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MANAGEMENT OF BIODIVERSITY UNDER EUCALYPTUS AGRO-ECOSYSTEMS IN CENTRAL AFRICA: AN CASE STUDY IN THE SUDANO-SAHELIAN ZONE AND THE HIGH GUINEAN SAVANNAH ZONE OF CAMEROON

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ABSTRACT

The aim of this study was to assess the diversity and structure of the understory vegetation in eucalyptus agro-ecosystems based on age. In zone I, there were 5671 individuals across 13 families, 19 genera, and 21 species, whereas in zone II, there were 21323 individuals from 24 families, 45 genera, and 65 species. Eucalyptus agro-ecosystems in zone II exhibited higher understory species richness compared to zone I. The most abundant family in zone I was Caesalpiniaceae, followed by Anacardiaceae and Verbenaceae. In zone II, the most represented family was Clusiaceae, Hymenocardiaceae and Myrtaceae. The average density was highest in 10–20-year-old plantations in the Ngaoundere I/II district (433 ± 84.7 indiv/ha). Basal area increased with age, ranging from 1.35 ± 0.32 m²/ha to 17.59 ± 3.71 m²/ha. In zone I, an exponentially decreasing, steep-sloped, and inverted (J-shaped) structure that better fit a fifth-degree polynomial function was observed in all plots. This information constitutes in order to elaborate management plans in view of a lasting management.

Keywords: Agro-ecosystems, Zone I, Zone II, diversity, Cameroon.

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1. INTRODUCTION

In recent decades, there has been a widespread degradation of natural ecosystems, fueled by unfavorable socio-economic and pedoclimatic conditions, leading to a significant reduction in plant formations (Goudiaby *et al.* 2017). Human activities such as deforestation, shortened fallow periods, overgrazing, and general resource degradation have contributed to this decline (Ferreira *et al.* 2006). To combat deforestation and meet timber demands, national natural resource management policies have shifted towards planting fast-growing exotic and local species with high wood yields (Djégo and Sinsin 2006). These exotic plantations now dominate large areas, displacing natural forests at an unprecedented rate (Sykes, 2001). This transformation from natural forests to exotic plantations threatens stable and diverse biodiversity (Nguyen *et al.* 2006). Researchers argue that native species play a crucial role in maintaining high biodiversity levels compared to introduced species (Pamela *et al.* 2003). Eucalyptus, a widely planted forestry genus, is known for its rapid growth, diverse species, and adaptability, although concerns exist about its negative impacts on soil and plant diversity (Tassin *et al.* 2011). The lack of comparative studies between eucalyptus plantations and monospecific local species plantations highlights the need for further research (Peterken 2001). Eucalyptus species alter soil physicochemical characteristics and reduce understorey light, potentially affecting plant diversity and soil biochemistry (Grierson *et al.* 2000). This growing interest in the effects of eucalyptus plantations on biodiversity and soil quality underscores the need for more comprehensive studies, particularly in regions like northern Cameroon where little research has been conducted since eucalyptus was introduced. The aim of this study is to evaluate the diversity and structure of understorey vegetation in eucalyptus agroecosystems in the Sudanian-sahelian and Guinea savannah zones of Cameroon, guided by the hypothesis that Eucalyptus sp. negatively impacts woody biodiversity. Savannah zones of Cameroon, guided by the hypothesis that Eucalyptus sp. negatively impacts woody biodiversity.

2. MATERIALS AND METHODS

2.1 Study area

The study was conducted in two areas: the Sudano-Sahelian zone of North region (zone I) and the high Guinea savannah zone of the Adamawa region (zone II) in Cameroon. Ngaoundere is located in the northern part of the central plateau of Adamawa (Tchotsoua 2006). The city occupies a plateau of about 2500 km^2, bounded to the north by the Ngaoundéré cliff and to the south by the Djérém (Tchotsoua *et al.* 1998). The Adamawa region is situated between 7°03' and 7°32' North latitude, and 13°20' and 13°54' East longitude (Fig. 1). It is characterized by granite massifs with some peaks and volcanic accumulations (Tchotsoua *et al.* 1999). The study was carried out in the Vina department and Ngaoundéré Ier/IIe and III districts. North region of Cameroon extends between 8° and 10° North latitude and between 13° and 15° East longitude, bordered to the North by the Extreme North region, to the South by the Adamawa region, to the East by Chad and the Central African Republic, and to the West by Nigeria (Noiha *et al.* 2017). The administrative region of Northern Cameroon comprises four departments: Bénoué with Garoua as the capital, Faro with Poli as the capital, Mayo Louti with Guider as the capital, and Mayo Rey with Tchollíré as the capital.

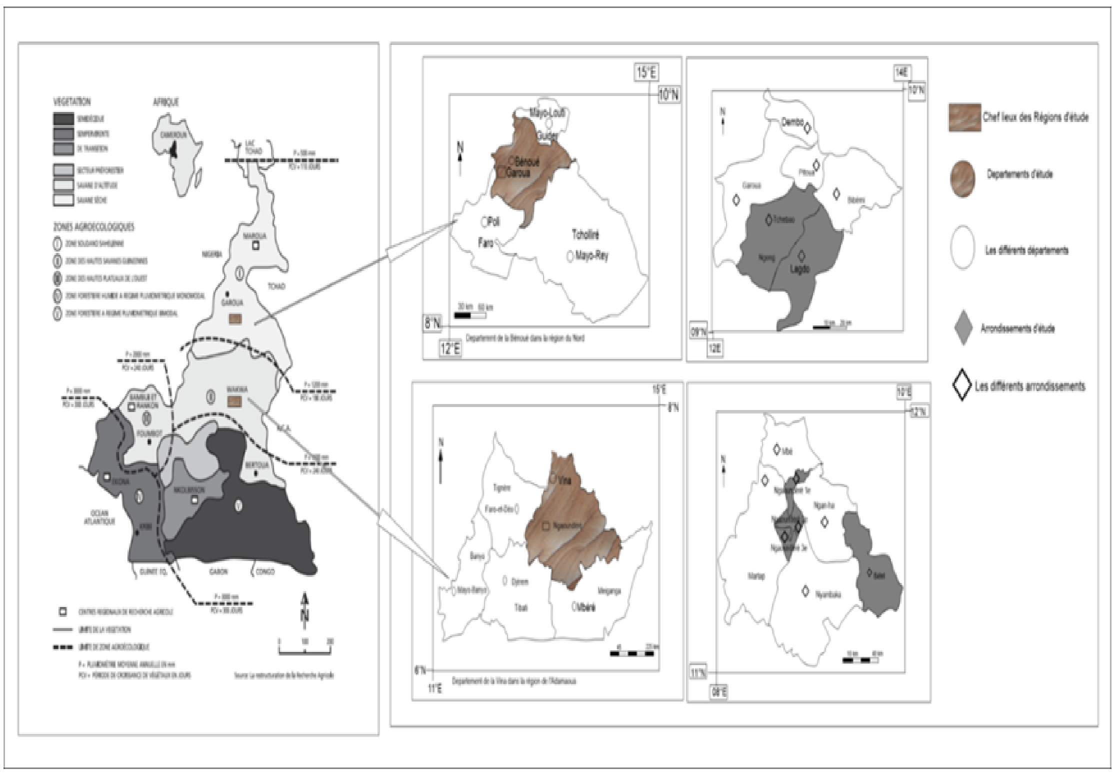

Figure 1: Map of study zone

2.2. Data collection and analysis

The choice of study site was based on the availability, age, area (≥1ha), and density of eucalyptus agroe-cosystems. Three age classes were defined: "immature" for plantations under 10 years, "young" for plantations between 10 and 20 years (Saj et al. 2017), and "Mature" for plantations over 20 years. The experimental design was a split-plot with 5 repetitions. The four Districts (Ngong, Lagdo, Ngaoundere I/II, and Ngaoundere III) were considered as main treatments, eucalyptus plantations (0-10 years, 10-20 years, and 20 years) chosen in each District were secondary treatments, and the 5 transects of 100 m x 20 m were

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repetitions. Transects measuring 100 meters in length and 20 meters in width were set up at each site, spaced 10 meters apart from each other (Fig. 2). A total of 5 transects were installed, providing a total sampling area of 1 hectare per site. Sampling strips were established using a compass, tape measure, GPS, and strings. At the ends of each strip, stakes were placed at 20-meter intervals. Along each transect, all woody plants were inventoried, with dendrometric data collected on diameter and height. The circumference of the plants was measured with a tape measure at 1 meter from the ground, and tree heights were measured using a clinometer. Circumference values were then converted to diameter (dbh) using the formula: $C = \pi D$, where C = circumference, D = diameter, and $\pi = 3.14$.

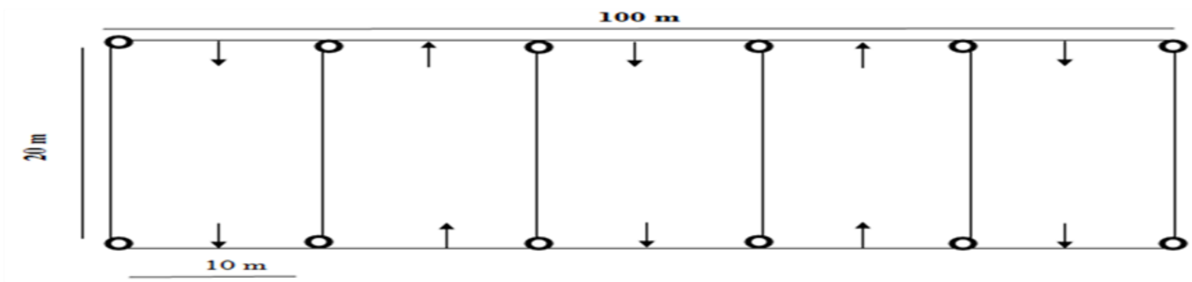

Figure 2: Plan of the illustrating a sampling unit

Analysis of plant species diversity

-Specific richness (S) represents the total number of species in the studied community. Absolute abundance is the total number of individuals of a species; while relative abundance is the ratio of absolute abundance to the total number of individuals in the whole.

-The Shannon Diversity Index (ISH) is calculated as $ISH = -\sum (ni/N) \text{ Log2 } (ni/N)$, with ni = number of individuals of species i, N = total number of individuals; ISH is expressed in bits. It measures species diversity and species richness (Frontier and Pichod-viale 1992).

-Piélou's Evenness (EQ) is calculated as EQ = ISH/Log2(N).

-Simpson's Diversity Index is represented as $D' = 1-\sum (ni/N)^2$, with ni = number of individuals of species i, N = total number of individuals. It compares species diversity and species dominance (Noiha *et al.* 2017).

-Sorensen's Similarity Coefficient is calculated as K = (2c/a+b) x 100, with a = number of species in sample 1, b = number of species in sample 2, c = number of common species in both samples. It is used to compare the similarity between two communities or ecosystems

based on species composition.

Structural characterization

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- Density (D) is calculated as D = n/S, where D is density (in trees/ha), n is number of trees on the area considered, and S is the area considered (ha).

- Basal area (S) is calculated as $S = \pi(Di^2/4)$, where S is expressed in m2/ha. It estimates the area occupied by individuals of a plant species in ecology (Noiha *et al.* 2017).

- Relative Frequency (FrRe) is determined by the formula: FrRe = FrA/FT x 100, with FrA = absolute frequency of species and FT = total frequency (sum of FrA).

- Relative Density (DeRe) is determined by the formula: DeRe = DAE/DA x 100, with DAE = absolute density of species and DA = absolute density.

- Relative Dominance (DoRe) is determined by the formula: DoRe = ABE/ABT, with ABE = basal area of the species and ABT = total basal area.

- Species Importance Value Index (IVIE), IVIE = FrReE x DeReE x DoReE, with FrReE = relative frequency of a species, DeReE = relative density of a species, and DoReE = relative

dominance of a species (Mori *et al.* 1983).

-Family Importance Value Index (IVIF) is calculated as IVIF = FrReF x DeReF x DoReF, with FrReF = relative frequency of a family, DeReF = relative density of a family, and DoReF

= relative dominance of a family.

- Structural (density, size, shape, and spacing) and vertical distribution of woody plants (canopy, shrub layer) were analysed. Five diameter classes with 10 cm intervals were established, and height classes with 4 m intervals were simplified into larger classes: regeneration, future stems, intermediate stems, and large trees. The data were encoded in the excel spreadsheet and then analysed using Statgraphics plus 5.0 and R software. Significance and correlation tests were performed using Anova and Duncan's 5 % test.

3. RESULTS

3.1. Floristic diversity of Eucalyptus agro-ecosystems

In total, zone I has 5671 individuals in 13 families, 19 genres, and 21 species. In contrast, zone II has 21323 individuals in 24 families, 45 genres, and 65 species. Among the four districts, the eucalyptus agro-ecosystems in Ngaoundéré in zone II, Vina department, have a significant diversity of understory species (Tab. 1).

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Table 1: Specific wealth of the undergrowth of *Eucalyptus sp* plantation

Area	Districts	Parcels	Number of species	Number of genera	Number of familie	Number of individuals
I	NGONG	0-10 years	15	14	10	510
		10-20 years	17	15	11	968
		+20 years	21	19	13	972
		Total	21	19	13	2450
	LAGDO	0-10 years	14	13	10	824
		10-20 years	13	13	9	1372
		+20 years	20	19	13	1025
		Total	20	19	13	3221
	Total General		21	19	13	5671
II	NGAOUNDERE I/II	0-10 years	29	28	20	1956
		10-20 years	20	20	15	2177
		+20 years	65	45	24	6736
		Total	65	45	24	10869
	NGAOUNDERE III	0-10 years	23	21	14	3097
		10-20 years	31	28	17	2856
		+20 years	55	43	24	4501
		Total	55	43	24	10454
	Total General		65	45	24	21323

In the sub-canopy of eucalyptus agro-ecosystems in the Sudanian-Sahelian zone of Garoua, the most abundant woody species is *Piliostigma thonningii* (47.09 %), followed by *Mangifera indica* (46.32 %), *Gmelina arborea* (38.79 %), *Senna siamea* (32.63 %), and Daniella oliveri (23.16 %). There are 44 other species with a relative abundance of less than 9%. On the other hand, in the high Guinea savanna zone of Ngaoundéré, specifically in the Vina department, the most abundant species in terms of individuals are *Harungana madagascariensis* (47.06 %), *Hymenocardia acida* (33.9 %), *Annona senegalensis* (25.20 %), *Allophyllus africanus* (19.95 %), and *Mangifera indica* (16.62 %) (Tab. 2).

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Table 2: Proportion of some species most represented in the undergrowth of agro-ecosystems in Eucalyptus (≥6 % de IVIE).

Area	Districts	Species	DoRe	DeRe	FeRe	IVI
I	NGONG	*Piliostigma thonningii*	5,85	20,62	20,62	47,09
		Mangifera indica	39,88	3,22	3,22	46,32
		Gmelina arborea	6,9	15,69	15,69	38,29
		Senna spectabilis	9,7	6,33	6,33	22,38
		Terminalia laxiflora	2,76	8,14	8,14	19,06
		Others	22,22	25,76	25,76	73,73
	LAGDO	*Piliostigma thonningii*	4,88	20,77	20,85	46,51
		Gmelina arborea	8,74	14,99	15	38,79
		Senna spectabilis	13,88	9,35	9,39	32,63
		Daniella oliveri	13,23	4,95	4,97	23,16
		Mangifera indica	18,95	2,06	2,07	23,09
		Others	29,24	29,58	29,58	88,08
II	NGAOU I/II	*Annona senegalensis*	0,61	12,29	12,29	25,2
		Harunganamadagascariensis	5,57	7,44	7,44	20,45
		Allophyllus africanus	0,91	9,52	9,52	19,95
		Mangifera indica	10,03	3,29	3,29	16,62
		Piliostigma thonningii	1,28	7,65	7,65	16,59
		Others	48,45	42,03	42,03	132,4
	NGAOUN III	*Harungana madagascariensis*	11,73	17,66	17,66	47,06
		Hymenocardia acida	9,77	12,06	12,06	33,9
		Albizia zygia	3,77	6,31	6,31	16,4
		Annona senegalensis	5,83	5,22	5,22	16,28
		Psidium guajava	4,67	5,77	5,77	16,23
		Allophyllus africanus	3,54	5,23	5,23	14,01
		Others	37,27	37,18	37,18	105,47

DoRe: relative dominance; **DeRe:** relative density; **FeRe:** relative frequency

In terms of the relative frequencies of plant families in the Bénoué department, the Caesalpiniaceae family is the most represented with 123.98 % of individuals, followed by Anacardiaceae (60.09 %), Verbenaceae (43.01%), Combretaceae (103.48 %), and Annonaceae (20.74 %). In the Vina department, the Clusiaceae family is the most represented with 51.3 % of individuals, followed by Hymenocardiaceae (33.9 %), Myrtaceae (31.96 %), Mimosaceae (26.04 %), and Euphorbiaceae (25.05 %). These families make up the floral composition of both regions (Tab. 3).

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Table 3: Proportion of some families most represented in the undergrowth of agroecosystems in Eucalyptus (≥6 % de IVIE)

Zones	Arrondissements	Familles	DoRe%	DeRe%	FeRe%	IVI%
I	NGONG	Caesalpiniacea	30,44	36,51	36,51	103,48
		Anacardiaceae	45,4	7,34	7,34	60,09
		Verbenaceae	7,39	17,8	17,8	43,01
		Combretaceae	6,11	11,16	11,16	28,44
		Myrtaceae	2,64	7,44	7,44	17,52
		Others	1,8	6,59	6,59	14,88
	LAGDO	Caesalpiniaceae	42,11	40,85	41,02	123,98
		Anacardiaceae	33,42	12,1	12,15	57,68
		Verbenaceae	9,02	16,36	16,43	41,82
		Annonaceae	3,38	8,66	8,7	20,74
		Mimosaceae	6,61	3,71	3,72	14,06
		Others	0,65	4,17	3,77	8,51
II	NGAOU I/II	Annonaceae	0,55	10,92	10,92	22,39
		Euphorbiaceae	3,94	8,77	8,77	21,49
		Sapindaceae	0,91	9,52	9,52	19,9
		Myrtaceae	7,21	6	6	19,21
		Anacardiaceae	10,62	4,25	4,25	19,13
		Others	50,51	48,92	48,92	148,37
	NGAOU III	Hypericaceae	12,78	19,26	19,26	51,3
		Hymenocardiaceae	9,77	12,06	12,06	33,9
		Myrtaceae	8,26	11,84	11,84	31,96
		Mimosaceae	10,01	8,01	8,02	26,04
		Euphorbiaceae	7,21	8,91	8,91	25,05
		Others	31,58	25,61	25,61	82,72

3.2. Ecological diversity index of Eucalyptus agro-ecosystems

Species richness is increasing in all understory plots of eucalyptus agro-ecosystems. It ranges from 2.6 ± 0.19 bits to 3.65 ± 0.14 bits (Tab. 4).

Table 4: Some clues of floristics diversities of the plots studied

Arrond	Parcelles	ISH	EQ	D'
NGONG	0-10 ans	2,6±0,19a	0,93±0,072a	0,29±0,002a
	10-20 ans	2,68±0,15a	0,94±0,06a	0,21±0,02a
	20 + ans	2,69±0,15a	0,94±0,06a	0,21±0,02a
	MOY±E	2,09±1A	0,94±0,06A	0,21±0,014A
LAGDO	0-10 ans	2,61± 0,27a	0,9±0,1a	0,34±0,025a
	10-20 ans	2,69± 0,22a	0,92±0,08a	0,32±0,027a
	20 + ans	2,75±0,24a	0,92±0,08a	0,17±0,015a
	MOY±E	2,62±0,24A	0,92±0,08A	0,24±0,02A
NGAOUNDEI /II	0-10 ans	3,29±0,36a	0,89±0,11a	0,05±0,00a
	10-20 ans	3,34±0,16a	0,95±0,05a	0,04±0,00a
	20+ ans	3,53±0,17a	0,96±0,04a	0,03±0,00a
	MOY±E	3,38±0,23A	0,93±0,06A	0,04±0,00A
NGAOUND III	0-10 ans	3,49±0,08a	0,99±0,01a	0,03±0,00a
	10-20 ans	3,54±0,19a	0,99±0,01a	0,03±0,00a
	20+ ans	3,65±0,14a	0,96±0,04a	0,02±0,00a
	MOY±E	3,53±0,14A	0,98±0,02A	0,026±0,00A
	F-Ratio	0,86	0,00001	15,36
	P-Value	0,58	0,999	0,00001

3.3. Similarity floristic of Eucalyptus agro-ecosystems

The calculation of the Sorensen similarity index shows that the values of this index range from 18.66 % to 96.55 %. The young plots (P1 and P2) have a high index value and have a similar floral composition. On the other hand, the greater the age difference, the lower the Sorensen similarity index, but it still remains (≥ 50 %) for plots (P1 and P3) on one hand and between (P2, P3) on the other hand (Tab. 5).

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Table 5: Sorensen similarity index of our plots

Zones	Districs		Ngong			Lagdo			Ngaounderer I/II			Ngaoundere III		
		P	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
I	Ngong	P1	100											
		P2	70,9	100										
		P3	47,	45,71	100									
	Lagdo	P1	96	66,67	42,43	100								
		P2	50	82,75	37,5	59,25	100							
		P3	35	45,72	94,73	42,43	50	100						
II	Ngaoundere I/II	P1	36,36	48,89	37,5	37,21	47,62	33,34	100					
		P2	28,58	50	20,51	35,30	48,49	20,52	53,06	100				
		P3	22,54	25	29,34	18,66	26,08	26,67	28,23	51,28	100			
	Ngaoundere III	P1	31,58	41,03	19,05	32,43	44,45	28,57	73,07	65,12	43,04	100		
		P2	39,19	42,55	32	40	45,46	28	56,67	50,98	45,97	62,96	100	
		P3	25,71	28,17	27,03	26,08	29,41	24,32	61,90	53,34	33,84	30,76	48,84	100

3.4. Vegetation structure index of Eucalyptus agro-ecosystems

Density: The average density of eucalyptus trees in different age groups varies from (433 ± 84.7 indiv/ha) to (119.4 ± 37.12 indiv/ha) across the four Districts, decreasing slightly with the age of the plots. Significant differences were found (F=15.42; P=0.0000 < 0.05) in the average density of eucalyptus plantations in different age groups. The highest density was observed in the Guinea high savanna zone in the 10–20-year-old plots of Ngaoundéré I/II District (433 ± 84.7 indiv/ha) (Tab. 6).

Basal Area: Across all plots, basal area increases with age, ranging from (1.35±0.32 m²/ha to 17.59 ± 3.71 m²/ha). In plots under 10 years, 10-20 years, and over 20 years, it ranges from (1.35 ± 0.32 m²/ha to 5.01 ± 1.53 m²/ha), (4.22 ± 2.91 m²/ha to 17.59 ± 3.71 m²/ha), and (11.00 ± 4.03 m²/ha to 13.66 ± 2.83 m²/ha) respectively. The highest basal area was observed in zone II, in Ngaoundéré I District (17.59 ± 3.71 m²/ha) in the 10–20-year-old plots. Significant differences were found (F=41.67; P=0.0000 < 0.05) in basal area between different plots in all four Districts studied (Tab. 6). Diameter at Breast Height and Total Height: The diameter at breast height (dbh) (F=17.8; P= 0.0000 < 0.05) and total height (Ht) (F=110.18; P=0.0000 < 0.05) of *Eucalyptus* sp. individuals showed significant differences across plots of different age groups in the four Districts studied. In the Sudanian-sahelian zone, the highest average dbh and Ht of *Eucalyptus* sp. individuals were observed in mature plantations in Ngong District (47.6 ±10.81 cm) and (14.9 ± 0.14 m). In zone II, the highest average dbh and Ht of *Eucalyptus* sp. individuals were observed in the young agroecosystems of Ngaoundéré I/II and mature plantations of Ngaoundéré III (90.08 ± 17.7 cm and 20.9 ± 0.35 m). Significant differences were found in the average dbh (F=15.38; P= 0.0000 < 0.05) and Ht (F=22.98; P= 0.0000 < 0.05) in eucalyptus agroecosystems between the four studied Districts (Tab. 6).

Table 6: Structural characterization of Eucalyptus agroecosystems in the four districts of the zones

zones	Arrondis	Parcelles	D(ind/ha)	A.B(m2/ha)	DBH(cm)	HT(m)
	NGONG	0-10 ans	167±34,32a	1,35±0,32a	14,8±3,18a	9,02±0,2a
		10-20ans	120,2±80,32a	4,22±2,91ab	23,03±15,65ab	13,35±1,6de
		20+ ans	144,4±35,53a	13,66±2,83cd	47,6±10,81d	14,9±0,14fg
		Moy±E	**143,87±38,62A**	**6,41±2,02ABCD**	**28,47±9,88ABD**	**12,43±0,64ADEFG**
	LAGDO	0-10 ans	199 ±85,92a	1,64±0,7a	17,6±8,25a	9,38±0,24a
		10-20ans	160,6±45,53a	4,78±1,6ab	28,18±8,18ab	13,02±1,29d
		20+ ans	119,4±37,12a	11,00± 4,03c	38,86±13,47cd	14,21±0,2ef
		Moy±E	**159,67±56,19A**	**5,81±2,11ABC**	**28,21±9,96ABCD**	**12,2±0,57ADEF**
II	NDEREI/II	0-10 ans	431 ±117,89c	5,01±1,53ab	46,95±12,67d	10,78±0,85b
		10-20ans	433±84,7c	17,59±3,71d	90,08±17,75e	14,56±0,09fg
		20+ ans	145,6±64,57a	13,5±6,78c	47,34±22,48d	15,39±0,0g
		Moy±E	**336,54±89,05AC**	**12,03±4,00ABCD**	**61,45±17,63DED**	**13,57±0,32BFG**
	NDERE III	0-10 ans	409,6±73,35bc	4,31±0,74ab	38,82±6,74bcd	10,59±0,0b
		10-20ans	327 ±102,23b	6,60±1,44b	42,79±9,65cd	11,93±0,66c
		20+ ans	187,4± 20,12a	11,00± 4,03c	84,08±6,65e	20,9±0,35h
		Moy ±E	**308±65,23ABC**	**14,87±2,21ABC**	**55,23±7,68CDE**	**14,47±0,34BCH**

3.5. Distribution diameter class of Eucalyptus agro-ecosystems

These four distributions all have a coefficient of determination (R^2) of 0.99. The distribution is then positively skewed or right-skewed, characteristic of single-species stands with a predominance of young or small-diameter individuals. The analysis of variance confirms that there is a highly significant difference (F=11.74; p=0.0000) (Fig. 3).

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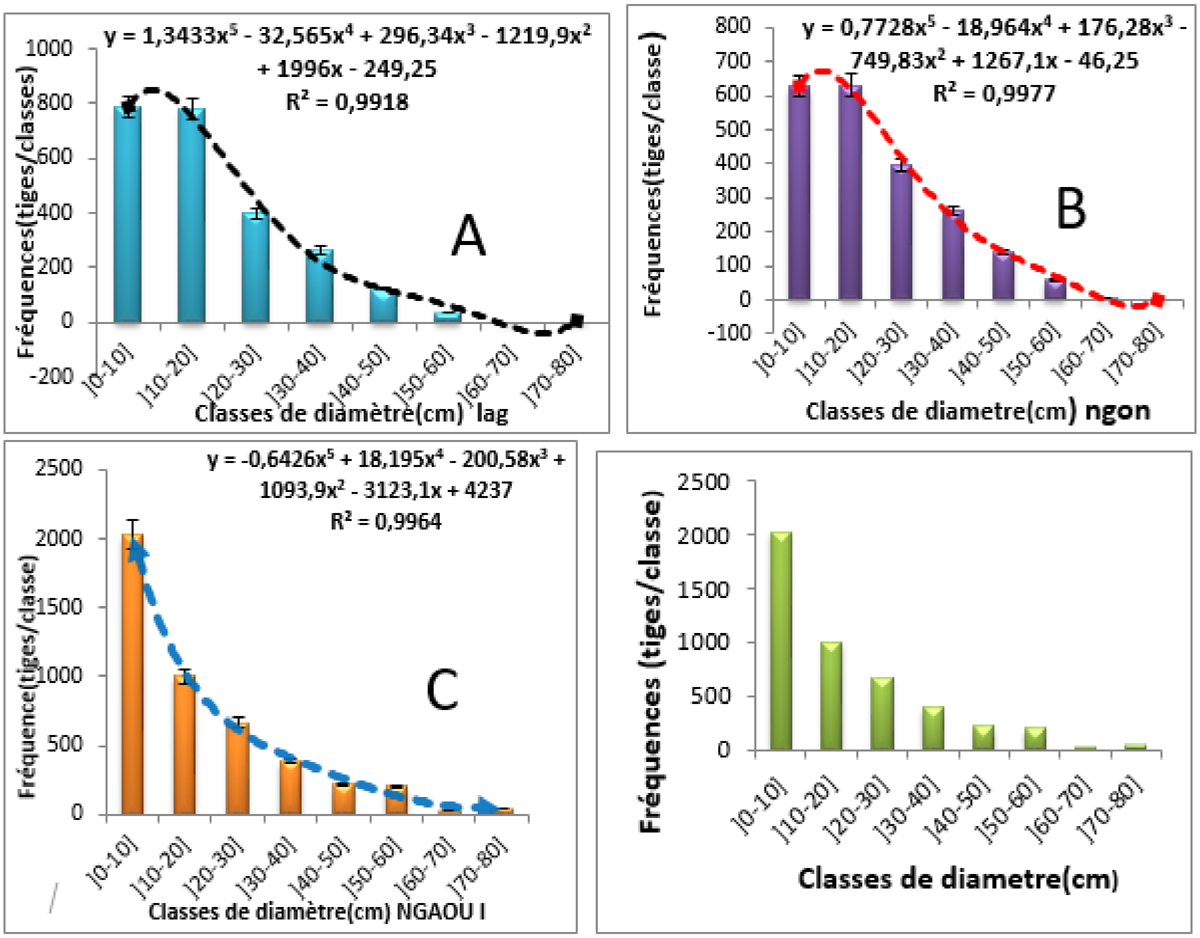

Figure 3: Distribution by class of diameter as a function of the frequencies of the feet of Eucalyptus sp. A: Lagdo; B: Ngong; C: Ngaoundéré I/II; D: Ngaoundéré III*)*

3.6. Distribution height class of Eucalyptus agro-ecosystems

The analysis reveals that all distributions have a bell shape and are best described by a third-degree polynomial function. These distributions have determination coefficients (R^2) ranging from 0.998 to 1. Similar to the diameter structure, the distribution by total height class of Eucalyptus sp. trees in the various plantations in the four districts shows a predominance of young trees. The bell-shaped structure, indicating a normal population, is characterized by a strong representation of median diameter classes. This is observed in all plots, suggesting high planting density during plantation creation. Trees in the 4-8m height class are the most dominant. Analysis of variance confirms a highly significant difference (F=7.16; p=0.002) with trees at 4m and 12m representing 12.79 % and 7.7 % of the population, respectively (Fig. 4)

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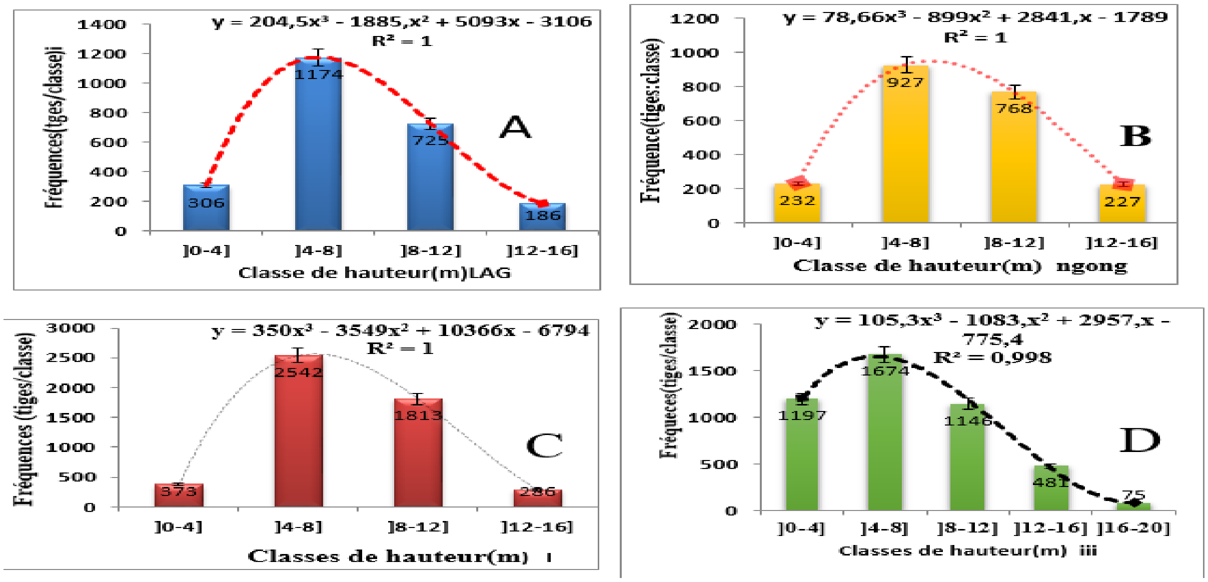

Figure 4: Distribution by class of total height according to the frequencies of the feet of *Eucalyptus* sp. A: Ngong; B: Lagdo; C: Ngaoundéré I/II; D: Ngaoundéré III

4. DISCUSSION

4.1. Floristic diversity of Eucalyptus agro-ecosystems

Eucalyptus plantations can play a crucial role in biodiversity conservation and species restoration, as shown by various authors (Cusack *et al.,* 2004; Brockerhoff *et al.*, 2008). Compared to other studies (Lucie *et al.,* 2018; Awe *et al.*, 2020) the diversity in Zone I is lower but still significant. Zone II also shows a lower diversity compared to other plantations in different regions of Cameroon (Manfo *et al.,* 2015). In the undergrowth of Eucalyptus plantations in Garoua, *Piliostigma thonningii* is the most abundant species. In Ngaoundéré, *Harungana madagascariensi*s and *Hymenocardia acida* are the most abundant species. The most represented family in the Bénoué department is Caesalpiniaceae, while in the Vina department, Hypericaceae and Hymenocardiaceae are dominant. Climate and management practices differ between the two zones, influencing the composition and structure of the flora (Noiha *et al.*, 2015; Ndiaye *et al.,* 2017; Noiha *et al.*, 2018a). Plant diversity is highest in the early stages of succession but decreases as the succession progresses (Yabi *et al.,* 2013).

4.2. Ecological diversity index of Eucalyptus agro-ecosystems

The Shannon index varies based on the age of the plots and zones. It is higher in the Mature plots of Zone II (3.53 ± 0.14 bits) and Zone I (2.75 ± 0.24 bits), indicating greater understory diversity in Zone II due to management practices and lower diversity in Zone I due to different management practices. The conditions in Zone II are beneficial for a wide range of species, while in Zone I they are less so. The Shannon diversity index in plots aged 0-10 years in zone I (2.6 ± 0.19 bits) is low due to a focus on eucalyptus plantation maintenance, which impacts the regenerating plant species negatively. This results in similar diversity within zone II plots and within zone I plots, reflecting a generally low understory diversity in Eucalyptus plantations overall. These findings are comparable to previous studies in other agro-ecosystems (Noiha *et al.,* 2018). The evenness of Piélou is consistently 1 in all studied plots, indicating a dominance of Eucalyptus over other species in the areas. Analysis shows no significant differences between plots or between study areas. High Piélou values suggest limited ecological organization and conditions favoring numerous species with few individuals (Noiha *et al.,* 2017).

Comparing *Eucalyptus* sp. plantations between different zones and districts, it is clear that eucalyptus plantations in the high savannah zone (Ngaoundere I/II and Ngaoundere III) are denser with respective densities of (336.54 ± 89.0 indiv/ha) and (308 ± 65.23 indiv/ha) compared to eucalyptus plantations in the sudano-sahelian zone (Ngong and Lagdo) with respective densities of (143.87 ± 38.62 indiv/ha) and (159.67 ± 56.19 indiv/ha). The differences in average density of eucalyptus stands could be linked to ecological characteristics of the study areas, such as soil types, topography, climate, land cover, and management practices. These results are lower than the values of 493 trees/ha obtained in Western Burkina Faso by Youl (2005); 156 trees/ha obtained by Muriga *et al.* (2012) in Ameru; and are also not close to those of Noiha *et al.* (2018a) in Eucalyptus sp. plantations (53.17 ± 0.08 indiv/ha) and cashew trees (60.09 ± 1.25 indiv/ha). Densities in immature stands are significantly higher than in young and mature stands. This difference suggests that lower tree densities could be due to harsh climatic conditions and increasing pressure (agricultural clearing, unplanned wood harvesting, overgrazing) exerted on these areas by nearby populations. According to Sounon *et al.* (2007), population growth and certain exploitation practices lead to land pressure, disrupting environmental balance (Abdourhamane *et al.,* 2013). In terms of age within eucalyptus stands, mature eucalyptus stands are less dense compared to young stands. These findings are higher than the values obtained by Noiha *et al*. (2017) in mature cashew tree stands (38.64 ± 47.42 indiv/ha) in Ngong. The observed differences between the studied stands and those of other authors may be explained by the efforts of operators to ensure ground cover, protecting it from sunlight and creating a microclimate conducive to eucalyptus growth.

4.3. Vegetation structure index of Eucalyptus agro-ecosystems

In all our plots, the root surface area increases with age and ranges from (1.35 ± 0.32 m²/ha to 17.59 ± 3.71 m²/ha). In the immature, young, and mature plots, it ranges from (1.35

± 0.32 m²/ha to 5.01 ± 1.53 m²/ha), (4.22 ± 2.91 m²/ha to 17.59 ± 3.71 m²/ha), and (11.00 ± 4.03 m²/ha to 13.66 ± 2.83 m²/ha) respectively. The highest root surface area is observed in Zone II, in the Ngaoundéré I District (17.59 ± 3.71 m²/ha) in the young plots. The high root surface area observed in the old plantations indicates the presence of large tree specimens. The low root surface area values in the young plantations are due to human activities such as tree felling during land clearing for plantation establishment, and the young eucalyptus trees still having small diameters. These results are similar to values obtained in cashew plantations in northern Cameroon by Awe et al. (2020) (2.02 ± 0.31 - 12.68 ± 2.01 m²/ha), in mature eucalyptus plantations by Noiha *et al.* (2017) (15.23 ± 0.07 m²/ha), in 20-year-old Pinus plantations by Kouam (2017) (14.53 ± 0.041 m²/ha), in 20-year-old neem plantations by Witanou (2016) (13.53 ± 0.041 m²/ha), and in 22-year-old cocoa plantations by Ngossomo (2016) (440.13 m²/ha). However, these values are significantly higher than those reported in 20-year-old Moringa plantations by Wanguili (2017) (3.57 ± 0.014 m²/ha). When comparing Young plots, those in the Benoue region have the largest root surface areas (9.58 ± 0.99 m²/ha).

4.4. Distribution diameter class of Eucalyptus agro-ecosystems

The analysis of tree distribution by diameter classes reveals a decreasing exponential structure with a steep slope at small diameters, which fits better with a fifth-degree polynomial function. This pattern indicates that the trees are concentrated in smaller diameter classes, suggesting sustained regeneration over time. The abundance of small-diameter trees in Eucalyptus sp. plantations shows a promising future for regeneration, a key feature of a population assumed to be in balance. These distributions have a high coefficient of determination (R^2) of 0.99, indicating a skewed distribution to the right, typical of singlespecies stands with a predominance of young or small trees (Ouédraogo *et al*., 2006; Rasatatsihoarana 2007; Sahu *et al.* 2007). Small-diameter trees are dominant in these plantations due to the heavy exploitation of larger-diameter species for fuelwood by local communities. These findings align with previous studies by various authors (Mapongmetsem *et al*. (2016); Diallo *et al*. (2012); Anup *et al*. (2013); Bazezew *et al*. (2015); Manfo *et al.* (2015); Mpalanga *et al.* (2015); Jiagho *et al.* (2016); Tsoumou *et al.* (2016); Sahu *et al.* (2016); Noiha *et al.* (2017); Noiha *et al.* (2018a, b), demonstrating a trend towards more small-diameter trees and ecosystem regeneration.

4.5. Distribution height class of Eucalyptus agro-ecosystems

The height class distribution shows a bell-shaped structure centered on the class 4-8 m, indicating a predominance of individuals of medium height in Eucalyptus sp. They are not stressed by human activities, bush fires, or other woody species, but are being conserved and protected, leading to their growth in height. This is because Eucalyptus sp. plantations are agroecosystems where most understorey woody species are used by people for various purposes, leading to their conservation and special care. These results differ from previous studies in baobab parks in Togo (Kebenzikato *et al.*, 2014), Cedrela odorata and Gmelina arborea stands in Ivory Coast (Bakayoko *et al.* 2012), and Gmelina arborea stands in Cameroon (Noiha *et al.*, 2018a). The presence of over 13 fruit species indicates the role Eucalyptus sp. plantations can play in conserving biodiversity.

5. CONCLUSION

The undergrowth of Eucalyptus sp. plots is not devoid of vegetation and does not have low floristic diversity. The species identified are mostly annual species, indicating that annual crop cultivation under Eucalyptus sp. stands is feasible. The negative influences on floristic diversity often mentioned were not observed at the plot level. However, a study on a larger scale encompassing all regions of Cameroon would be necessary.

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