Volume 4(1): 11-23

Research Article

Vegetation characterization and carbon sequestration under *Anacardium occidentale* orchards: the case of the Septentrion cashew basins from Cameroon

Fabrice Pius ATLOVE WONBON'N[a*], TCHOBSALA[a,b] and TOUA VROUMSIA[a]

[a]*Department of Biological Sciences, Faculty of Science, University of Ngaoundéré, P.O. Box: 454 Ngaoundéré, Cameroon*
[b]*Department of Biological Sciences, Faculty of Science, University of Maroua, P.O. Box: 46 Maroua, Cameroon.*

**Corresponding author: E-mail: fabriceatlove@gmail.com; Phone: (00237) 697969319/ 678265691*

Received: 19 November 2023 *Revised: 25 March 2024* *Accepted: 28 March 2024*

Abstract

PADF-CAJOU is a cash crop diversification and poverty alleviation project in the Cameroon Septentrion. Cameroon is aiming for world leadership. This crop has proven its worth elsewhere in economic, social, and ecological terms. This study is a contribution to the characterization of the vegetation and its contribution to carbon storage under *Anacardium* orchards to assess the environmental impact of cashew cultivation in the Septentrion. A methodology based on floristic inventories in *Anacardium* orchards in the localities of Yagoua, Vele, Doukoula, and Kalfou in Mayo-Danay; Garoua II, Garoua III, Pitoa, and Ngong in Benue; Martap, Ngaoundéré III, Ngan-Ha and Mbe in Vina. This method consisted of making one hundred and forty-four quadrats of 100 m x 100 m, according to age groups of [0-5[, [5-10[, [10-15[and [15-+ [(years), to measure dendrometric parameters. 27827 woody individuals, including 9771 cashew trees, divided into 81 species, 68 genera, and 34 families were recorded. The majority of these trees have diameters between 0 and 10 cm in Far North and Adamawa and between 20 and 30 cm in North. Shannon index varies from 1.41 bits in North to 2.92 bits in Adamawa. Biological type distribution is between micro and mesophanerogams. The regeneration rate is between 15 and 32% in Adamawa and Far North. Carbon sequestration varies from 9.63 TCO2/ha in Adamawa to 163.74 TCO2/ha in Far North. All in all, cashews could contribute more to the ecological service if the government would agree to put more means to encourage the cashew sector.

Keywords: *Anacardium occidentale*, carbon sequestration, orchards, Septentrion-Cameroon, vegetation

1. Introduction

Forests are an area of exceptional biological diversity. Non-wood forest products are an important, albeit underestimated, part of the economy in many countries. For hundreds of millions of people, trees are an indispensable source of food, medicine, raw materials, and cash income. The populations of various societies, especially in Africa, have ancestral knowledge of how to make the most of these products (Dekalikan, 2003). Trees provide many ecological services and their products can be used to diversify crops and create jobs in a region.

This is the case with cashew (*Anacardium occidentale* L.), which is a part of a government project to diversify cash crops in the Septentrion region and reduce poverty. Cameroon is aiming for world leadership in cashew nut production, thanks to a program to plant 100000 hectares of cashew trees. Since July 2018, the Institute of Agricultural Research for Development has embarked on a vast free distribution operation of an initial shipment of

50000 cashew seedlings in Cameroon's three Northern regions (Adamawa, North, and Far North), in part of the Eastern and Central regions (MINADER, 2018). Through this project to promote cashew nut cultivation, which is currently being implemented in Cameroon, the government is paving the way for the development of a second cash crop in the country's three Northern regions, which until now have been hostage to cotton (ACFCAM, 2020).

The history of cashew nuts in Cameroon began in 1972, at virtually the same time as in Ivory Coast (Adaman and N'dri, 2016), a country that has become the world's leading producer, although Cameroon only claims to produce around 111 tonnes (ACFCAM, 2020). In Africa, between 2011 and 2018, raw nut production rose from 1 million tonnes to 1.8 million tonnes, with an annual growth of 5.8%, half of which was produced by Ivory Coast (Hien, 2019). The first cashew plantations in Cameroon were planted during a reforestation campaign in the locality of Sanguéré, not far from the town of Garoua (Rassida *et al*., 2023). A total of 10000 hectares of plantations were planned. Unfortunately, 46 years later, only 650 hectares of cashew trees have been planted, including 60 hectares in 2017 alone, thanks to an operation led by the National Forestry Development Agency (ANAFOR, 2019).

However, this crop has proved its worth in improving people's living conditions in West Africa. In particular, in Benin (Balogoun *et al*., 2014), Ivory Coast (Adaman and N'dri, 2016), Guinea-Bissau (Kambaye *et al*., 2021), and Senegal (Ndiaye *et al*., 2021). Moreover, the first cashew plantations were introduced in the Northern Ivory Coast as plant cover to halt the advance of the desert in the early 1959-1960s, but since 1972 the economic function of cashews has taken precedence over the ecological function (Adaman and N'dri, 2016). Cashew is among the world's leading nut export crops, with 5.35 million hectares of plantations in 2011 (FAO, 2014). This agricultural crop helps to solve economic, social, and environmental problems worldwide (Tandjiékpon *et al*., 2003; Dwomoh *et al*., 2008; Hammed *et al*., 2008; Yabi *et al*., 2013; Balogoun *et al*., 2014). Can *A. occidentale*, which has proved its worth elsewhere in economic, social, and ecological terms, have a truly positive environmental impact on the Northern regions of Cameroon? This study is, therefore, a contribution to the characterization of vegetation and its contribution to carbon storage under *Anacardium* orchards.

2. Materials and methods

2.1. Presentation of the study area

This work was in the Northern regions of Cameroon, specifically, in the Mayo-Danay, Benoue, and Vina Divisions respectively in the Far North, North, and Adamawa regions of Cameroon. Located in what geographers call the "duck's beak", the Mayo-Danay Division lies between the 10th and 11th 67 degrees North latitude and 14° and 15°East longitude, in the Far North Region (Bakoulou, 2022). Belonging to the North Region, the Division of Benoue is located between 9°0"0" and 9°15"0" North latitude and 13°12"0" and 13°30"0" East longitude 70 (Aboubakar, 2022). The Division of Vina is part of the Adamawa plateau, which lies 71 between 7°03 "and 7°32" North latitude and 13°20" and 13°54" East longitude (Tchotsoua *et al*., 2000). The climatic and the relief of these regions are favorable to farming.

2.2. Data collection

This method consisted of making one hundred and forty-four (144) 100 m x 100 m quadrats in cashew orchards in villages belonging to the selected Divisions of the Septentrional Regions. All cashew plants were counted, as well as other woody plants from 1.5 m in height. The dendrometric parameters used were the circumference at the base of the trunk at 1.30 m, the height, and the diameter of the shoot. The number of young plants was determined by systematic counting. Seedlings whose height was less than or equal to 1.30 m and/or whose Dbh < 5 cm were considered to be regenerated. These parameters were measured using a tape measure.

2.3. Vegetation parameters

To obtain the vegetation parameters, the floristic inventory was carried out in twelve villages of the Septentrional Regions, i.e. four villages per Division of these Regions, according to the following age classes: [0-5[; [5-10[; [10-15[and [15-+[(years). By grouping the villages into these age classes, it was possible to determine whether cashew cultivation had evolved in a balanced, progressive or regressive manner.

Studied vegetation parameters include (1) density (Dr) = N/S where N=total number of individuals in the sample and S=area sampled (S) (Ngom *et al*., 2013); (2) relative frequency (Fr) = Frequency of the species x / Sum of all frequencies ×100, (3) relative abundance (Ar) = Number of individuals of the species x / Total number of individuals ×100 (Dona *et al*., 2016), and (4) species Importance Value Index (SIV) = Relative Abundance + Relative Frequency + Relative Dominance (Cottam and Curtis, 1956).

2.4. Diversity indices

Studied diversity indices include: The Shannon index H' = -Σ pi × ln pi (pi is the proportion of a species about the total number of species) (Frontier and Pichod-Viale, 1995). H' is expressed in bits. Piélou equitability (J') J' = H' / log S or H'/Hmax (H' is Shannon diversity and S is species richness) (Dajoz, 1982). Simpson index (D): D = Σ Ni (Ni-1)/N (N-1) (D=Simpson index, Ni=number of individuals of the given species, N=total number of individuals).

2.5. Biological types

The rate of vegetation renewal at the studied sites (Poupon, 1980) was calculated as follows:

$$\boldsymbol{TR} = \frac{Total\ number\ of\ young\ plants}{Total\ stand\ size}$$

The specific importance of regeneration (Akpo and Grouzis, 1996) was calculated as indicated below:

$$\boldsymbol{SIR} = \frac{Number\ of\ seedlings\ of\ a\ species * 100}{Total\ number\ of\ seedlings\ counted}$$

2.6. Carbon stock assessment and data processing

Studied Carbon stock assessment includes above-ground biomass and quantity of carbon in above-ground and root phytomass: Above-ground biomass AGB = expo (- 1.996 + 2.32*ln (dbh)) (Brown *et al*., 1997) (AGB = above-ground biomass, dbh = diameter at breast height). Below-ground biomass BGB = expo (- 1.0587 + 0.8836*ln (AGB)) (Cairns *et al*., 1997) where BGB = below-ground biomass. Estimation of the quantity of carbon in above-ground and root phytomass QCa = Ba x Cv (IPCC, 2003) where QCa = above-ground carbon; Ba = above-ground biomass. QCr = Br x Cv (Ibrahima and Abib, 2008) where QCr = root carbon; Br = root biomass, and Cv = vegetation carbon concentration (0.5).

-Estimation of total carbon:

$QC_{total} = QC_{above\text{-}ground} + QC_{below\text{-}ground}$

- Estimation of ecological service: the ecological service will be estimated by the ratio 44/12 corresponding to the CO_2/C ratio.

Analysis of variance was performed using STATGRAPHICS plus 5.0 software. The Duncan test was used to compare the means. Excel 2013 was used to produce tables and graphs.

3. Results

3.1. Vegetation characteristics

3.1.1. Floristic composition of *Anacardium* orchards by region and age group

Tables 1 and 2 show the floristic composition of *Anacardium* orchards by region, age group, and village. They show that 27827 individuals, including 9771 cashew trees and 18056 other woody plants, have been recorded, divided into 81 species, 68 genera, and 34 families. In the Far North, 8577 (178.69 ind/ha) woody plants were recorded, including 4665 (97 ind/ha) cashew trees and 3,912 (81.5 ind/ha) other woody plants, divided into 33 species, 32 genera, and 19 families. In the North, 12813 (266.94 ind/ha) individuals, including 4009 (83.52 ind/ha) *Anacardium* and 8804 (183.42 ind/ha) other woody plants, divided into 40 species, 33 genera and 16 families. In Adamawa, 6437 (134.1 ind/ha) individuals, including 1097 (22.85 ind/ha) *Anacardium* against 5340 (134.1 ind/ha) other woody plants, divided into 48 species, 45 genera, and 28 families. In the villages of the Far North, the greatest number of *Anacardium* trees are found in the [0-5[and [15-+[age groups. In all villages in the North, *Anacardium* is found in the [0-10[and [15-+[age groups. In the villages of the Adamawa, the number of *Anacardium* trees decreases as the age group increases. Orchards with individuals in the [15-+[age bracket are absent from the localities of Ngaoundéré 3 and Martap. Analysis of variance revealed a highly significant difference in floristic composition between age groups, regions, and villages (P<0.001). The Duncan test reveals heterogeneity between groups in terms of floristic composition, but three homogeneous groups.

Table 1: Floristic composition of *Anacardium* orchards according to age group

Regions	Woody species	Age (years)				Mean density
		[0-5[	[5-10[	[10-15[	[15- +[	
Far-North	*A.occidentale* (ind/ha)	213.33	24.42	37.5	105.17	97
	Other woody (ind/ha)	52.08	86.5	60	127.42	81.5
	TWP (ind/ha)	**265.42**	**110.92**	**97.5**	**232.58**	**178.69**
	Species	12	12	8	21	33
	Genera	10	12	8	20	32
	Families	9	9	7	16	19
North	*A.occidentale* (ind/ha)	86.75	91.83	54.42	232.58	83.52
	Other woody (ind/ha)	39	219.5	72.75	402.42	183.42
	TWP (ind/ha)	**125.75**	**311.33**	**128.17**	**502.5**	**266.94**
	Species	12	13	17	17	40
	Genera	9	10	16	15	33
	Families	8	10	10	12	16
Adamawa	*A.occidentale (ind/ha)*	66.67	10	7.67	7.08	22.85
	Other woody (ind/ha)	28.83	109.58	175.25	131.33	111.25
	TWP (ind/ha)	**95.55**	**119.58**	**182.9**	**138.42**	**131.1**
	Species	12	15	16	31	48
	Genera	12	13	16	31	45
	Families	9	12	12	20	28

TWP: Total woody plants; ind/ha = individuals per hectare

3.2. Distribution of diameter at breast height (DBH) of cashew trees according to study area

Table 3 shows the distribution of cashew tree DBH by region and village. In the Far North, cashew trees with diameters of 0-10 cm are the most numerous (2721), while those with diameters of 50-60 cm are less numerous (59). In the North, those between 20-30 cm (1396) are the most numerous, and those between 40-50 cm (157) the least. In Adamawa, the number of individuals decreases as the diameter class increases. Analysis of variance revealed a highly significant difference in the distribution of DBH between Regions and between diameter bands ($P<0.001$). The Duncan test reveals heterogeneity between the different groups.

3.3. Vertical distribution of cashew trees by region and village

Table 4 shows the vertical distribution of cashew trees by region and village. It shows that for the Far North and Adamawa, the vertical distribution decreases with increasing size. For the North, this distribution decreases between 5-10 m. It increases between 10-15 m. Analysis of variance reveals a highly significant difference in the vertical distribution between regions and height bands ($P<0.001$). The Duncan test reveals heterogeneity between the different groups.

Table 2: Density of *Anacardium* (ind/ha) according to village and age

Regions	Villages	Age (years)				Mean density
		[0-5[	[5-10[	[10-15[	[15-+[	
Far-North	Yagoua	175.5	19.5	33.5	104.25	110.92
	Vele	167	14.25	30.25	100.75	104.08
	Doukoula	130.75	15.25	20.5	56	74.17
	Kalfou	166.75	24.25	28.25	54.75	91.33
North	Garoua 2	63.5	66.75	39	73.25	80.83
	Garoua 3	66.25	69.75	42.75	80.25	86.33
	Pitoa	61.25	64.75	41.25	71	79.41
	Ngong	59.25	74.25	43.25	75.75	87.5
Adamawa	Ngan-Ha	50.5	9.5	9	11.75	26.91
	Ndéré 3	47.75	6.75	3.75	0	19.41
	Martap	46.5	5.75	0	0	19.41
	Mbe	52.25	8	10.25	9.5	*27.67*

Ind = Individuals; ind/ha = individuals per hectare; Ndéré 3 = Ngaoundéré 3

Table 3: Distribution of the diameter at breast height of cashew

Regions	Villages	Age (years)			Total
		[0-5[	[5-10[	[10-15[	
Far-North	Yagoua	872	180	279	1331
	Vele	819	169	261	1249
	Doukoula	583	120	187	890
	Kalfou	718	148	230	1096
North	Garoua 2	517	306	147	970
	Garoua 3	552	327	157	1036
	Pitoa	508	301	144	953
	Ngong	560	332	158	1050
Adamawa	Ngan-Ha	287	22	14	323
	Ngaoundéré 3	212	21	0	233
	Martap	191	18	0	209
	Mbe	295	22	15	332

Table 4: Vertical distribution of cashew trees

Regions	Villages	Age (years)			Total
		[0-5[	[0-5[	[0-5[	
Far-North	Yagoua	785	182	364	1331
	Vele	737	171	341	1249
	Doukoula	525	122	243	890
	Kalfou	647	150	299	1096
North	Garoua 2	277	542	151	970
	Garoua 3	296	579	161	1036
	Pitoa	272	532	149	953
	Ngong	300	586	164	1050
Adamawa	Ngan-Ha	244	44	35	323
	Ngaoundéré 3	192	41	0	233
	Martap	171	38	0	209
	Mbe	251	45	32	332

3.4. Diversity indices

Table 5 shows the floristic diversity of *Anacardium* orchards by region and age class. It shows that, at the regional level, orchards in Adamawa (2.92 bits) are more diverse than those in the Far North (1.67 bits) and the North (1.41 bits). The Pielou equitability tends less towards 0 in Adamawa (0.75) than in the Far North (0.48) and the North (0.45). The Simpson index is higher in the Far North (0.34) and the North (0.33) than in Adamawa (0.08).

In terms of age classes in the Far North, the Shannon index is lower in orchards aged 0-5 years (0.81 bit) and higher in those aged 5-10 years. The North is more diverse in 10–15-year-old orchards than in 0–5-year-old orchards. In Adamawa, orchards aged [15-+[are the most diverse, whereas orchards aged 0-5 years are less diverse.

3.5. Distribution of biological types according to region

Figure 1 shows the distribution of biological types by region. It can be seen that ligneous individuals are of two main types. Microphanerogams with rates of around 50%, 42%, and 36% for the Far North, Adamawa, and the North. Mesophanerogams: 58% in the North, 43% in Adamawa, and 41% in the Far North. Table 6 shows the distribution of biological types by age group. It can be seen that in the Far North, the 0-10 age group comprises mainly microphanerogams; from 10 to]15- +] years, mesophanerogams. In the North, except for the 5–10-year age group, microphanerogams are the most abundant. In Adamawa, the 0–15-year class is dominated by mesophanerogams, while the over-15-year class is dominated by microphanerogams

Table 5: Diversity indices according to age groups (years)

	Far-North				North				Adamawa			
Indices	]0-5]	]5-10]	]10-15]	]15- +]	]0-5]	]5-10]	]10-15]	]15- +]	]0-5]	]5-10]	]10-15]	]15- +]
ISH	0.81	1.72	1.49	1.42	1.09	1.15	1.26	1.13	1.19	2.16	2.4	2.5
EQ	0.32	0.69	0.76	0.47	0.44	0.44	0.65	0.54	0.46	0.84	0.87	0.76
1–D	0.34	0.72	0.72	0.67	0.49	0.58	0.65	0.66	0.5	0.85	0.88	0.89
D	0.66	0.28	0.28	0.33	0.51	0.42	0.35	0.34	0.5	0.15	0.12	0.11

ISH=Shannon Index; EQ: Piélou Equitability Index; D=Simpson Index and 1-D its inverse.

Table 6: Distribution of biological types according to age groups (years)

	Far-North				North				Adamawa			
Biological types	]0-5]	]5-10]	]10-15]	]15- +]	]0-5]	]5-10]	]10-15]	]15- +]	]0-5]	]5-10]	]10-15]	]15- +]
Nph	18	0	0	0.85	34.78	0.43	0.99	0.15	72.05	4.06	3.39	1,71
Miph	76.72	90.13	43.65	5.53	45.36	11.78	56.38	50.46	14.16	9.81	45.4	66,47
Mph	5.28	19.87	56.35	93.48	19.35	87.8	28.24	45.2	13.8	86.13	50.7	30,52
MPH	0	0	0	0.15	0.51	0	14.39	0.04	0	0	0.51	1,29

Nph: nanophanerogam; Miph: microphanerogam; Mph: mesophanerogam; MPH: macrophanerogam

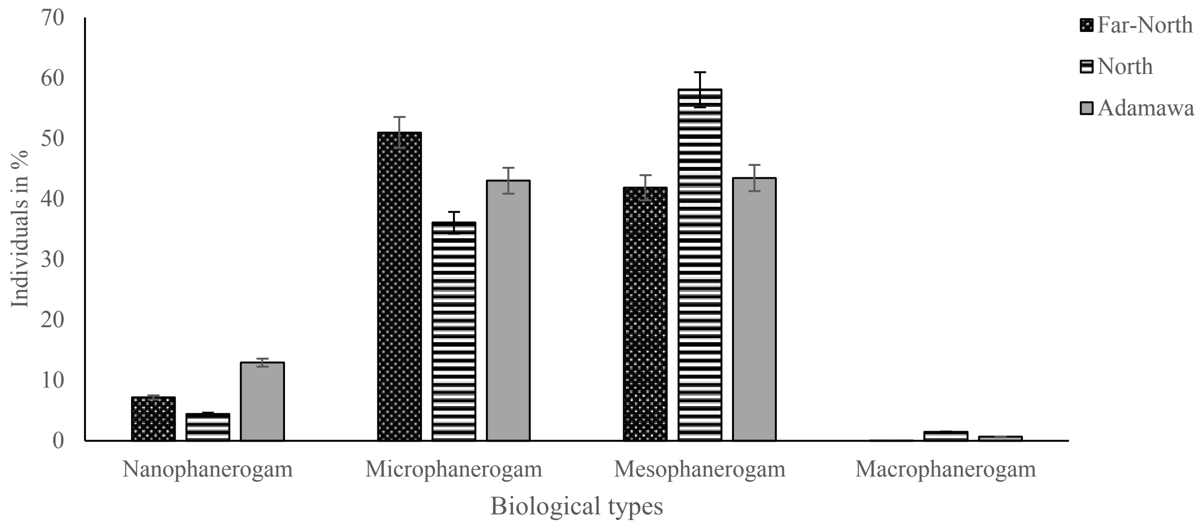

Figure 1: Distribution of biological types according to regions

3.6. Regeneration dynamics in *Anacardium* orchards

Figure 2 shows the regeneration rate, figure 3 the specific importance of regeneration in *Anacardium* orchards, and figure 4 the regeneration rate in *Anacardium* orchards according to villages. Figure 4 shows that the Far North has an overall regeneration rate of 37%, including 32% for *Anacardium* and 5% for other woody species. The North is 23%, of which 16% for cashew trees and 7% for other woody species. Adamawa 21%, of which 15% for *Anacardium* and 6% for other woody species. Figure 3 shows that the specific importance of regeneration in *Anacardium* orchards in the Far North is 87% for cashew trees and 13% for other woody species. In the North, 69% for *Anacardium* and 31% for other woody species. In Adamawa, 70% for *Anacardium* and 30% for other woody species. Figure 4 shows that in *Anacardium* plantations in villages in the Far North, cashew trees have a regeneration rate of 32%, 32%, 30%, and 34% in Yagoua, Vele, Doukoula, and Kalfou. 16%, 16%, 15%, and 17% in Garoua 2, Garoua 3, Pitoa and Ngong in the North. 16%, 15%, 14% and 17% in Nagan-Ha, Ngaoundéré 3, Martap and Mbe in Adamawa.

3.7. Carbon sequestration rate of *Anacardium* orchards

Table 7 presents the rate of CO_2 sequestered (t/ha) in *Anacardium* orchards, according to age class Regions (R). The overall total of 1024.42 TCO_2/ha was sequestered in all cashew orchards in the three regions. The orchards of the Far North enabled 329.47 tCO_2/ha to be stored, including 163.74 TCO_2/ha for *Anacardium (A.o.)* and 165.73 TCO_2/ha for other ligneous trees. In the North (N), 428.49 TCO_2/ha, including 149.19 TCO_2/ha for *Anacardium (A. o.)* and 279.3 tCO_2/ha for another tree. In Adamawa, 266.5 tCO_2/ha, including 9.63 tCO_2/ha for *Anacardium* and 256.82 tCO_2/ha for other trees. For the age groups, in the *Anacardium* orchards of the Far North and Adamawa, the rate of CO_2 sequestration increased with the age group, both for *Anacardium* and for other woody species. In the North, this rate increases for all woody species between the ages of 0-10 years. The rate drops between 10 and 15 years of age, then increases in the [15- +[age group. Analysis of variance revealed a significant difference ($P<0.001$) in the rate of CO_2 sequestration between regions and between age classes ($P<0.001$). The Duncan test detected homogeneity between the averages of carbon dioxide sequestered between the Far North and the North and between the [5-10[and [10-15[year age groups.

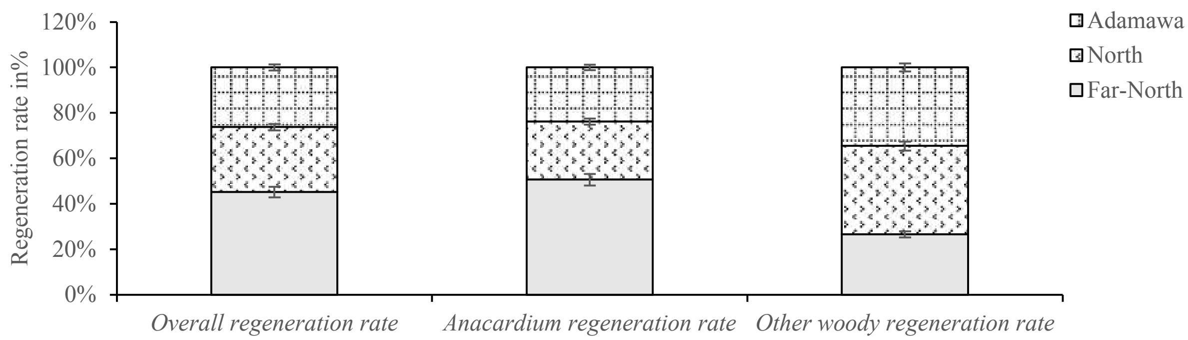

Figure 2: Regeneration rate in *Anacardium* orchards according to Regions

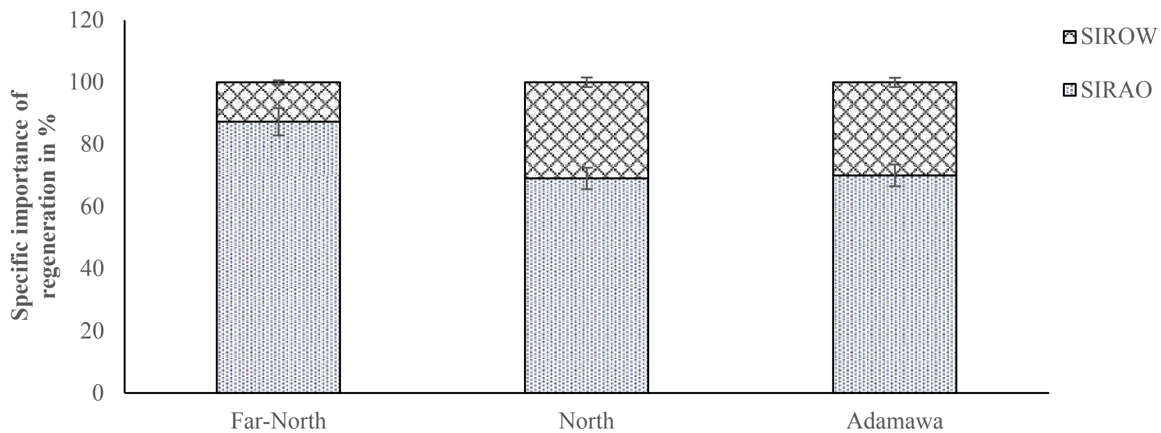

Figure 3: Specific importance of regeneration in different regions

SIRAO: Specific importance of regeneration *Anacardium occidentale;* SIROW: Specific importance of regeneration other woody.

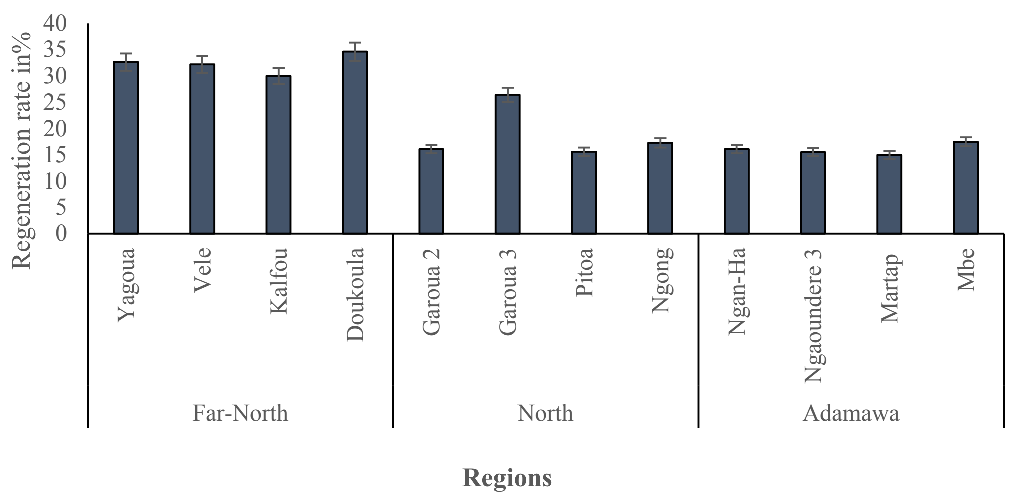

Figure 4: Regeneration rate in *Anacardium* according to villages

Table 7: TCO_2/ha sequestered in tones according to regions and age group (years)

Region	W. s.	[0-5[	[5-10[	[10-15[	[15- +[	T/Region
Far-North	A. o.	2.61	7.06	14.91	139.15	163.74
	O. w.	18.2	31.95	28.54	87.07	165.73
	Total	**20.82**	**39.01**	**43.45**	**226.19**	**329.47**
North	A. o.	2.99	82.57	13	50.62	14.19
	O. w.	35.06	145.31	42.18	56.74	279.3
	Total	**38.05**	**227.88**	**55.19**	**107.36**	**428.49**
Adamawa	A. o.	1.59	0.7	3.56	3.77	9.63
	O. w.	15.79	60.74	110.32	69.97	256.82
	Total	**17.39**	**61.45**	**113.88**	**73.74**	**266.5**

W. s.: Woody species; A. o.: *Anacardium occidentale*; O. w.: Other woody; T/Region: Total by Region

4. Discussion

4.1. Floristic composition

Floristic composition and density are higher in *Anacardium* orchards in the North and Far North than in Adamawa. This trend can be explained by the planting of a high number of *Anacardium* trees in these regions, as opposed to Adamawa. The development of cashew cultivation has not been balanced over time in the North and Far North. There is a high number of cashew trees in the [15- +[age bracket, which decreases between 10-15 years and increases between 0-5 years. This state of affairs can be explained by the interest shown by the populations of these two regions when this crop was introduced, an interest that has waned over the years due to a lack of training for farmers on the one hand, and a lack of outlets offered by the government on the other. The increase in the number of 0-5-year-olds growing *Anacardium* is evidence of renewed interest in this crop. This renewed interest has been encouraged by the government through its PADF-CAJOU project and its campaigns to distribute free cashew seedlings, which have been underway since 2017. In Adamawa, *Anacardium* orchards have developed gradually over time. The number increases as the slice decreases. This trend can be explained by the recent enthusiasm of the population for this crop.

In the Far North, these results differ from those obtained by Il Mataï (2020) because she worked on a reforestation site and carried out her inventories over a total area of 3 km2. In the North, these results do not corroborate those of Djongmo *et al*. (2021) because they worked on different sites from ours and carried out their inventories on 60 plots measuring 100 m x 20 m. In Adamawa, these results differ from those of Nyasiri (2018) because he carried out his inventories on 84 inventory units of 50 m X 20 m and carried out his work at the escarpment known as the "Ngaoundéré cliff", which is a zone with a high concentration of biodiversity.

Analysis of variance revealed a highly significant difference in floristic composition between age groups, regions, and villages ($P<0.001$). The Duncan test reveals heterogeneity between groups in terms of floristic composition, but three homogeneous groups in terms of the number of *Anacardium* individuals between villages: the Yagoua-Vele group in the Far North, all the villages in the North Region and finally the Ngaoundéré IIIe-Martap group in the Adamawa Region.

4.2. Diameters at Breast Height distribution

Examination of these results shows that small-diameter individuals are the most numerous in the Far North. This observation may suggest that *Anacardium* trees are regenerating well in this part of the Septentrion. However, the presence of a fairly large number of large-diameter trees suggests that farmers in this part of the country were curious about this species when it was first introduced. This curiosity has diminished over the years due to the lack of a proper marketing and processing circuit, as is the case for cocoa, coffee, and cotton. In the North, the predominance of medium-diameter trees may suggest poor regeneration of *Anacardium* trees. However, the cultivation of this crop has been fairly balanced over the years, because the people of the North have been more resilient than those of the Far North, and have themselves devoted themselves to small-scale processing. In Adamawa, the number of individuals decreases as the diameter increases. This suggests that *Anacardium* trees are regenerating well in this region. This state of affairs augurs a new and growing enthusiasm on the part of local people, who see this crop as a godsend because they no longer grow it as an isolated tree, but are now experimenting with it more and more in orchards.

These results differ from those of Noiha *et al*. (2017), because of the classification in steps of 10 in their work, compared with a classification in steps of 5 in ours. These works also disagree because of the difference in study years. Analysis of variance revealed a highly significant difference in the distribution of DBH between Regions and between diameter bands ($P<0.001$). The Duncan test reveals heterogeneity between the different groups.

4.3. Horizontal structure

These results show that in the Far North, individuals with small crown diameters are the most numerous, followed by individuals with large diameters, with medium diameters being the least representative. These results can be explained by the fact that cashew tree cultivation in this part of the country has not been balanced over time. In the north, small-diameter trees are the most numerous, followed by medium-diameter trees. Small-diameter individuals are the least important. This could be explained by the training pruning that is regularly carried out in *Anacardium* orchards in the North. In Adamawa, the number of *Anacardium* trees decreases as the diameter of the cluster increases. This phenomenon is the result of a recent craze for this promising crop. These results are similar to those of Atlove (2020). Analysis of variance revealed a highly significant difference in the distribution of the diameter of the tassel between Regions and diameter bands ($P<0.001$). The Duncan test reveals heterogeneity between the different groups.

4.4. Vertical structure

These results show that in the Far North, the majority of individuals are found in the extreme size ranges, i.e. small (5-10 m) and large. In the North, the majority of individuals are found in the small (0-5 m) and medium (5-10 m) size ranges. In Adamawa, the number of individuals decreases as the size range increases. These results may be explained by the fact that cashew orchards are older in the Far North and North than in Adamawa. These results differ from those obtained by Il Mataï (2020) because his work covers only the Far North. Analysis of variance reveals a highly significant difference in the vertical distribution between regions and height bands ($P<0.001$). The Duncan test reveals heterogeneity between the different groups.

4.5. Diversity indices and distribution of biological types

These results show that floristic diversity is lower in the North and Far North than in Adamawa. Similarly, in terms of diversity according to age class, diversity decreases as the number of *Anacardium* individuals increases. The most diverse stands are those with fewer *Anacardium* trees. It can therefore easily be said that in this study, the floristic diversity of stands in *Anacardium* orchards is correlated with the number of *Anacardium* individuals. Similar results were reported by Chanceyambaye *et al.* (2018). Looking at our results, we note that the distribution of biological types is neither homogeneous at the level of regions, nor age groups. This is favored by the fact that the samples were taken in three different Regions and according to different age groups. As a result, these results do not corroborate those of Ousman *et al.* (2017).

4.6. Regeneration dynamics

These results show that cashew trees have the highest regeneration rate in the study sites. The specific importance of regeneration in *Anacardium* orchards also ranks this species ahead of the others. This could be explained firstly by the fact that these studies were carried out only in *Anacardium* orchards, but also by the recent creation of *Anacardium* orchards in the Northern part of the country, encouraged by the PADF-CAJOU project.

4.7. Carbon sequestration rate

Of the three regions, *Anacardium* orchards in Adamawa contributed the least to CO_2 sequestration. This is because orchard cultivation of this crop is still at an embryonic stage. In addition, for most age classes, *Anacardium* trees sequestered less carbon dioxide than other woody species, indicating that much remains to be done to boost the cultivation of this plant species. In the study regions, carbon dioxide sequestration is proportional to the age of the orchards. This is because an increase in the age of an individual leads to an increase in biomass production and therefore its capacity to store CO_2.

These results are in line with those of Noiha *et al.* (2017) and Atlove (2020). Analysis of variance revealed a significant difference ($P<0.001$) in the rate of CO_2 sequestration between regions and between age classes ($P<0.001$). The Duncan test detected homogeneity between the averages of carbon dioxide sequestered between the Far North and the North and between the [5-10[and [10-15[year age groups.

5. Conclusion

The present study characterized the vegetation and its contribution to carbon storage under *Anacardium* orchards in the cashew basins of the Septentrion-Cameroon; to assess the environmental impact of cashew cultivation. It made it possible to determine the floristic composition of *Anacardium* orchards in the regions and villages of the Septentrion according to age classes. It also provided information on the structure of the vegetation in *Anacardium* orchards, through the distribution of diameters at breast height, crown height, and vertical height. It also revealed the ecological characteristics of plants in *Anacardium* orchards through diversity indices. The biological characterization of plants in *Anacardium* orchards was highlighted through the distribution of biological types and regeneration dynamics. Finally, this work enabled the carbon stock of plants in *Anacardium* orchards to be assessed. *Anacardium occidentale* was able to store carbon in the study areas, although this storage was lower than that of other woody plants. This trend could develop positively, in favor of *Anacardium occidentale*, if the government were to invest more in this crop on the one hand and encourage local people to invest in it on the other. *Anacardium occidentale* therefore has a social function, an economic function, and an ecological function.

Acknowledgments

We would like to thank the traditional and administrative authorities and the local population for their contribution to the fieldwork. To Mr PA AÏ Vivien NENWALA for proofreading, and to all the anonymous readers of our manuscript.

Authors Contributions

This work was carried out in collaboration among all authors. Author AWFP designed the study, performed the statistical analysis, wrote the protocol, and managed the literature searches. Author Tchobsala wrote the first draft of the manuscript. Author VT managed the analyses of the study. All authors read and approved the final manuscript.

Competing Interests

The authors have declared that no competing interests exist.

References

Aboubakar, S. (2022). Phytoécologie, dynamique et gestion des écosystèmes du sud de la Bénoué au Nord Cameroun. Thèse de Doctorat/Ph.D. Université de Maroua. 175p.

ACFCAM, (2020). Étude de faisabilité technique et socioéconomique de l'introduction de l'arboriculture d'anacarde par les collectivités territoriales décentralisées en zone de savane sèche du Cameroun. CRIS N°2018/400-359.

Adaman, S. & N'dri, K. A. (2016). Impacts Socio-Economiques De La Culture De L'anacarde Dans La Sous-Prefecture D'odienne (Côte d'Ivoire). *European Scientific Journal*. vol.12, No.32 ISSN: 1857 – 7881.

Akpo, L.E., Grouzis, M. (1996). Influence du couvert sur la régénération de quelques espèces ligneuses sahéliennes (Nord-Sénégal, Afrique occidentale). *Webbia,* 50(2): 247-263.

ANAFOR, (2019). Le sylviculteur. Magasine semestriel de l'Agence Nationale d'Appui au Développement forestier, N° 015, 28p.

Atlove, W. F. P. (2020). Dynamique contrastée des peuplements de palmier et de l'Eucalyptus et leurs pouvoirs de séquestration de carbone dans l'Arrondissement de Mayo-Darlé Région de l'Adamaoua-Cameroun. Mémoire de Master. Université de Ngaoundéré-Cameroun. 104p.

Bakoulou, N. A. (2022). Dynamique et gestion de la phytodiversité des écosystèmes de la Zone Soudano-Sahelienne du Cameroun : cas du Département du Mayo-Danay (Région de l'Extrême-Nord). Thèse de Doctorat/Ph.D. Université de Maroua. 180p.

Balogoun, I., Saïdou, A., Ahoton, E. L., Amadji, G. L., Ahohuendo, B. C., Adebo, I. B., Babatounde, S., Chougourou, D., Adoukonou-Sagbadja, H., Ahanchede, A. (2014). Caractérisation des systèmes de production à base d'anacardier dans les principales zones de culture au Bénin. *Agronomie africaine,* 26(1) : 9-22.

Bikoué, MAC, Essomba, H. (2007). Gestion des ressources naturelles fournissant les PFNL alimentaires en Afrique centrale. Document de Travail N°5. Organisation des Nations Unies pour l'Alimentation et l'Agriculture. 104 p.

Brown, S, Gilespie, A.J.R., Lugo, A. E. (1997). Biomass estimation methods for tropical forest with application to forest inventory data. *Forest Science,* 35(4): 881 – 902.

Cairns, M., Brown, S., Helmer, E., Baumgardner, G. A. (1997). Root biomass allocation in the world's upland forests. *Oecologia* 111, 1–11.

Chanceyambaye, N., Fidèle, T. N.F., Ibrahima, A. (2018). Caractérisation des ligneux de la savane sahélienne à *Acacia senegal* (L) Willd dans la région du Guéra, Tchad. *International Journal of Applied Research,* 3(4): 600-606.

Cottam, G. & Curtis, J. C. (1956). The use of distance measure in phytosociological sampling. Ecology, 37(3) : 45-460.

Dajoz, R. (1982). Précis d'écologie, 4è édition, Bordas, Paris, 503 p.

Dekalikan, K. (2003). Importance de la forêt dans la vie de l'homme en zone rurale. Mémoire soumis aux XIIe congres forestier mondial, Québec city, Canada.

Djongmo, V. A., Noumi, V. N., Bi, T. A. V., Louis, Z. (2021). Biodiversity Management under Cashew Agro-ecosystems in Central Africa: A case study from Cameroon. *Open Journal of Agricultural Research*, 1(2) : 45-61.

Dona, A., Mapongmetsem, P. M., Dongock, N. D., Pamboudem, N. A., Fawa, G., Aoudou, D. S. (2016). Phytodiversity and carbon stock in Sudanian savannahs zone of Tandjile-East of Chad. *International Journal of Applied Research*, 2(9): 455-460.

Dwomoh, E. A., Ackonor, J. B., Afun, J. V. K. (2008). Survey of insect species associated with cashew (*Anacardium occidentale* Linn.) and their distribution in Ghana. *African Journal of Agricultural Research,* 3: 205-214.

FAO (Food and Agriculture Organization) (2014). Base des données de la FAO 2011. http://faostat3.fao.org.

Frontier, S., Pichod-Viale D. (1995). Écosystèmes : structure, fonctionnement, évolution. Masson, 447 p.

Gning, O, Sarr, O, Gueye, M, Akpo, L.E., Ndiaye, P.M. (2013). Valeur socio-économique de l'arbre en milieu malinké (Khossanto, Sénégal). *Journal of Applied Biosciences,* 70 : 5617Ŕ5631.

Grall, J., Coic, N. (2005). Synthèse des méthodes d'évaluation de la qualité du benthos en milieu cotier. Institut Universitaire Européenne de la mer-Université de Bretagne Occidentale.90p.

Hammed, L. A., Amnikwe, J. C., Adededji, A. R. (2008). Cashew nuts and production development in Nigeria. *American-Eurasian Journal of Scientific Research* 3(1) : 54-61.

Hien, S. (2019). Aperçu de l'évolution de la production d'anacarde et évolution du marché de noix brutes de cajou dans la sous-région et perspectives pour 2019/2020, N'Kalô, Papier de conférence, Forum sur le cajou sahélien du 5 au 7 août 2019, 16 p.

Ibrahima, Abib, F. (2008). Estimation du stock de carbone dans les faciès arborés et arbustifs des savanes soudano-guinéennes de Ngaoundéré, Cameroun. *Cameroon Journal of Experimental Biology,* 4(1) : 1-11.

IPCC (2003). Good Practice Guidance for Land Use, Land-Use Change and Forestry. (Eds). Institute for Global Environmental Strategies. *Hayama*, 126: 197-207.

Kambaye, M., Ngor, N., Dasylva, M. (2021). Contribution de la roduction anacardière aux moyens de subsistance des ménages Balantes de Mansoa (région d'Oio, Guinée-Bissau). *International Journal of Biological and Chemical Sciences*, 15(2): 511-523.l'Extrême-Nord).

Malela, K.E., Miabangana, E.S., Petit, J., N'zikou, J.M., Scher, J. (2016). Enquête ethnobotanique sur les fruits comestibles de la flore spontanéede la République du Congo. *International Journal of Pure & Applied Bioscience*, 4 (2) : 346 - 357.

Mataï, (2020). Dynamique végétale dans les sites de reboisement de la zone soudano-sahélienne (Extrême-Nord, Cameroun). Thèse de Doctorat Ph D. Université de Ngaoundéré. 176p.

MINADER, (2018). Stratégie nationale de développement des chaînes de valeurs de la filière anacarde au Cameroun 2019 – 2023. Document final. 90p.

N'Guessan, K.E., Adou, C. Y., Goné Bi, Z. B., Vroh Bi, T. A., Monssou, E. O. (2016). Evaluation De La Diversité Et Estimation De La Biomasse Aérienne Des Arbres Du Jardin

Botanique De Bingerville (District d'Abidjan, Côte d'Ivoire). *European Scientific Journal*, 2(6):168-184.

Ndiaye, I., Camara, B., Ngom, D., Sarr, O. (2017). Diversité spécifique et usages ethnobotaniques des ligneux suivant un gradient pluviométrique Nord-Sud dans le bassin arachidier sénégalais. *Journal of Applied Biosciences,* 113: 11123-11137.

Ndiaye, S., Mohamed, M., Charahabil, Malaïny, D. (2021). Caractéristiques des plantations d'anacardiers (*Anacardium occidentale* L.) et déterminants économiques des exploitations en Casamance. *VertigO - la revue électronique en sciences de l'environnement*, 20 (3) : 22.

Ngom, D., Fall, T., Sarr, O., Diatta, S., Akpo, L. E. (2013). Caractéristiques écologiques du peuplement ligneux de la réserve de biosphère du Ferlo, Sénégal. *Journal of Applied Biosciences,* 65:5008 Ŕ 5023.

Noiha, N. V., Zapfack, L., Awe, D. V., Witanou, N., Nyeck, B., Ngossomo, J. D., Hamadou, M. R., Chimi, C. D., Tabue, M. R. B. (2017). Floristic structure and sequestration potential of cashew agroecosystems in Africa: A case study from Cameroon. *Journal of Sustainable Forestry***.**

Noiha, N.V., Zapfack, L., Mbadé, L.F. (2015**).** Biodiversity Management and Plant Dynamicina Cocoa Agroforest **(**Cameroon**).** *International Journal of Plant & Soil Science*, 6(2):101-108.

Nyasiri J., Tchobsala, Dongock N. D., Ibrahima A., (2018)**.** Impact of anthropization on the spatio-temporal dynamics of the forest landscapes of the Ngaoundéré cliff, Adamawa –Cameroon. *International Journal of Advanced Research in Biological Sciences,* 5(3): 60-74.

Ousmane, L. M., Oumarou, T. G., Boubé, M., Saley, K., Ali, M. (2017). État de la végétation ligneuse au Sahel : cas de Guidan Roumdji au Sahel Central du Niger. *Journal of Animal and Plant Sciences*. 3 : 5033-5049.

Poupon, H. (1980). Structure et dynamique de la strate ligneuse d'une steppe sahélienne au nord du Sénégal. ORSTOM éd. (Études & Thèses), 307 pages.

Rassida, A., Abel, T., Jules, B., Bourou, S. (2023). Caractérisation de *l'Anacardium occidentale* L. au Nord-Cameroun : cas du terroir de Garoua III. *Les cahiers de l'ACAREF.* 5(11) : 1-29.

Raunkiaer, C. (1934). The life forms of plants and statistical plant. *Georgaphy Claredon Press Oxford*, 632 p.

Sarr, O, Ngom, D, Bakhoum, A, Akpo, L.E. (2013). Dynamique du peuplement ligneux dans un parcours agrosylvopastoral du Sénégal. *VertigO, la revue électronique en sciences de l'environnement,* **13**(2) : 16p.

Schnell, R. (1971). Introduction à la phytogéographie des Pays Tropicaux, les problèmes généraux, les milieux, les groupements végétaux, Ed. GauthierVillars, Paris, 52 p.

Tandjiekpon, A., Lagbadohossou, A., Hinvi, J., Afonnon, E. (2003). La culture de l'anacardier au Bénin : *Référentiel Technique*. Edition INRAB, ISBN 99919-51-66-0, 86 p.

Tchotsoua, M., Mapongmetsem, P. M., Tago, M. (2000). « Urbanisation, crise économique et dynamique de l'environnement en milieu soudanien d'altitude : cas du plateau de Ngaoundéré au Cameroun ». In Fouodoup K., Courade G. (éd.) : Sociétés et environnement au Cameroun, *Revue de géographie du Cameroun*, numéro spécial, pp. 117-127.

Thiombiano, S.T. (2010). Contribution à la facilitation de l'accès des petits producteurs d'anacarde aux crédits carbone au Burkina Faso. Master en Génie Electrique, Energétique et Energies Renouvelables, Institut International d'ingénierie de l'eau et de l'environnement, 74p.

Yabi, I., Yabi, B. F., Dadegnon, S. (2013). Diversité des espèces végétales au sein des agro-forêts à base d'anacardier dans la commune de Savalou au Benin. *International Journal of Biological and Chemical Sciences* 7(2): 696-706.

How to cite this paper?

Atlove Wonbon'n, F.P. Tchobsala & Vroumsia Toua (2024). Vegetation characterization and carbon sequestration under Anacardium occidentale orchards in Cameroon: the case of the Septentrion cashew basins from Cameroon. *Journal of Experimental and Applied Tropical Biology*, 4(1): 11-23