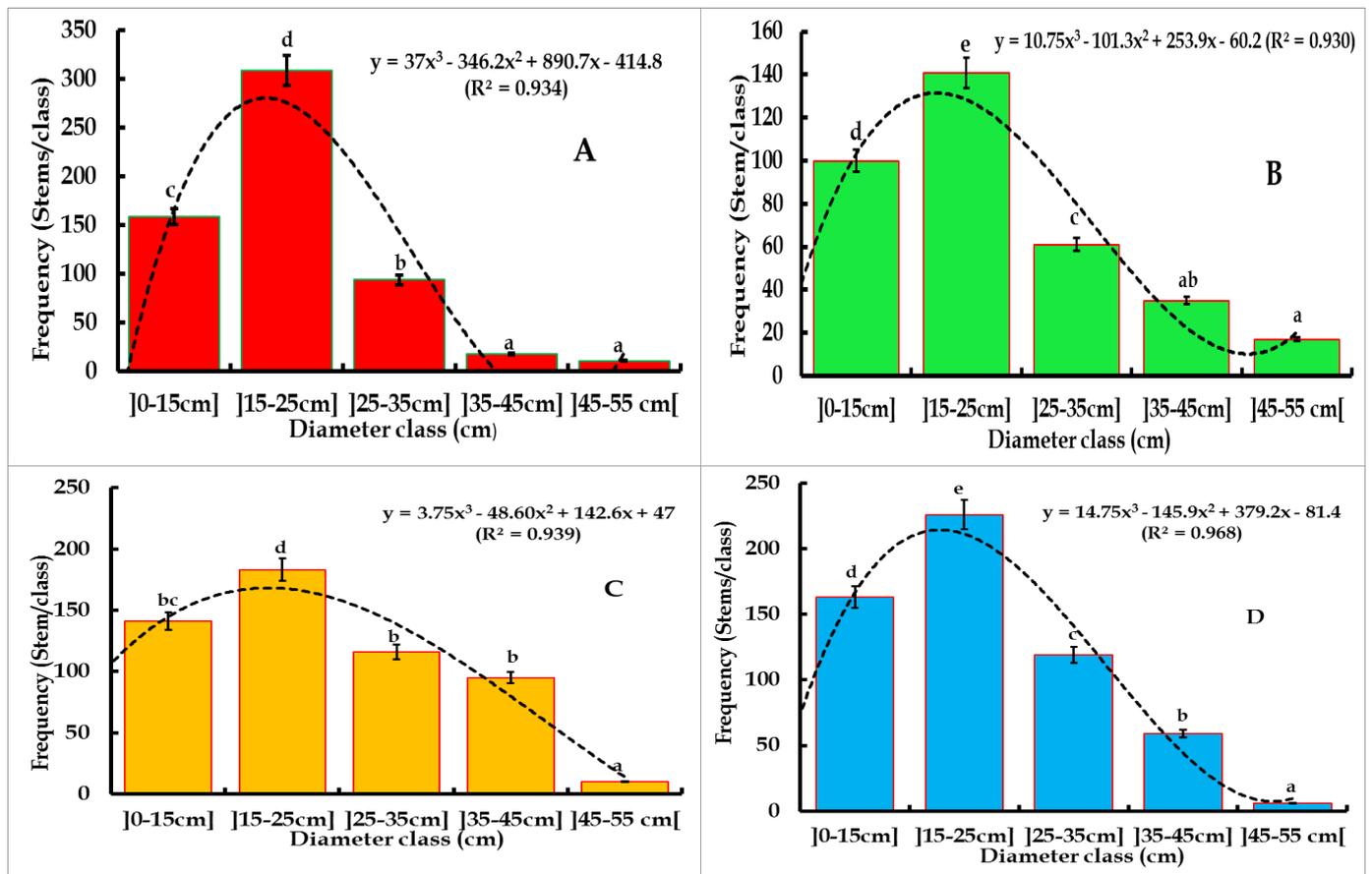


Figure 3: Distribution by diameter class according to the frequency of cashew trees' feet. A: Bé-noué; B: Faro; C: Mayo-Loutii; D: Mayo-Rey. The assigned values of the same letter are not statistically different ($p > 0.05$, Duncan's test).

3.8. Distribution by total height class

The analysis of this figure shows that the distributions have a closed form and adapt better to a polynomial function of degree three. These four distributions have determination coefficients (R^2) ranging from 0.728 to 0.998. Like the diametric structure, the distri-

bution by total height class of cashew plantations in the four subdivisions shows a predominance of young feet. Trees in the total height class] 5–9 m] is the most dominant. The analysis of variance shows that there is a highly significant difference ($p < 0.01 < 0.05$) in the diameter class. Indeed, in all four subdivisions, individuals in the 5 to 9 m height class are in the majority (68.69 %), followed by those in the 1 to 5 m class (17.95 %). The 9–13 m and more than 13 m classes represent 10.74% and 2.62 % of the stand, respectively (Figure 4).

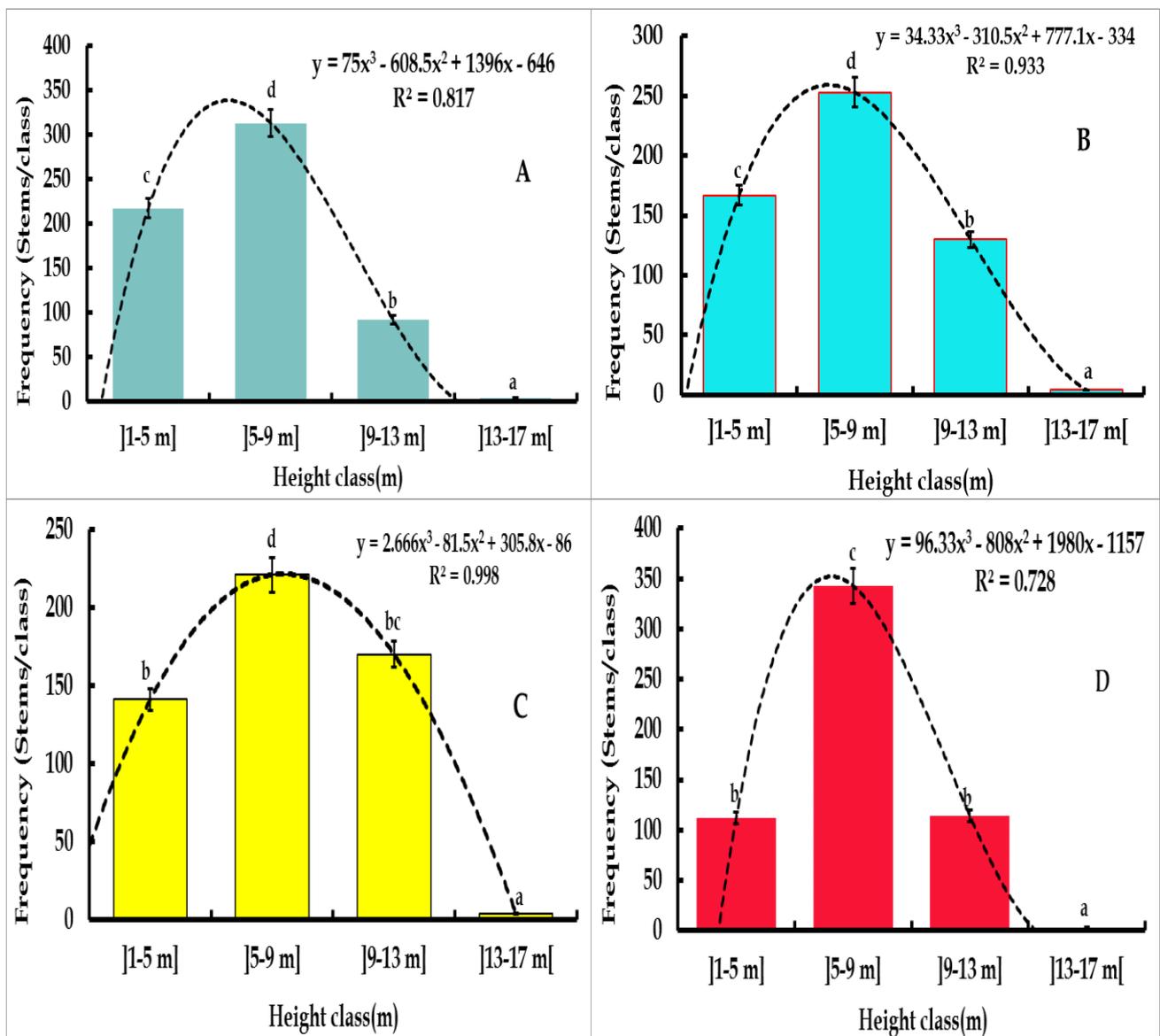


Figure 4. Distribution by total height class according to the frequency of cashew trees' feet. A: Bé-noué; B: Faro; C: Mayo-Loutii; D: Mayo-Rey. The assigned values of the same letter are not statistically different ($p > 0.05$, Duncan's test).

3.9. Species associations in cashew plantations

Fruit species found in plantations

In addition to the associated annual species, some tree species co-exist with cashew seedlings. These are useful trees that were saved during the establishment of cashew orchards. In the four study subdivisions, *Vitellaria paradoxa* is the most dominant fruit tree (15 %) in the plots of different age groups (Figure 5).

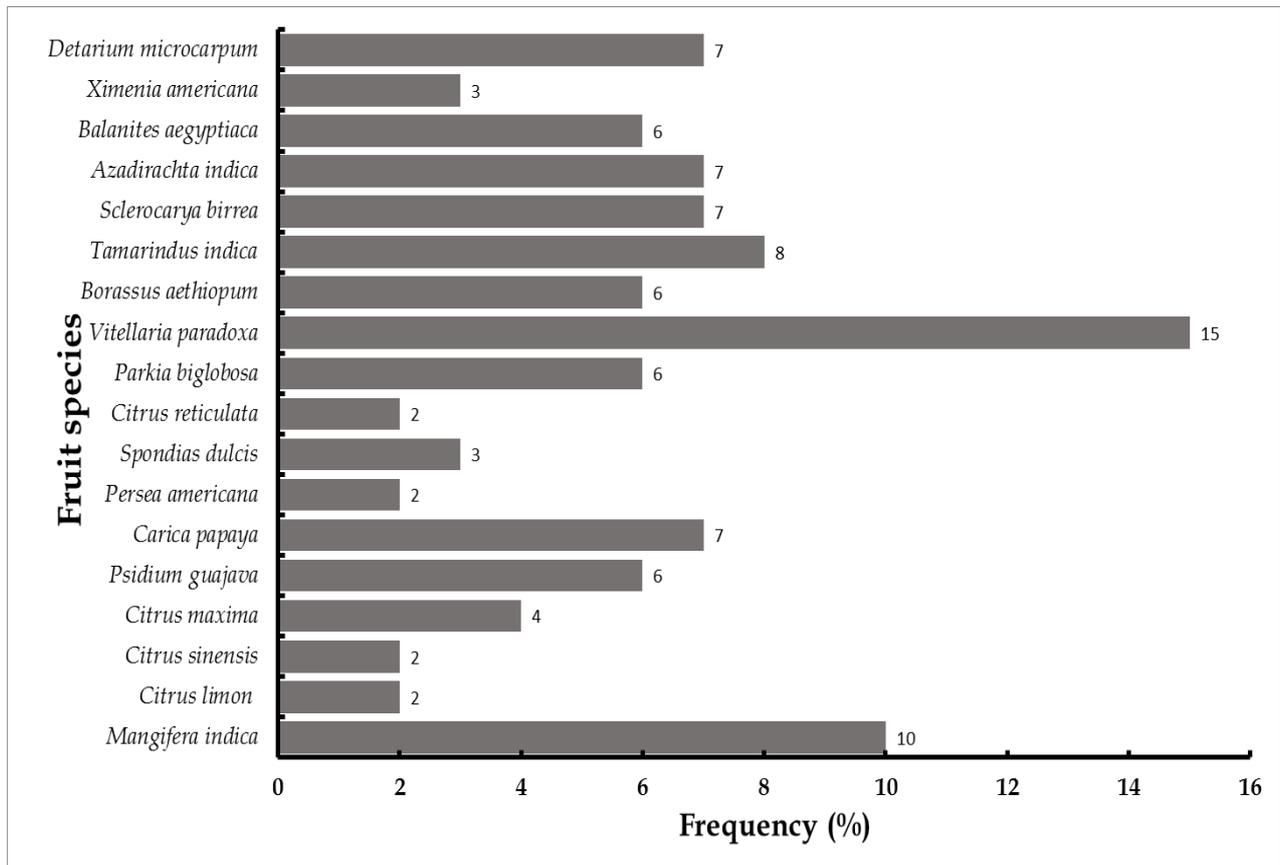


Figure 5. Representative of fruit species in cashew tree plantations in the four Study areas.

3.10. Annual crops associated with the undergrowth of cashew plantations

For the associations of annual crops in the undergrowth of cashew tree plantations studied in the four subdivisions, it appears that fourteen (14) species are the most cultivated, *Arachis hypogea* is the most cultivated (40.54%) in the undergrowth of cashew tree plots. The *Corchorus olitorius* (10.4%) is ranked third after *Vigna unguiculata* (20.11%) (Table 7).

Table 7. The proportion of crops associated with cashew trees.

Scientific Names	Families	Proportion (%)
<i>Arachis hypogea</i>	Fabaceae	40.54
<i>Pennisetum glaucum</i>	Poaceae	2.45
<i>Zea mays</i>	Poaceae	2.7
<i>Glycine max</i>	Fabaceae	3.19
<i>Hibiscus esculentus</i>	Malvaceae	1.54
<i>Vigna unguiculata</i>	Fabaceae	20.11
<i>Sesamum indicum</i>	Pedaliaceae	1.89
<i>Vigna subterranea</i>	Fabaceae	1.65
<i>Dioscorea alata</i>	Diocoreaceae	1.58
<i>Manihot esculantus</i>	Euphorbiaceae	5.43
<i>Capsicum annuum</i>	Solanaceae	1.33
<i>Corchorus olitorius</i>	Tiliaceae	10.4
<i>Ipomoea batatas</i>	Convolvulaceae	2.65
<i>Hibiscus sabdariffa</i>	Malvaceae	4.54

3.11. Species with special status

The general list of species surveyed reveals 14 species of special status, representing 36.84% of all species surveyed. Among these species, 14 are cited as rare and endangered species of Cameroonian flora. These species are used by local communities for nutritional, medicinal and commercial purposes. It is necessary to promote education and awareness among local populations and to put in place measures for protection, enhancement and domestication of these endangered species (Table 8).

Table 8. Endangered species of IUCN (**VU: Vulnerable; LR: Lower risk; EN: endanger; LC: Least concern**)

Species	Families	IUCN Criteria
<i>Adansonia digitata</i>	Bombacaceae	VU
<i>Anogeissus leiocarpus</i>	Combretaceae	VU
<i>Khaya senegalensis</i>	Meliaceae	VU
<i>Sclerocarya birrea</i>	Anacardiaceae	VU
<i>Vitellaria paradoxa</i>	Sapotaceae	VU
<i>Ximenia americana</i>	Olacaceae	VU
<i>Detarium microcarpum</i>	Fabaceae	LC
<i>Entada africana</i>	Leguminosae	LC
<i>Prosopis africana</i>	Fabaceae	LC
<i>Tamarindus indica</i>	Fabaceae	LC
<i>Vitex doniana</i>	Lamiaceae	LC
<i>Balanites aegyptiaca</i>	Balanitaceae	LR
<i>Diospyros mespiliformis</i>	Ebenaceae	EN
<i>Erythrina sigmoidea</i>	Leguminosae	EN

4. Discussion

A total of 7849 individuals were counted in all plots in the four subdivisions studied in this study. They are divided into 17 families represented by 20 genera and 38 species. In terms of species diversity, the results of the inventories in the different plots show a lower diversity compared to the inventories of [11] identified 69 species comprising 31 families and 58 genera in cashew plantations in North Cameroon; in the Adamawa region, [20] respectively identified 70 species comprising 30 families, 53 genera in *Eucalyptus* sp plantations. Cashew plantations in the Bénoué subdivision are richer in phytodiversity (24 species). These results conclude that land management methods offer a significant floristic diversity that varies according to techniques, ages and regions. The importance value index of the different plots is of the order of 300. The presence of tall trees in these plots explains the importance value index. This result leads to the same conclusion as those of [19, 21] who state that trees with large crowns contribute more to cover and to some degree of cover, they modify ecological conditions by reducing air evaporative power, promoting the soil water balance and improving fertility. This value is higher than that found in northern Cameroon by [11] who found 150. In the cashew plantations of the four subdivisions, Combretaceae is the most important, followed by the Mimosaceae and Caesalpiniaceae. These results are similar to those of [22, 23, 24, 25, 26]. Indeed, in the Combretaceae, we find species capable of resisting disturbances. This family is the most common and strongly represented in tropical countries, particularly in the savannah of Africa and more typically in the Sudano-Sahelian zone. *Terminalia laxiflora* is the best represented species and therefore has a better recovery, therefore is the most predominant species.

The Shannon index is higher under plots of more than 20 years old in the Bénoué subdivision (3.47 ± 0.17 bits). This Shannon index indicates a medium diversity within the plant group under consideration, which means that the conditions at the station are favourable for the installation of a large number of species equal proportions. The value of the average Shannon index of the undergrowth of cashew plantations is less than 3. These values show homogeneity and testify to a flora that is not diversified in the undergrowth of cashew trees. These results are relatively close to those of [11] to cashew agro-ecosystems of Cameroon. The Pielou equitability tends toward one in all plots being high represents the presence of no dominant species. These results are very far from those of [27] to cocoa agroecosystems (Cameroon). But are similar to those of [28] to *Eucalyptus* sp agroecosystems in the Adamawa region of Cameroon. These values reflect the presence of preexisting savannah species in the stands of the systems studied and these associated species are homogeneously and equitably distributed. The Simpson index is sensitive to the distribution of individuals between species. These values can also be interpreted as resulting from the effect of increased plant density, which is accompanied by an increase in species diversity after forest disturbances in tropical environments [3]. Simpson's index tends toward one in all plots. These results are similar to the values obtained by [29] in the agroforests of the peri-urban area of the city of Bafia (Central Region of Cameroon). A two-by-two comparison of the floristic composition of the four subdivisions, using Sorensen's method, indicates a similarity threshold greater than or equal to 90 %, thus showing that the different subdivisions studied are part of the same floristic ensemble. The pressure of timber exploitation exerted by the peasant populations explains the variation in the abundance of cashew tree plantations from one subdivision to another.

In comparing cashew plantations in the four subdivisions, note that cashew plantations in the Bénoué subdivision are denser (125 ± 2.64 indiv/ha). These results are lower than the values of 200 indiv/ha, 250 indiv/ha, 475 indiv/ha, 225 indiv/ha obtained, respectively, by [30] in cashew plantations in the North-western, Southern, and Central of Benin. However, these results are close to the value of 100 indiv/ha and 139 indiv/ha obtained by [30] in cashew plantations in the Far North and North-West of Benin; But are higher than the value of 77 indiv/ha obtained by [31] in the Talba of Central Cameroon. They are also not close to those of [28] in *Eucalyptus* plantations (53.17 ± 0.08 indiv/ha). In terms of age according to cashew tree stands, cashew tree plots over 20 years old in Bénoué subdivision are denser (123 ± 1.81 indiv/ha). These results are higher than the values obtained by [11] to cashew trees over 20 years old (38.64 ± 47.42 indiv/ha). The farmers' desire to provide plant cover, thus protecting it from light radiation and creating a microclimate favorable to the flowering of the cashew tree explains the differences observed between the plots studied and those of other authors. High density is observed in cashew trees 0–10 years old in the Bénoué subdivision (128 ± 6.36 indiv/ha). This high density means that the stems that make it possible to reconstitute the environment are shrubs. In addition to the fruit trees left in the cashew trees, the dominance of cashew is responsible for the high density of the stems. Stand density and tree distribution patterns vary with topography, soil, exposure, silvigenetic stages, and human activity. The highest values of basal area are observed in plots older than 20 years. The existence of large tree specimens in plots over 20 years old explains the higher basal area values. The impact of human activities, such as the killing of individuals during clearing for the establishment of agricultural plots and the devastating actions of animals (cattle) explains the low values of basal area in the 0-10 year-old plots. These results are close to the values obtained by [11] to over 20 years old cashew tree plantations (15.23 ± 0.07 m²/ha). The ecological characteristics of the study environments, in particular the types of soil, topography, climate and cover, explain the differences in the basal area of the cashew agro-ecosystems studied.

The highest biovolumes were recorded in cashew trees over 20 years old in Bénoué subdivision ($68.03 \pm 13.21 \text{ m}^3/\text{ha}$), which means that these plots have a high wood potential due to their large diameters. The absence of anthropogenic activities in these cashew plots explains the high biovolume values. The results obtained in this study are much lower than the $428.68 \text{ m}^3/\text{ha}$; $285.57 \text{ m}^3/\text{ha}$; $105.66 \text{ m}^3/\text{ha}$ found respectively by [32] in Agroforests, semi-deciduous dense forests and forest galleries and the wooded and shrubby savannas of the Akposso Plateau in the sub-humid zone in Togo.

The bell-shaped distribution skewed to the left, characterized by a decreasing distribution of individuals, from small diameter classes to large diameter classes. Germinations occurring in cohorts explain the strong presence of young individuals. This type of distribution is obtained by [33] in *P. butyracea* populations in the municipalities of Natitingou, Boukombé and Toucountouna, similar to that of *Isoberlinia* spp. tree / wooded savannas of the classified forest of Wari-Marou (Center Benin) by [34].

The height class distribution has a bell-shaped structure centered on the class] 5–9 m] reflecting a predominance of medium height individuals. Large individuals are more traumatized by humans and animals; being under anthropogenic pressure, they do not have the chance to grow, explain these results obtained. However, the bell-shaped structure is a sign that the ecosystem as a whole is in a state of degradation as also concluded by [28] after finding the same structure in the *Eucalyptus* sp agroecosystems of Adamawa in Cameroon.

The local species found in cashew tree plantations come from natural regeneration. They have socio-economic importance and the exploitation of their seeds generate substantial income. These results are similar to those of [35,36] in the agroforestry from Cameroon. The productivity of corn grown under tree cover are below expectations. Good yields are only observed in agro-systems where all the trees are pruned. The plantations established have a soil cover rate that is not very favorable to the productivity of sun-loving crops, which explains this situation. Associations are rare in cashew plantations after 10 years of planting. The reason is that according to the farmers, the land that houses these trees is poor, and that is what we have also found. The presence of special-status species, particularly in terms of their numbers (14), confirms the role that cashew plantations can play in conserving biodiversity in general. The significant and uncontrolled overexploitation has an influence on the presence of IUCN Red List species cited in this study.

5. Conclusion

The objective of this study is to demonstrate the effectiveness of Cashew agro-ecosystems in the food security of the populations, the conservation of phytodiversity. Cashew agro-ecosystems of North region (Cameroon) thus contain a remarkable high biodiversity. This study reveals a significant potential of even the most threatened taxa in the Sudano-Sahelian zone of Cameroon. Thus, 38 species belonging to 17 families represented by 20 genera are inferred from cashew plantations in the Sudano-Sahelian zone of Cameroon, which illustrates the conservative nature of the plant diversity of these agro-ecosystems. The presence of threatened plant species in these agro-ecosystems confirms their ecological usefulness and justifies the need for their conservation. Given the importance of this agro-ecosystem on the social, ecological and environmental levels, such systems are considered as factors of local development and guarantee food security for local populations. This study also showed that crops associated with cashew trees, mainly legumes and fruit trees, are important for increasing the productivity of these agro-ecosystems. The latter have indeed revealed a not insignificant floristic diversity but exposed to intense and continuous degradation that risks in the near future to make the species

useful for humans disappear. In the end, these results are also of great economic, ecological and dynamic informative value that should serve as a basis for guiding any action program aimed at the conservation and management of these agroecosystems.

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Conflict of Interest

The author declares that there is no conflict of interest regarding the publication of this manuscript.

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