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Floristic diversity and carbon stock in the Agrosystem of *Persea americana* Mill (Lauraceae) in the high Guinean savannahs of the Adamawa Cameroon

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***Abstract*— *The knowledge on the floristic diversity of Persea americana agrosystem and their contribution to carbon stock was evaluated in the high-Guinean savannahs of Adamawa Cameroon. Three sites of different ages were identified according to the age of plantation. The savannah zone was chosen as the witness treatment. Sampling was done along five transects of 20 x 100m² installed in each site giving a total of 20 transects. An inventory of shrubs with dbh ≥ 5 cm was carried out. The average estimates aboveground and belowground carbon stock in shrub biomass was calculated using the algometric equation. A total of 3296 individuals from 30 families, 53 genus and 61 species were counted. Comparative analysis was carried out to show that abundance, Shannon index and land area were significantly different in the different plots. Contrarily, Piélou equitability and ecology importance index do not vary much between pear trees and savannah. The total carbon stocks were estimated at 4.57t/ha (savannah) to 18.76 t/ha (others sites). Carbon sequestration ecological service value in the agrosystems was estimated to be more than 7126.6 dollars/ha with a liberation potential of about 712.66±2.11 tCO_2/ha. These data show the capacity of the agrosystem of Persea americana to sequestrate more carbon compared to savannah vegetation that is subjected to constant disturbance by anthropic activities. Ecological services related to carbon can be an opportunity for financial benefits if the credits from the development of mechanism improves incomes of rural populations who contribute in the management and the conservation of the ecosystem.*

Keywords— **Floristic composition, agrosystem, *Persea americana*, carbon stock, Adamawa Cameroon.**

I. INTRODUCTION

Multistorey farming systems add considerable interspecific interaction, especially competition, to whatever existing intraspecific competition for water, nutrients, light, and CO_2, thereby creating a more complex agroecosystem (Rao *et al.*, 1999). Agroforestry is recognized as an integrated applied science that has the potential for addressing many of the land-management and environmental problems found in both developing and industrialized nations. From the 18th century, with the start of industrialization, there is an increasing rate of greenhouse gases in the lower atmosphere, causing the higher temperature on the earth. (Frederic, 2015). This alarming rate has brought about climate change, causing enormous irreversible damages to the environment and human society. The consequence linked to climatic variation include among others: rapid regression of ice caps, (3 million of km² from 1975 to 2010), polar cold waves, silting and eutrophication of the lake Chad (Volume ten times less than it was 40 years ago) accentuated inundation of terrestrial ecosystem during heavy rains and many others (GIEC, 2014). Anthropics activities, the effect of industrial agriculture and energy supply contributes significantly to the pollution of the Earth and therefore constitute the main causes of the emission of greenhouse gases. (GIEC, 2007). Thus, the effective and economic engagement toward the reduction of greenhouse gases, carbon sequestration and stocking in order to avoid temperature increase of 4ºC or more by 2100 should be noted (Frederick, 2015).

The Cameroonian law of 1994 on forest, fauna and fishing provides a political and strategic framework on the conservation of biodiversity and sustainable management. Which it is articulated around points like sustainable management of forest, contribution to economic growth, participative management and the reinforcement of the public sector on essential functions (Fondemba, 2010). Therefore, it is important and necessary to know the carbon sequestration potentials of agroforestry systems which specifically offers goods and services (food, medicine, cosmetics, fuel and construction wood) to local populations. In Cameroon research has focused mainly on floristic diversity and carbon stock in parks and agroforestry systems (Frieden *et al.*, 2005; Peltier *et al.*, 2007; Mapongmetsem *et al.*, 2011; Zapfack *et al.*,2013 ; 2016; Noiha *et al.*, 2015 ; 2017).These works generally concerned only the agrosystem of forest zone. However, the savannah zones already weakened by climate change, abound with a fairly large flora which would also contribute to the sequestration of a significant amount of CO_2 contained in the atmosphere. Promoting agroforestry is one option perceived as a major opportunity to deal with problems related to land-use and CO_2-induced global warming. In this paper agroforestry is defined as any land-use system that involves the deliberate retention, introduction or mixture of trees or other woody perennials with agricultural crops, pastures and/or livestock to exploit the ecological and economic interactions of the different components (Albrecht and Kandji, 2003). The interest of this present study is to evaluate the biodiversity and carbon stock in agrosystem of *Persea americana* (ASPA) in Adamawa region for a greater importance to given to its conservation and sustainable management.

II. MATERIAL and METHODS

Presentation of the study zone

The study is carried out in Cameroon in the Adamawa region, Vina division. This zone covers an area of 63701km^2 between 6º to 8º North latitude and 11º and 15º East longitude (Table1).

Table 1: Geographical coordinates and direction of the sampling bands of the sites.

Sites Altitude Geographic Coordinate Area Direction

Sites	Altitudes	Geographicscoordinates	Areas	Directions
Ngadamabanga	1114	07°N 21’ 838’’013°E 35’ 779’’	1 ha	North-South
Mardock	1090	07°N 20’ 971’’013°E 34’ 162’’	1 ha	South-North
Nord-CIFAN	1120	07°N 19’ 219’’013°E 36’ 559’’	1 ha	North/West-South/East
Savannah	1075	07°N 26’ 225’’013°E 32’ 998’’	1 ha	South-North

It is made up mainly of highlands that crosses and stretches from West to East between the Federal Republic of Nigeria and Central African Republic. The Adamawa with its latitudinal extent has an extremely diversified landscape, ecosystems, geomorphological and climatic zones divided into two main agro-ecological zones with specific physical characteristics (Tchotsoua, 2006). The Adamawa plateau has an average altitudes of 1100m. The relief is very contrasting and compartmented with a vast block of a raised bed rock. The climate is the tropical type characterised by a short dry season (November to April) and a long rainy season (April to November) with peaks in September. The average monthly temperature does not go above 34ºC. The annual average rainfall varies between 900mm to 1500mm (PAN-LCD, 2007). Some patches of ferruginous soils are found on slopes with steep gradient, they are essentially ferraltic formed from different old rocks that dominate in this region (Humbel, 1966). The P^H is between 4 and 5.5 (Danboya, 2011). Agriculture, bush fire, mining, the search for fuel wood are the main causes of soil degradation (Danboya, 2011; Hamadou, 2017). The rivers of the zone flow into the Niger river, lake Chad and Atlantic Ocean. The Biographic homogeneity found in this region correspond to Sudano-guineen Shrubs or trees of *Daniella Oliveri* and *Lophira lanleolata* (Letounzey, 1968). The Mboum were the oldest population in the zone before Fulbe invasion. They are found especially on the Ngaoundéré plateau whereas the Peul, Dii or Dourou and the G’baya who came often occupies the North and East of the plateau respectively. The other ethnic groups were migratory.

2.2 Data collection

The sites were choosing based on the age of plantation and the representability of *Persea americana* in the area. Three plots were retained: < 10 years; 10-20 years and < 20 years. The witness site had not undergone dense anthropogenic activities for at least one year. The distance between the three sites was about 4 km while the witness plot was far at 10 km from the plots < 10 and 10-20 years, and from 13km from the plot >20 years.

Transects of 100m x 20m were constructed in each site and each of these transects was separated from another by a distance of 20m (Fig. 1). The sampling bands were established with the aid of compass and GPS. The circumferences (5≤ circumferences ≤155) for trees was measured at 1.30m above the ground and at 0.30m for small trees with the decameter. At the end of each bands, milestones were fixed at an equidistance of 20m, all the wooded plants were systematically counted.

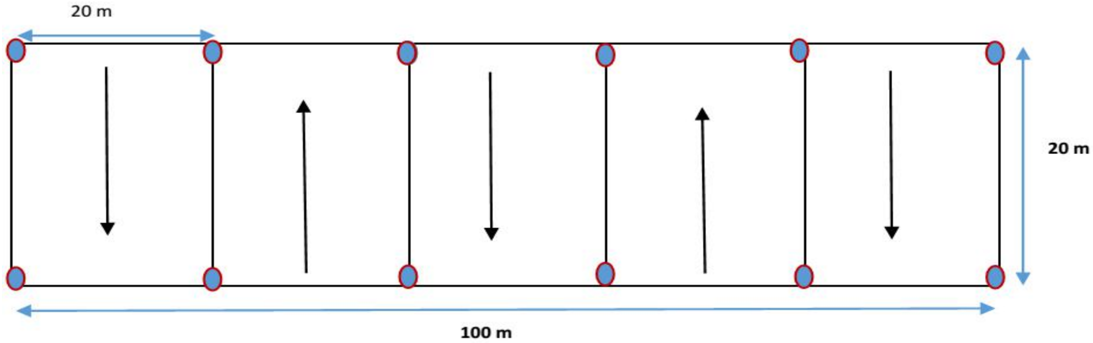

Fig.1: Plan of the device illustrating a sampling unit. (Legend: = milestones; = sampling direction in 20 × 20 m² strips)

Floristic inventory

The dendrometric data concern only the dbh. The dbh obtained was divided into six classes of diameter:]0-10],]10-20],]20-30],]30-40],]40-50],]50-60]. The sampled trees were wounded on the bands delimited by the twins to avoid double counting. For the trees at the border of transect, they were taken into account those situated at the right in the direction of the transect.

The specific richness (S) was the total number of species from floristic inventory. The Relative abundance was calculated using the formula proposed by Doucet (2003): RA (%) = n/N×100

(RA= relative abundance; n= number of individual at the taxonomy level; N= total number of all the taxon considered).

The Shannon diversity index (ISH) was calculated using the Frontier and Pichod-viale (1991) method: ISH= $-\sum (ni/N) \, Log_2(ni/N)$ (ni = numbers of the species, N= numbers of the total species).

The Piélou Equitability (EQ) according to Ngueguim *et al*. (2009) was calculated,

EQ = ISH/Log_2N ; N= number of species

The Sorensen Similitude Coefficient was calculated using the formula applied by Ngueguim *et al* (2009): K= (2c/a+b) x 100 (a= number of relieves 1, b= number of of relieves 2, c= number of species common in the two relieves).

Ecological importance index (IIE) $IIE = \left(\sum_{i=1}^{n} \frac{ni}{N} + \sum_{i=1}^{n} \frac{Si}{S}\right) x\ 100.$

(ni / N: relative frequency of individuals of a species; ni is the number of individuals of the species and N is the total number of individuals in the group. The Si / S ratio is the relative dominance of individuals for the species "i"; “Si” is the basal area of individuals of species i and S is the total basal area.

Diameter classes of species

The circumferences of all tree species are measured, the dbh obtained are divided into six classes of diameters. These allow to appreciate the behavior of the vegetation in general, and of the different dominant species in particular. The classes help to assess the dynamics of the formations studied. A distribution according to a decreasing exponential was a sign of ecological vigor.

Density and basal area

The density of a species was obtained by dividing the total number of individuals belonging to this species by the area of the sampling area (Jagoret *et al.*, 2011). This was the number of individuals per hectare. The following formula has been applied: D = n/S. (D: density (Trees/ha), n:

number of trees present on the surface considered and S: surface considered (ha)).

The basal area is the area of the cross section of a tree trunk. It is used to determine the relative importance of a species and is expressed by the following formula: S = π ($Di^2/4$). It allows a better visualization of a forest ecosystem since it highlights the species and families that occupy the most space. It is a descriptor directly linked to the diameter and commonly used in forestry studies (Jagoret *et al.*, 2011). The basal area of the stand was: $S = \frac{\pi}{4}\sum_{i=1}^{n} d_i^2 = \frac{1}{4\pi}\sum_{i=1}^{n} C_i^2$(S: basal area (m²/ha), d: diameter (m), C: circumference (m)).

Carbon stock

The method used is the so called nondestructive method concerning the volumes of wood. It takes into account the diameters at breast height (dbh), it is less cumbersome to undertake and less expensive (Brown, 1997; Chave *et al.*, 2005).

Aboveground carbon

The Aboveground carbon (AGC) was evaluated by taking into account the diameters obtained during the floristic inventory, according to the allometric formula of Chave *et al.* (2005): AGB = α Exp [-1.499 + 2.148 * ln (dbh) + 0.207 * $(\ln (dbh))^2$ - 0.0281* $(\ln (dbh))^3$]. (AGB = aboveground biomass/kg, (dbh) = diameter (cm) above the ground; α = density). For species whose density has not been estimated, the value of the average specific density of wood for tropical forests: α = 0.58g/cm³ was used. For the evaluation of specific densities of wood in all species, an online data item "Global Wood Density Data Base" was used (Zanne *et al.*, 2009).

From this biomass, the quantity of carbon (Kg/ha) was obtained by multiplying this biomass by a conversion factor equivalent to 0.47 (Zapfack *et al.*, 2013); then it is converted into tonnes of carbon per hectare (tC/ha).

Belowground carbon

After evaluating the biomass of the woody species surveyed, the allometric equation developed by Brown (1997) was necessary to deduce the belowground carbon (BGC), according to the following model: BGB = expo (-1, 0587 + 0, 8836 * ln (AGB)). (AGB and BGB in kg).

Total carbon of standing trees

The total biomass (TB/kg) of standing trees was estimated using the formula:

TB (kg) = AGB + BGB; then convert to t/ha (FAO, 1992) (AGB = aboveground biomass (kg); BGB = Belowground Biomass (kg))

Estimate of the ecological service

The ecological service was estimated by the 44/12 ratio corresponding to the CO_2/C ratio representing the molecular weight, used in this investigation to convert carbon stocks into the amount of CO_2 sequestered by the agrosystem. Subsequently, this quantity of CO_2 was evaluated in monetary value using the value of the ecological service estimated at 10 USA/t CO_2 (Kelley and Gallant, 2017).

Analysis of variance

A one-way ANOVA test is done using the XLstat (2017) and STATGRAPHICS plus 5.0 software to compare the quantitative data obtained in the different agroforestry systems.

III. RESULTS

Specific riches and taxonomies abundance

From the floristic inventory in the ASPA, a total of 2101 individuals were obtained, grouped into 24 species, 23 genus and 17 families. Taxonomic diversity varies with the age of the agrosystem (Table 2). The ASPA >20 age presents the highest diversity with 860 individual (28 species, 26 genus and 16 families), followed by the youngest (>10 years) with 689 individuals (23 species, 22 genus and 18 families). The witness site compared to ASPA presents a remarkable diversity with 1195 individual (36 species, 32 genus and 23 families). Six families dominate the floral of the plots and constitute 67.73% of the total number.

Table 2. Specifics richness and taxonomic abundance in the sites

Sites (years)	individuals	species	genus	famillies
< 10	689	22	22	18
10-20	552	23	22	18
> 20	860	28	26	16
Savannah	1195	36	32	23
Total	3296	61	53	30

The most represented families in terms of individuals were Lauraceae (33.07%), Myrtaceae (14.08%), Mimosaceae (7.97%), Sapindaceae (5.04 %), Anacardiaceae (3.85%) and Euphorbiaceae (3.72%). However, in the witness plot, 80.24% of individuals were represented by Hymenocardiaceae (34.47%), Caesalpiniaceae (21%), Combretaceae (9.37%), Annonaceae (7.03), Anacardiaceae (5.44 %) and Proteaceae (2.93%).

At the specific level, five species present a remarkable abundance in the undergrowth of the ASAP. These are *Persea americana*, *Psidium guajava*, *Citrus aurantifolia*, *Albizia zygia*, *Allophylus africanus*, which the cumulative total number represents 72.46% of the flora; while in the savannah, the densest species were *Hymenocardia acida*, *Daniellia oliveri*, *Piliostigma thonningii*, *Annona senegalensis* and *Terminalia laxiflora* with a relative density of 70.65%. The other species are poorly represented with 29.37% as a cumulative density.

Floristic diversity index

The floristic diversity index was summarized in the Table 3. The Shannon diversity index varies depending on the plots. It is significally high in witness plots (3.09) compare to ASPA (2.75, 2.54 and 2.31 respectively for the sites > 20 years, 10-20 years and < 10 years).It is showing a great diversity in the savannah compare to ASPA. The youngest sites (< 10 and 10-20 years) were lowest diversify. Concerning the floristic value, there was a great significant difference between those sites (P<5%).The individual plants were equally distributed within species in the ASPA and the savannah site (Piélou equitability is around 1 in all the sites).

Table 3. Diversity indexes in the sites.

Sites (Years)	Shannon index	Piélou equitability	Importance value (%)
< 10	2.54^a	1^a	200.11^a
10-20	2.31^a	1^a	200.07^a
> 20	2.76^a	1^a	200.02^a
Savannah	3.09^b	1^a	200.22^b

A total of 11 species have the highest importance value in the plots: *Persea americana* (113.46), *Hymenocardia acida* (38.89), *Psidium guajava* (24.48), *Citrus aurentifolia* (16.5), *Daniellia oliveri* (21.2), *Mangifera indica* (14.37), *Albizia zygia* (18.39), *Annona senegalensis* (8.85), *Terminalia laxiflora* (8.1), *Vernonia amygdalina* (7.97) and *Dacryodes edulis* (4.94). *Persea americana* is highly spread and predominates in the ASPA. The statistical analysis shows a significant difference between the ASPA and the whitness (p > 0.05) concerning the importance value.

The similitude coefficient varies from 60.09 in the site > 20 years to 68.33 in <10 years (Table 4). The similarity index are generally very high, not reflecting a significant difference between the plots of different ages. However, these four plots are more floristically similar, since they have floristic affinities between them greater than or equal to 60% which form the same plant community.

Table 4. Similitude coefficient in the sites.

Sites (Years)	**< 10**	**10-20**	**> 20**	**Savannah**
< 10	100			
10-20	66.66	100		
> 20	68.33	66.52	100	
Savannah	67.28	61.57	60.09	100

Diametric structure

The number of individuals by diameter reduces with the increase of diameter (Fig. 2). However, the plants with class diameter of the site <10 years were the most represented in all the sites and the witness plot. The general distribution of the plots studied presents a decreasing exponential form "L" with a high tendency in]0-10] and]30-40] classes. It is lowly represented in diameter between]40-50] and]50-60] and completely absent in the witness plot. This structure shows that the plots disposes many future individuals to assure the regeneration of forest species with many individuals of small diameter and few individuals of larges diameter.

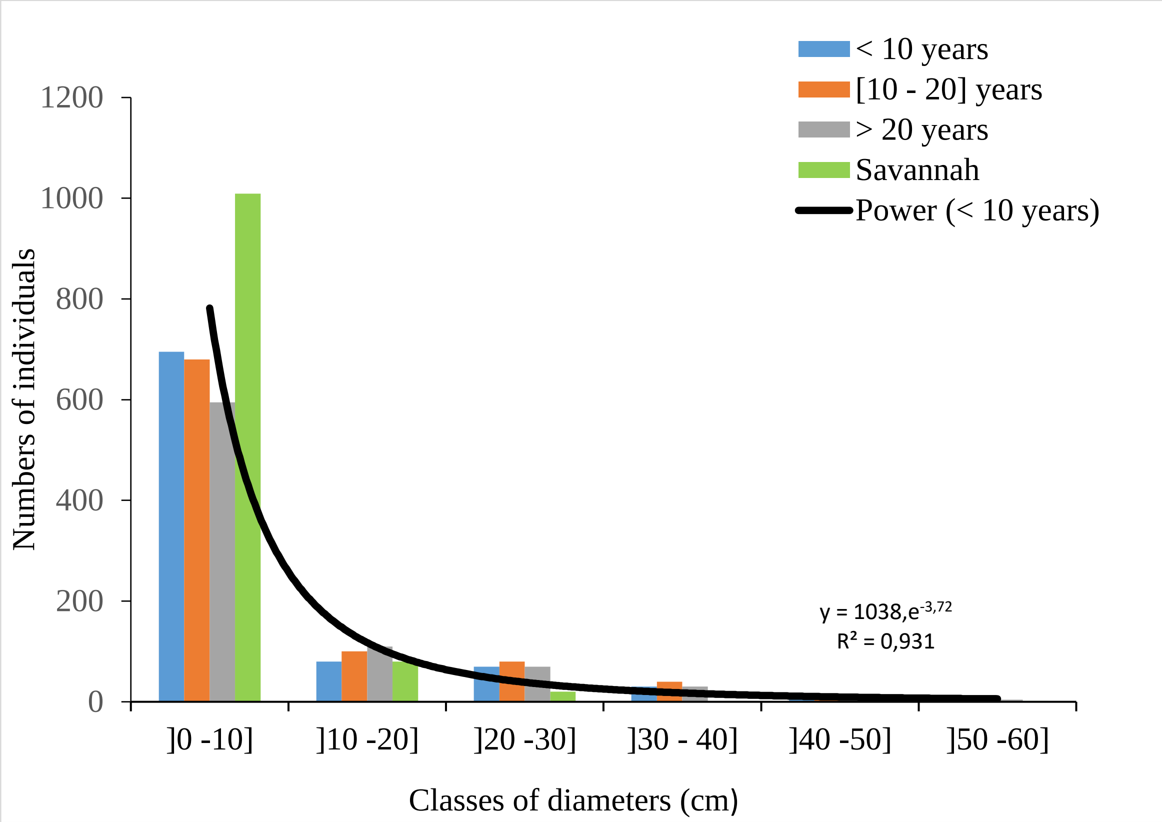

Fig.2: Distribution of individuals between the classes of diameters

Density

The density of species is highly significant between the witness site and the three ASPA (F = 90.72; p = 0.00 < 0.05) (Fig. 3). The value is maximum in the savannah with a significant rate of 1195±48.2 stems/ha. It gradually decreases by 860 in the plantations > 20 years, 689 stems/ha in that of < 10 years and to 552 in the sites of]10-20]. Six species are the most represented in the savannah with 910 inds/ha in the plots of > 20 years with 693 individuals, 588 individuals in that of < 10 years and finally 443 individuals for]10-20] years. Compared to the other plots, the control has the highest density. Of all these species, the highest value is for the witness site with *Hymenocardia acida* that has a density of 1246 inds/ha.

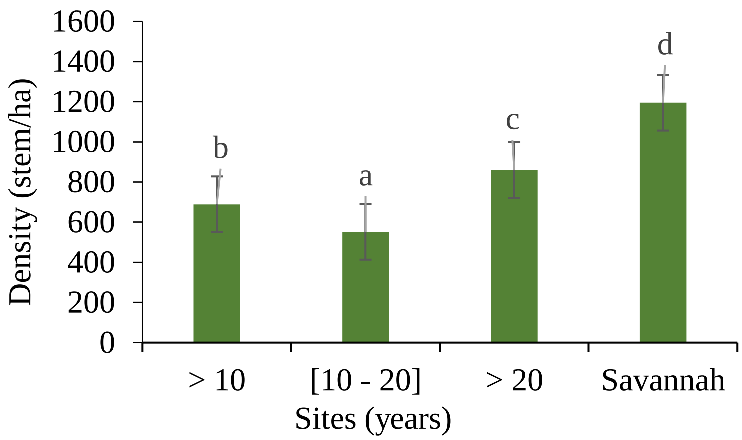

Fig.3: Variation in density between the different plots studied

(*Histograms with the same letters are not significantly different at the probability threshold of 0.05*).

Basal area

The basal area (Fig. 4) varies from 0.75 m²/ha for the savannah to 10.02 m²/ha for the site of site >20 years. The plots < 10 and]10-20] years has respectively the basal area of 0.32 and 5.36 m^2 /ha, this surface was maximum in the plot > 20 years (10.02±0.09 m^2 /ha). Statistical analysis shows that the basal area is highly significant between the savannah and the different ASPA studied ($F = 92.89$; $p = 0.001 < 0.05$). At the family level the basal area of the most represented six families was 0.66 m^2/ha in the savannah, 5.24 m^2/ha in the site <10 years, 7.07 m^2/ha in the site]10-20] years and 9.05 m^2/ha in the ASPA >20 years.

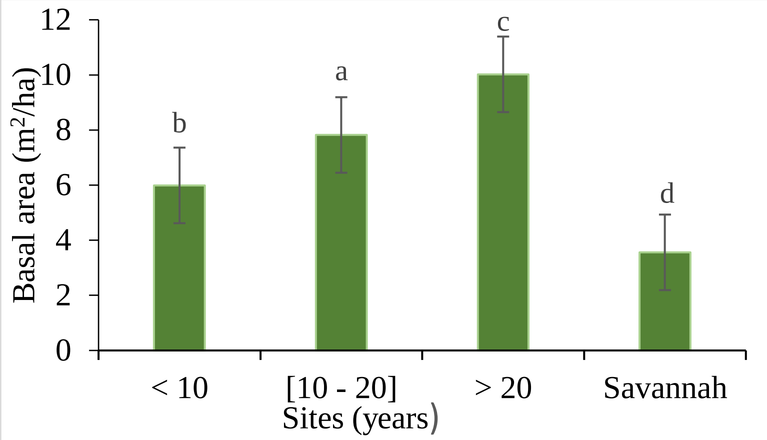

Fig.4: Variation of the basal area between the plots studied

(*Histograms with the same letters are not significantly different at the probability threshold of 0.05*).

Biomass and carbon stock

The largest AGB returns to the ASPA > 20 years with 59.31 tC/ha against 56.90 tC/ha for]10-20] and 15.98 Ct/ha for those < 10 years (Table 5). The savannah has a very low biomass with 2.93 tC/ha. There is a significant statistical difference for the aboveground carbon stocks between the different plots studied ($F = 92.89$; $p = 0.001 < 0.05$). The family with the highest amount of aboveground carbon stock was Lauraceae (31.87 tC/ha), followed by Anacardiaceae (2.55 tC/ha), Rutaceae (2.12 tC/ha) and Myrtaceae (0.55 tC/ha). The species with the highest amount of aboveground carbon stock was *Persea americana* (31.87 tC/ha), followed by *Mangifera indica* (2.56 tC/ha), *Citrus aurantifolia* (2.17 tC/ha), *Albizia zygia* (1.12 tC/ha). The others species stock are equal or than 4.29 tC/ha on average.

The ASPA > 20 years gives a highest BGB of 19.75 t/ha (Table 5), compared with 16.57 t/ha for that of]10-20], 2.78 t/ha for the plot of >10 years. The savannah reveals the lowest BGB (1.64 t/ha). The BGB seems to increase with the age of the area. Statistical analysis ($p < 0.01$) shows the significant difference between the belowground carbons stocks of the plots studied.

Table 5 : Carbon stocks and the economic value of ASPA (*AGB= Aboveground biomass, BGB= belowground biomass, QCO_2 = Quantity CO2*)

Sites (Years)	AGB (t/ha)	BGB (t/ha)	Stock (t/ha)	QCO_2 (t/ha)	EV (Dollars/ha)
< 10	15.98 ± 0.16[a]	2.78 ± 0.04[a]	17.76	28.49 ± 0.56 [b]	284.9
10 -20	56.09 ± 3.03[b]	16.57 ± 0.6[b]	75.47	287.99 ± 0.58 [a]	2879.9
> 20	59.31 ± 5.43[c]	19.75 ± 1.03[c]	83.06	304.82 ± 0.82 [d]	3048.2
Savannah	2.93 ± 0.03[d]	1.64 ± 0.01[d]	4.57	11.15 ± 0.17 [c]	913.6
Total	**128.12 ± 2.16**	**36.74 ± 0.42**	**180.86**	**712.66 ± 2.11**	**7126.6**

Values with the same letters are not significantly different in the column at the probability threshold of 0.05.

Carbon stock affected by diameter classes

The carbon stock varies depending of the diameter of trees and the age of the agrosystem (Fig. 5). In the ASPA > 10 years, carbon stock was highest in the diameter class of]20-30] cm and reduces slightly in the class of]30-40] cm but less represented in the other classes. In the plot with]10-20] cm of diameter, the quantity of carbon was very high in the diameter class]30-40] cm and]40-50] cm and low in the diameter class]0-10] cm. In the site >20 years, the sequestration of carbon is highly represented in three diameter classes]40-50],]30-40] and]20-30] with 25.03; 24.49 and 20.55 cm respectively, giving the total of 70.07 tC/ha. The small diameter classes store less carbon. The savannah generally was less represented in carbon stock. There is a significant difference in total carbon stocks between the different sites studied (P < 0.01). According to the result, it is convenient to note that carbon sequestration in different agrosystems is important in the large diameter classes whose evaluation depends significantly on dbh).

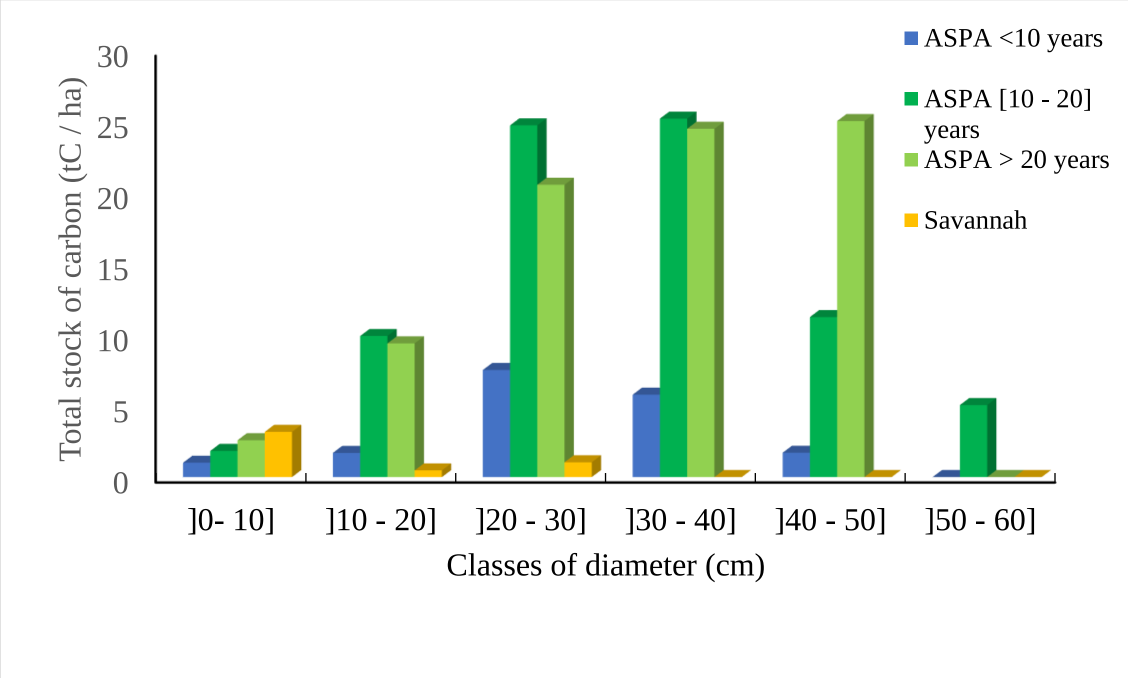

Fig.5: Stock of total carbon following classes of diameter in ASPA

Carbon stock in function of taxons

In ASPA, Lauraceae (53.32 tC/ha), Anacardiaceae (7.56 tC/ha), Rutaceae (3.6 tC/ha) and Myrtaceae (1.35 tC/ha) constitute the families which contributed significantly to the sequestration of total carbon. The families of the whitness site which contributed significally to the sequestered of total carbon were respectively Caesalpiniaceae (2.52 tC/ha), Hymenocardiaceae (0.82 tC/ha), Combretaceae (0.33 tC/ha) and Anacardiaceae (0.27 tC/ha) (Fig. 6). The species with the highest amount of total carbon stock was *Persea americana* with 53.32 tC/ha. It is followed by *Mangifera indica* (5.56 tC/ha), *Citrus aurantifolia* (3.6 tC/ha) and *Albizia zygia* (1.63 tC/ha). In contrast, the species with the highest amount of total carbon stock in the savannah is *Daniellia oliveri* (2.3 tC/ha), followed by *Hymenocardia acida* (0.75 tC/ha), *Piliostigma thonningii* (0.23 tC/ha) and *Terminalia laxiflora* (0.19 tC/ha) (Fig. 7).

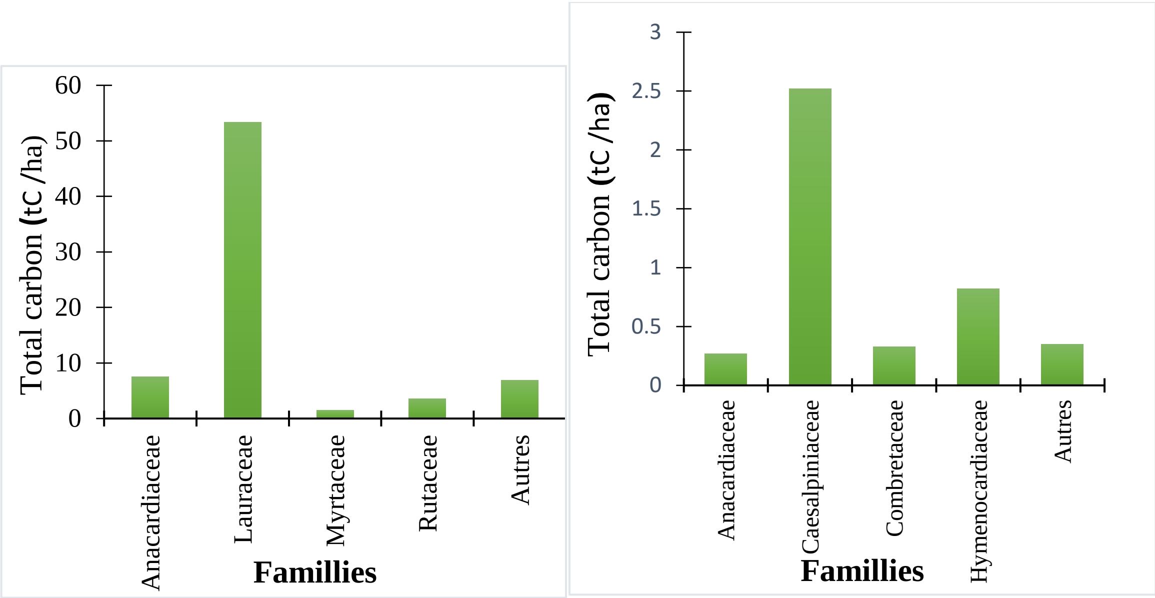

Figure 6: Total carbon of most represented families in the ASPA (A) and in the savannah (B).

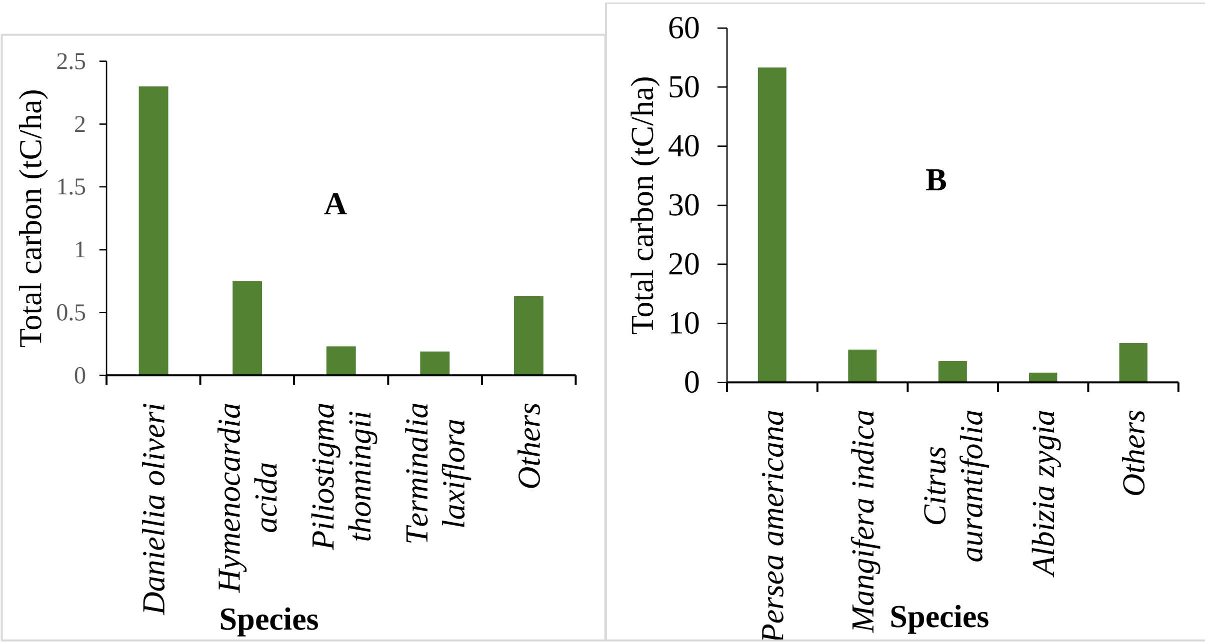

Fig.7: Total carbon of most represented species in the savannah (A) and in the ASPA (B).

Sequestration potentials and economic value

The potential for CO_2 sequestration is significantly different between the sites (p= 0.001<0.05). The highest stock of CO_2 was observed in sites of >20 years with 304.82 ± 0.82 tCO_2/ha). The economic value between the different sites also varies significantly (p=0.001<0.05). The greatest economic value is observed in the site of > 20 years (54153.28 ± 109.60 FCFA/ha).

Correlations

The correlation between carbon stocks and the number of species, the density or the basal area and the economic value is strong (r > 0.5). It is highly significant between carbon stock and the number of species for the aboveground carbon (r = 0.831; p < 0.001), belowground carbon (r = 0.967; p < 0.001) and total carbon (r = 0.973; p < 0.001). This means that carbon stocks were correlated with the numbers of species. There is also a strong and significant correlation between the carbon stock and the density for the aboveground carbon (r = 0.978; p < 0.001), belowground carbon (r = 0.991; p < 0.001) and total carbon (r = 0.999; p < 0.001). Thus a strong and significant correlation is also highlighted between the carbon stock and the basal area for the aboveground carbon (r = 0.881; p < 0.001), belowground carbon (r = 0.835; p < 0.001) and total carbon (r = 0.999; p < 0.001) and also between carbon stocks and economic value where for the carbon aboveground (r = 0.996; p < 0.001), belowground carbon (r = 0.998; p < 0.001) and total carbon (p < 0.001) (Table 6).

Table 6: Correlation between the number of species, density, basal area, economic value aboveground carbon (AGC), belowground carbon (BGC) and the total carbon (TC).

	AGC (tC/ha)	BGC (tC/ha)	TC (tC/ha)
Numbers of species	r= 0.831 p=0.0000	r =0.967 p =0.0000	r =0.973 p =0.0000
Density (stems/ha)	r =0.978 p =0.0000	r =0.991 p=0.000	r =0.999 p =0.0000
Basal area (m²/ha)	r =0.881 p =0.0000	r =0.835 p =0.0000	r =0.999 p =0.0000
Economic value (dollar/ha)	r=0.996 p =0.0000	r=0.998 p =0.0000	r=0.888 p =0.0000

(r = correlation coefficient, P= significance level)

Ascendant hierarchical analysis of species affected by total carbon stock

The hierarchical ascendant classification of the data obtain according to the similarity index confirms the different agroforestry systems sampled. At the threshold of the coefficient of similarity of about 98%, the analysis shows that the species forms five groups indicated in the dendrogram (Fig.8). Group 1 comprising 62 species, group 2 presents 5 species, groups 3 and 4 has one specie each, group 5 has three species. These species are grouped according to their diameter at breast height. The five groups form four complexes with different similitudes, (G4-G1): 07.5%; (G4-G5): 07.5%, (G1-G5): 49.51% and (G3-G2): 35.5% and are dependent on their carbon stock.

The principal component analysis (PCA) shows that the four plots are positively correlated with each other and the different species are also positively correlated with each other (Fig. 9A). The factorial correspondence analysis (AFC) shows that *Persea americana* was the most represented in the plots thus justifying pear agrosystem (Fig. 9B). The species dispersed in the sites were high represented, indicating a high frequency of finding them in all the four plots sampled. The other species that are less represented forms clouds around the two F1 and F2 axes (78.50%). The species represented in the form of clouds were less dense hence they cannot be found everywhere in the sampled plots. In the column function, the isolated species show correlation between the basal area, dbh, density and carbon stocks. From the ecological point of view, there species are accidental dotted in these plots.

IV. DISCUSSION

Vegetation

The agrosystems offers an important floristic diversity which varies with the maintenance technics and the climate of the region. This diversity in some areas is very different or close to that of a primary forest (Zapfack *et al*., 2002; Sonwa *et al*., 2007; Mapongmetsem *et al*., 2011; Noiha *et al*., 2015; Dona *et al*., 2016). However, there is a high specific riche in the savannah. A total of 2101 individuals distributed in 17 families, 23 genus and 25 species have been inventoried in agrosystems, four species constituting 87.78% of the undergrowth were the most represented: *Albizia zygia*, *Allophylus africanus*, *Citrus aurentifolia* and *Psidium guajava*.

The savannah comprises 1195 individuals divided into 23 families, 32 genus and 34 species. Four species also, representing 98.56% of the total species, are the most represented. These are: *Hymenocardia acida*, *Gmelina arborea*, *Annona senegalensis* and *Allophylus africanus*, however there was a high specific richness in the savannah plot. The owners of ASPA clean the undergrowth during each rainy season where food crops are planted. The results of inventory in this agroforestry shows a low diversity compared to the cashew agrosystem in Northern Cameroon where Noiha *et al.*(2017) identified a total of 16488 taxa from 69 species, 58 genus and 31 families. In the other hand this result was closed to that obtained in Obala by Moneye (2004) who identified 26 species, 24 genus and 14 families. The ASPA woody biodiversity present different characteristics in relation with the geographical space considered, age and the agroforestry system. However, we have noted the significant biodiversity of our savannahs compared to the Sudanese savannahs of the Tandjile area of Eastern Chad (Dona *et al.*, 2016).

The analysis of floristic diversity in agroforestry landscape in this study point to a consistent difference in the scale of the plots. Indeed, the comparison of the structural parameters (floristic composition by family, genus and species) of the plots, reflects their evolution compared to the witness plot. It emerges from this analysis that the savannah was densest (1195 individuals) than the others ASPA. Similarly, in terms of specific richness, the savannah system was more diversified than those in the agroforestry landscape. Despite the noticed difference in biodiversity between the agroforestry plots compared to the savannah, they are clearly more diverse and denser because the farmer promotes the development of fruit trees establishment for their economic and food importance to the detriment of non-fruit trees. So, the density of individuals according to the agroforestry practice gives them a structure close to the forest in the landscape. But taking into account the unfavorable ecological conditions and anthropic pressures, complete regeneration is hardly possible due to the exploitation of the undergrowth of avocado plantations.

In all of the plots studied, the value of the Shannon index of the avocado undergrowth is less to 3, indicating this low diversity and a strong homogeneity of the agrosystem. while it was a moderately diversified in the whiteness (3.9±1.85). These results are similar to those of Noiha *et al*. (2017) in cashew plantations in North Cameroon; Diedhiou *et al*. (2014) in Senegal in the *Faidherbia albida* park and in the *Faidherbia albida* and *Prosopis africana* park in south-central of Niger respectively. This can be explained by the ecological conditions which would be favorable or unfavorable for the development of the species.

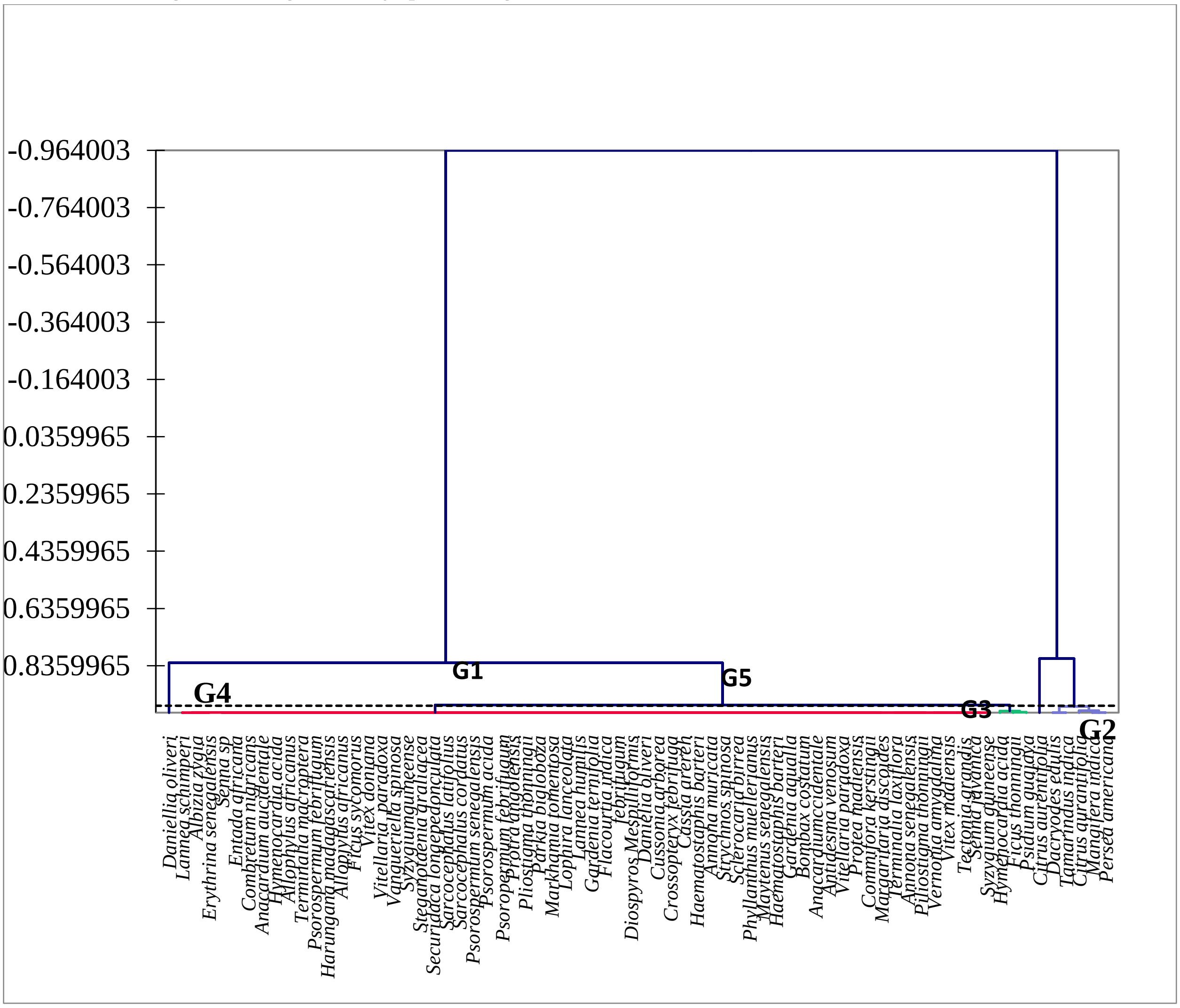

Fig.8: Dendrogramm of species in function of carbon stock in the sites

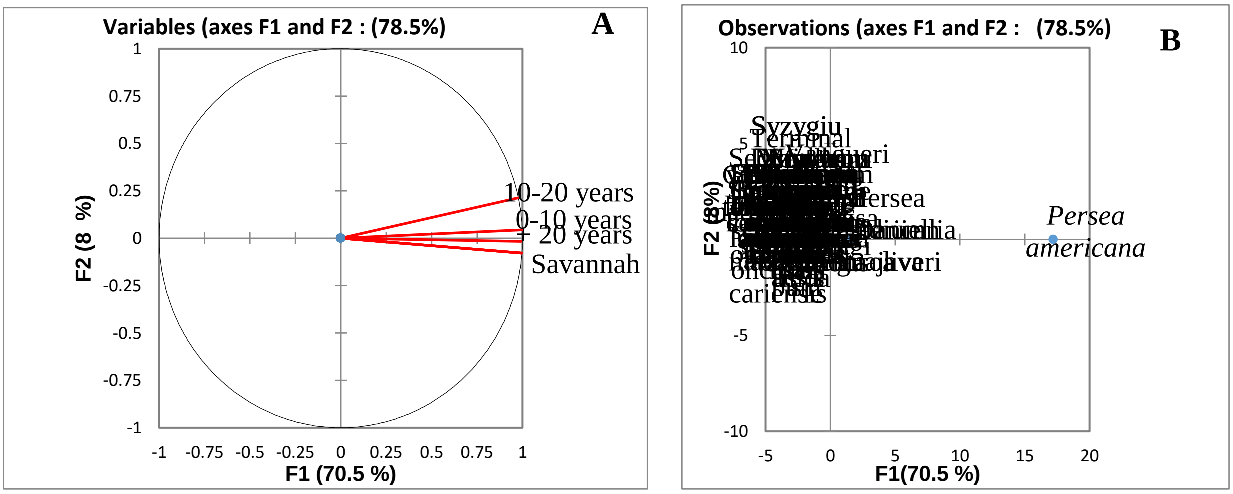

Fig.9 : Principal Component Analysis (PCA) (A) and Correspondances Factorial Analysis (CFA) (B) in the sites.

In the plots studied, the equitability of Piélou is equal to 1. This result is very close to that found by Noiha *et al.* (2017) in cocoa agrosystems in Cameroon and in cashew plantations in Cameroon between 2015 and 2017 respectively. This high value reflects a great diversity and a good reconstruction of the floristic diversity of the undergrowth, no doubt due to the favourable conditions set up by the agroforestry system. The importance value index (IIE = 200) was similar in all the sites studied. This result is substantially close (IIE = 214.52) to that found by Kabore *et al.* (2013) in the North-East of Burkina Faso. But remains higher than the value (IIE = 150) found by Noiha *et al*. (2017) in cashew plantations in North Cameroon. This could be due to the strong presence of tall crown trees in the plots studied. The result confirms the idea of Ngom *et al*. (2013) who state that trees with large crowns contribute more to the recovery and to a certain degree of recovery, they modify the ecological conditions by reducing the evaporating power of the air, by favoring the water balance of the soil and by improving soil fertility. A high similarity in species composition is observed in the population of *Persea americana*. It is due to the fact that the plots are located in the same agro-ecological zone, means that there are few differences between the three plots of different ages, hence a low beta diversity. These results are perfectly in accordance with those of Hamadou (2017) in the Eucalyptus plantations of Ngaoundéré (Adamawa-Cameroon).

The diametric structure has a decreasing exponential shape (L-shaped structure) with a strong slope of equation ($y= 1038e^{-1.14x}$ and $R^2= 0.931$) showing that the least represented stems are the stems of the future and regeneration, with a very large difference compared to other stems. This result corroborates those of Tchobsala *et al*. (2010), Noiha *et al*. (2015), Hamadou (2017), Zapfack *et al.* (2016) and Noiha *et al*. (2017).

The densities obtained in the different study plots vary from 552 ± 14.54 to 1195 ± 48.2 inds/ha with an average of 873.5 ± 31.37 inds/ha which would represent better regeneration. These results differ from those of Tayo Gamo (2014) and Durot (2013) in cocoa agroforestry systems respectively in Ngomedzap and Bokito (central Cameroon); from Ali *et al*. (2014) in the sacred forests of south-eastern Benin; Dorvil (2010) in tropical rain forests of Guadeloupe, Anobla *et al*. (2016) in the Agboville region (Côte d'Ivoire). The high density of trees in savannah considered as witness explains the opening of tree strata of savannah. This opening favors the development of woody plants facilitated by the penetration sun's rays to the ground. This is not the case with pear trees vegetation where there is competition between the species of the dominant stage for light. The difference in density of avocado population could be linked to the ecological characteristics of the study area, notably the growing of undergrowth (tomatoes, okra, peppers, parsley and peppers, etc.), soil types, topography, climate and recovery. The highest value of the basal area was 10.02±0.09 m²/ha obtained in the APSA of > 20 years which indicates the existence of large trees specimens. The low value of the basal area of the savannah population explains the impact of anthropic activities on this plot such as the slaughter of individuals during clearings for the agricultural and buildings activities or for firewood, uncontrolled bush fire etc.

Biomass and Carbon stock

The site >20 years sequestrated high carbon (59.31±5.43 tC/ha, with 31.87 tC/ha stocked by *Persea americana*) compared to the other sites. The difference observed can be explained by the presence of parameters such as the density, the high basal area and the diameter (dbh) of tall trees. This result is largely superior to those obtained by Thiombiano (2010) in 22 years old cashew trees in Burkina Faso and by Noiha *et al*. (2017) in cashew plantations of >20 years in North Cameroon. However, these data remain largely inferior to those obtained by Zapfack (2005) in degraded secondary forests in the Center Cameroon region, but is appreciably close to those obtained by Mosango (1991) in young forests of Congo, according to Albrecht and Kandji (2003), the carbon storage capacity of an Agroforestry system varies between 12 and 228 tC/ha with an average value of 95 tC/ha. Indeed, the quantity of carbon sequestered by an agrosystem largely depends on the cropping system put in place, the structure and the function, the counting methodology, but also mainly on the variability of density of the undergrowth, which itself is also in function of the level of maturity of the secondary forest. In the Savannah, on the other hand, it was noted that the above-ground carbon stocks (2.93 tC/ha) are large inferior than those studied by Tchobsala *et al*. (2016) in the tree and shrub savannas of Ngaoundéré (Adamawa-Cameroon) and to those of Dona *et al.* (2016) in the Sudanese savannas of the Tandjile-East zone of Chad in the shrub savannah and the dry forest. This difference would be due to strong anthropic activities. The underground in avocado plantations of > 20 years (19.75±1.03tC/ha) was higher than the other plots studied. This value compared to those obtained by Traoré *et al*. (2004) in the shea park of Mali, Noiha *et al*. (2017) in cashew plantations in North Cameroon was higher. It is close to the value found by Ordonez *et al.* (2007 in the avocado plantation (13.6 tC/ha) in the Center of the Highlands of Mexico. The savannah, on the other hand, stocks 1.64tC/ha of underground carbon which is very different from the result found by Tchobsala *et al*. (2016) in the shrub savannah of Ngaoundéré (Adamawa-Cameroon). This difference would be due to the fact that in the control savannah, anthropic factors (bush fires, wood cuts, shifting and slash-and-burn agriculture) and biophysical factors (erosion, stripping of surface layers and oxidation of organic matter) destroy and reduce organic restitution from the environment to the soil. It should be noted that inappropriate agricultural practices in this area with intensive use of chemical fertilizers can also contribute to the destruction of organic matter to the detriment of mineralization. This stock is also different from that found by Traoré *et al*. (2004) in the Shea Park in Mali, probably due to the warm climatic conditions in the Sudano-Sahelian zone of Mali compared to the climate of the high-Guinean savannah of this study. The consequence was the rapid mineralization of organic matter in the Sudano-Sahelian zone and a decrease in the stock of organic matter in the soil.

The total carbon stock increases significantly (17.76 to 83.06 t/ha) with an average value of 58.76 t/ha in the avocado plantations but remains higher than the witness treatment (4.57 t/ha). The difference would be due to the higher diameter of the trees (dbh) and the basal area in the avocado plantations compared to those in the savannah. The highest total carbon stock was obtained in the plot of > 20 years. This result was much higher than those obtained by Kanmegne (2004) in the dense humid forests of South Cameroon in primary forest, banana plantation and old fallow; Ibrahima *et al*. (2002) in the tropical dance and humid forests of Southern Cameroon and Nolte *et al*. (2001) on land that has suffered the effects of slash and bush fire in Cameroon. In the savannah, carbon stocks (4.57 tC/ha) were lower than those of Mosango (1991) obtained in the Democratic Republic of Congo (6.63 tC/ha) were the total carbon in the three plots studies of different ages was 176.29 tC/ha. We can however note that our values were clearly lower than those obtained by Chavan and Rasal (2012) in the mango plantations (206.84 tC/ha) of Aurangabad in India and those of Deheza and Bellassen (2010) in the temperate forest (206.4 tC/ha) in France. This difference could be explained by the nature of the hypotheses adopted by the various researchers. Given these different results, we can deduce that ASPA are excellent carbon sinks.

Sequestration potential and economic value

In the context of this study, the CO_2 equivalent stock varies according to the different study sites, which determines the compensatory role of tree species in the emissions of carbon dioxide from anthropic activities that avocado trees can play. This variation is from 304.82 tCO_2/ha in plantations of > 20 years which constitutes the highest CO_2 stock, 287.99 tCO_2/ha in plantations of <20 years, 28.49 tCO_2/ha in that of < 10 years with a cumulative total of 621.3 tCO_2/ha and finally 11.15 tCO_2/ha lower in the savannah. However, the economic value being the value of Carbon, if it is sold on the international market, it is defined according to carbon sequestration. The larger the stock, the greater the economic value. The sale of carbon would make it possible to benefit from 66918.54±109.60 FCFA/ha to 4221851.58 FCFA/ha depending on the plots considered. These values are higher than those found by Noiha *et al*., 2017, but lower than of Hamadou (2017) in Adamawa. This difference is explained by the fact that avocado trees store more carbons compared to Neem and Cashew trees, but less carbon compared to Eucalyptus. The savannah considered as witness has low sequestration potential and value economic compared to the different plots of avocado trees, these due to numerous anthropic disturbances, and, given the importance of these avocado systems in carbon sequestration (176.29 tC/ha), it can be deduced that they are excellent carbon sinks.

V. CONCLUSION

From this work, it emerges that the biodiversity of the Avocado Agroforestry Systems in Adamawa was relatively important. The plots of over 20 years ago were much diversified and have the highly significant basal area while the density of species was highly significant in the savannah. *Persea americana* and *Hymenocardia acida* were respectively the most dominants species of agrosystems and savannah. The plants with diameter of < 10 cm class were the most represented whatever the site. These agroforestry systems offer great potential for carbon sequestration compared to savannah. Especially the value of the ecological carbon sequestration service in the event of payment which has been estimated at more than $ 7126.6/ha in the agrosystems. To effectively combat global warming, it is imperative, at this stage, that pilot projects be initiated and developed.

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