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Estimation of Species Diversity and Carbon Storage in 5-, 15- and 22-year-old Mango Agroforest (Cameroon)

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Abstract

In the Tropics, as the rate of deforestation continues to rise, agroforestry may serve as a way of conserving species diversity and climate change mitigation. The aim of this study was to assess species richness and Carbon storage in *Mangifera* agrosystems. Three ages of mango stands were selected with a tropical savannah as control. A randomized complete block design (RCBD) was used to collect data and each treatment was replicated 3 times. Data were collected in 5 transects of 100x20 m² each; so, a surface area of 1 ha was surveyed for each treatment. As a result of the survey, 39 species from 23 families and 36 genera were recorded in agrosystems and 37 taxa from 23 families, 31 genera in savannah. Species abundance, diversity, density and basal area were significantly different ($p<0.05$) amongst treatments. The lowest Carbon stocks were found in the savannah due to the anthropogenic activities. Aboveground biomass (AGB) and belowground biomass (BGB) following the age of the stands varied with dbh and timber's density. AGB ranged from 18.09±0.03 to 64.07±0.16; BGB from 8.88±0.01 to 26.10±0.05 and total stock from 26.97±0.04 to 90.18±0.22 Mg C/ha with the lowest values in savannah and the highest in the oldest *Mangifera* stands. C sequestration potential ranged from 99.00±0.17 to 330.96±0.82 Mg CO_{2eq}/ha with the lowest values in savannah. Ecological service payment ranged from 990.07±1.79 to 3309.69±8.22 $/ha. From the results obtained, these stands could be a potential for Carbon sequestration and may increase potentially with the age of agrosystems.

Keywords

Agrobiodiversity, agrosystems, carbon storage, carbon sequestration, diversity, species conservation

1. Introduction

Since 1750, the atmosphere CO_2 concentration has increased to 31 %. This increase due to fossil fuel combustion and land use change necessitates an identification of strategies for mitigating the threat of the attendant global warming. Deforestation, biomass burning, conversion of natural to agricultural ecosystems, drainage of wetlands and soil cultivation are principal factors of greenhouse gas emissions [1]. Several works have demonstrated the role of agroforestry as an opportunity to reduce CO_2 concentrations in the atmosphere by increasing carbon (C) stocks in agricultural lands [2-20]. It is certain that accurate and reliable estimates of carbon (C) storage in agrosystems are critical to the development of effective policies and strategies to mitigate atmospheric gas and climate change. As part of the fight against climate change through mitigation of greenhouse gas (GHG) emissions and in view of the clauses agreed at CoP21 and CoP22, agrosystems can offer palliative solutions to the detrimental effects resulting from the deterioration of the climate system. Over the past two decades, even though several works showing the role of agrosystems in mitigating climate change were carried out through over the Tropics, all agrosystems have not yet been assessed. Additionally, these former works describe the structural functioning of the nominated agrosystems; few of them are comparing the data with that of a terrestrial tropical natural ecosystem. At this time when natural ecosystems are disappearing at an alarming rate, the present study aims to compare Carbon sequestration potential in *Mangifera* systems of three ages to that of a terrestrial Tropical savannah. This work aims to find a way of implementing Clean Development Mechanism in order to help smallholders of *Mangifera* agroecosystems the access to Carbon market in Africa, especially in Cameroon.

2. Methods

2.1 Site description

The study was conducted in Cameroon, Adamawa region, Vina division located between 6°-8° N and 11°-15° E (63,701 km²) which is vast base block raised, punctuated by small volcanoes [21] (Figure 1). Soils are ferruginous with intrusions of lateritic soils overlying basaltic rocks, granitic and sedimentary. The climate is tropical with bimodal rainfall in lowland savannah of Central and Eastern and single mode (a dry season and a wet season) in the northern part. The annual rainfall varies between 900-1500 mm and decrease as one moves northward. Temperatures vary between 22° C and 24° C down to 10° C at certain times. The Adamawa plateau is the country's water castle and separates Cameroon in two separate hydrographic regions and two climatic regimes [22]. Vegetation consists of low altitude and Sudanese savannahs dominated by *Danielliaoliveri* and *Lophiralanceolata* [23] corresponding to the Guinean phytogeographic unit and representing in its southern part as the transition area or buffer zone between the forest and the southern Sudano-Sahelian savannah of the north.

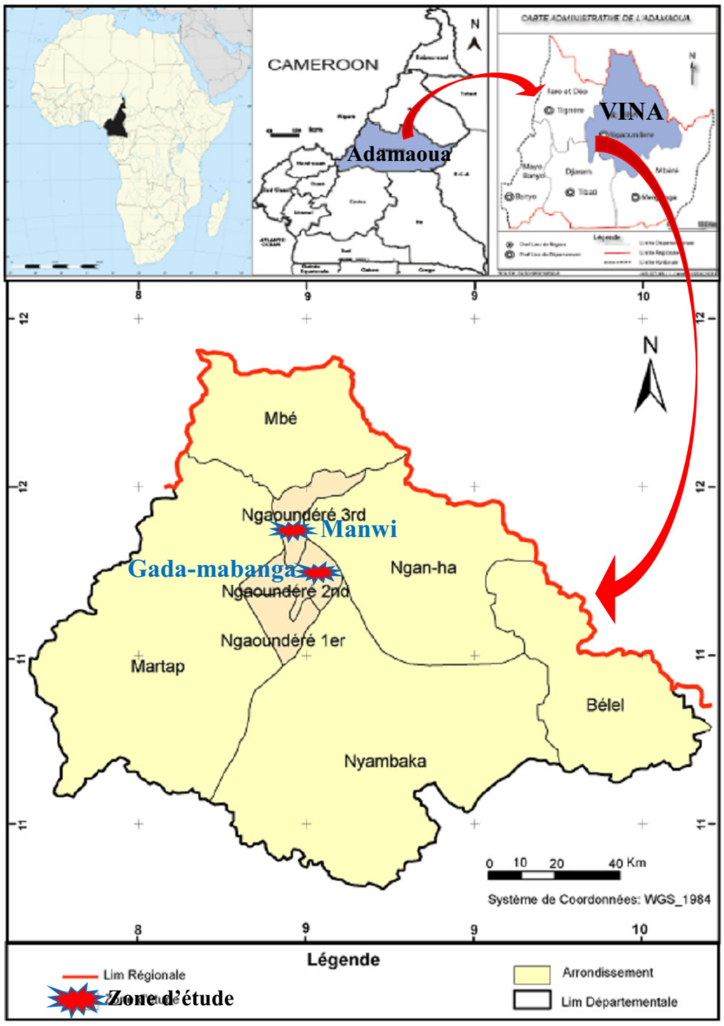

Figure 1. Localization of the studied site (source PSFE, 2010).

2.2 Data collection

A randomized complete block design (RCBD) was used to collect data for statistical analysis. The RCBD is one of the most widely used experimental designs in forestry research [24]. The design is especially suited for field experiments where the number of treatments is not large and there exists a conspicuous factor based on which homogenous sets of experimental units can be identified. The primary distinguishing feature of the RCBD is the presence of blocks of equal size, each of which contains all the treatments. For this study, four treatments (5-year-old; 15-year-old; 22-year-old mango stands and a savannah as control) were considered. Each treatment was replicated three times. To enumerate and identify floristic composition, community sampling units were established. Within five 100 m x 20 m sampling transects established in each chronosequence (covering 1 ha, Figure 2), we carried out surveys from May-July 2017. This methodology was similar to that of [25]even though they established nine 20x50 m² sampling plots of five stages. The survey area was 1 ha per site. Several blocks or squares (quadrates) with definite size (5x5 m²) were established in the stands and savannah to identify total number of timbers. The Spatial data layers contours (altitude, slope and aspect) and vegetation types were extracted from topo sheet. Suunto Hypsometer was used for measuring height of the trees. Likewise, for measuring diameter and circumferences, instruments like Caliper, Finnish Caliper and measuring tape were employed for all woody species (dbh≥2 cm). GPS and compass were used to install and locate stands. The diameter was measured at 1.30 m aboveground for trees and at 0.30 m for shrublets.

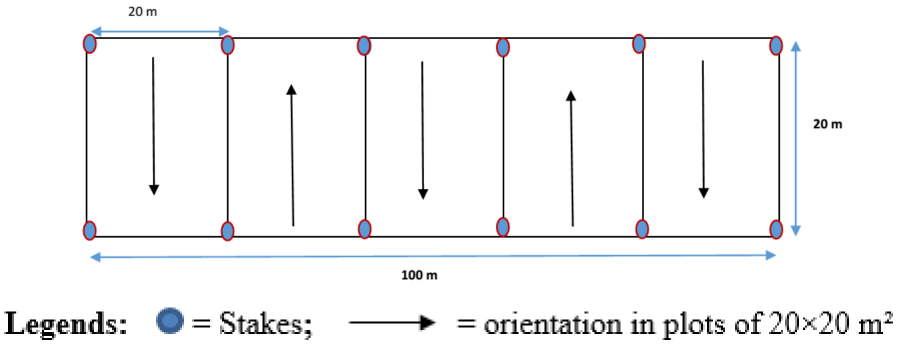

Figure 2. Detail of a transect used.

2.3 Data Analysis

All statistical analyses were performed with STATGRAPHICS plus version 5.0 (2016) for Windows. One-way analysis of variance (ANOVA) was used to find out whether the age of stands had an effect on the floristic parameters, the average of carbon storage and the sequestration potential of the stands. We also compared density, basal area, diversity and carbon pools between stands and savannah using Duncan test. A p-value = 0.05 was used to reveal the statistical significance. We used the correlation test of Pearson (r) to find out whether there was a relationship between the floristic parameters and carbon sequestration potential.

2.4 Vegetation

The analysis of the floristic diversity has focused on:

- The diversity of Shannon (ISH) index [26]: ISH= $-\sum\frac{ni}{N}\text{LOG}_2(\frac{ni}{N})$, with ni= number of the species i, N = number of all species; ISH is expressed in bit.
- The equitability of Piélou (EQ) (1966) [27]: EQ = $\frac{ISH}{Log\,2N}$.
- Coefficient of similarity of Sorensen (K) (1948) [27]: K = $\frac{2c}{a+b}x100$, with a = number of species of the statement 1, b = number of species of the statement 2, c = number of species common to the 2 statements.
- Index of Ecological Importance (IVI) (Curtis and Macintosh (1950) in [28]. IVI= relative Dominance $_{\text{(species)}}$ + relative Density $_{\text{(species)}}$ + relative Frequency $_{\text{(species)}}$.
- Density (D): This is the number of individuals per ha. In the plots, the density (D) is calculated based on the formula: D $=\frac{n}{S}$; D: density (trees/ha), n: number of trees present on the considered surface and S: reporting surface (ha)
- Basal Area (BA): This allows presenting in m²/ha the surface of each species at 1.30 m (dbh); the formula: BA $=\frac{\pi}{4}\sum_{i=1}^{n} d_i^2 = \frac{1}{4\pi}\sum_{i=1}^{n} C_i^2$ with BA: basal area (m²/ha), d: diameter (m), C: (m) circumference.

- Floristic structure: to catch the diametric structure in the understories of the eucalyptus stands, timbers were grouped in class of diameters with amplitude of 10 cm. Thereby, the aspect of the evolution of species in the understories was forecasted through a histogram of distribution.

2.5 Carbon Stock Assessment

- Aboveground biomass (AGB): $AGB= \alpha e^{[-1,499 + 2,148*\ln(DBH) + 0,207*(\ln(DBH)2 - 0,0281*(\ln(DBH))3]}$ [29].
- Belowground biomass (BGB): BGB=AGB×R [30, 31]with R = Root to shoot ratio = 0.26.
- Total biomass (TB): TB = AGB + BGB [32].

2.6 Estimation of the sequestration potential

The total stock of carbon estimated in t/ha was converted into equivalent amount of CO_2 equivalent (CO_{2eq}) absorbed using the ratio 44/12 corresponding to the CO_2/C report. This value was subsequently evaluated in monetary value using the ecological service value estimated at 10 USD/t CO_{2eq} [33].

3. Results

3.1 Floristic richness and taxonomic diversity

As a result of our fieldwork, the vascular flora contains a total of 39 species from 23 families, 36 genera in the stands and 37 species from 23 families, 31 genera in the savannah (Table 1). The largest families in terms of the number of individuals were Anacardiaceae, Myrtaceae, Hymenocardiaceae, Caesalpiniaceae and Hypericaceae. These families represent the most common in both the *Mangifera* stands and savannah (control). In terms of the number of taxa, the control was the richest site (91 taxa from 23 families, 31 genera and 37 species) comparatively with the studied stands of mango (5-year-old stands: 58 taxa from 15 families, 21 genera and 22 species; 15-year-old stands: 55 taxa from 15 families, 20 genera and 20 species and 22-year-old stands: 71 taxa from 20 families, 25 genera and 26 species). In terms of species, *Albizia zygia, Allophylus africanus, Annona senegalensis, Antidesma venosum, Diospyros mespiliformis, Harungana madagascariensis, Lannea schimperi, Persea americana, Psidium guajava* and *Syzygium guineense* were the most abundant in the understories of *Mangifera* stands with 48.61 % of individuals. In savannah, *Annona senegalensis*, *Daniellia oliveri, Hymenocardia acida, Piliostigma thonningii* and *Terminalia laxiflora* were the most abundant.

Table 1. Floristic richness and taxonomic diversity (ni; number of individuals)

Treatments	Species	Genera	Families	ni
5-year-old	22	21	15	387
15-year-old	20	20	15	729
22-year-old	26	25	20	796
Savannah	37	31	23	1195
Total	62	54	30	3107

Sorensen's coefficients of floristic similarities between the studied sites were generally low between *Mangifera* stands and savannah (<40%) indicating smooth species composition changes among the sites (Table 2). Significant positive similarities were between the different *Mangifera* stands (K>50 %). There was no floristic similarity between the understories of the *Mangifera* stands and savannah flora.

Table 2. Floristic similarities between the studied sites

	Sorensen's coefficients of floristic similarities			
Treatments	5-year-old	15-year-old	22-year-old	Savannah
5-year-old	100			
15-year-old	66.66	100		
22-year-old	58.33	56.52	100	
Savannah	37.28	31.57	38.09	100

3.2 Stand diversity, density, basal area and ecological importance

Stand diversity, density and basal area were significantly different between the studied sites ($p<0.05$). The highest diversity and density were found in savannah although the highest basal area was found in the oldest stands of *Mangifera* agroforest (Table 3).

Table 3. Floristic structure parameters (ISH: Shannon diversity indices; EQ: Pielou's equitability; BA: Basal area; D: density.

sites	ISH (bit)	EQ	BA (m²/ha)	D (ind./ha)
5-year-old	1.31 ± 0.006 ^{b}	1	5.25 ± 0.026 ^{b}	387 ± 5 ^{b}
15-year-old	1.56 ± 0.003 ^{a}	1	11.68 ± 0.027 ^{a}	729 ± 15.3 ^{a}
22-year-old	1.93 ± 0.004 ^{d}	1	14.53 ± 0.041 ^{d}	796 ± 12.5 ^{d}
Savannah	3.07 ± 0.002 ^{c}	1	3.55 ± 0.007 ^{c}	1195 ± 17.2 ^{c}
P value et F	P=0.0000 F=807.01		P=0.000 F=622.987	P=0.0000 F=807.63

Notes: Values affected with the different letters are significantly different in the same column.

Albizia zygia, Allophylus africanus, Annona senegalensis, Daniellia oliveri, Harungana madagascariensis, Hymenocardia acida and *Psidium guajava* were the most important species in terms of the index of ecological importance (Table 4).

Table 4. The most important species of the understories of *Mangifera* stands

Species	DoRe	DeRe	FeRe	IVI
Albizia zygia	0.37	14.02	15.02	29.42
Allophylus africanus	0.43	12.804	14.80	28.04
Annona senegalensis	1.32	13.66	14.66	29.65
Daniellia oliveri	78.78	11.88	12.88	103.55
Harungana madagascariensis	0.26	16.38	18.38	35.04
Hymenocardia acida	4.66	38.02	39.02	81.72
Psidium guajava	5.54	41.46	43.46	90.46

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

3.3 C stocks and sequestration potential

Carbon stocks (TC) and sequestration potential (VCO_{2eq}) were found significantly different between the studied sites ($p<0.05$). The highest biomasses were found in the oldest stands of *Mangifera* and the lowest in savannah (Table 5). Above Ground Biomass (AGB) ranged from 18.09±0.03 (savannah) to 64.07±0.16 (oldest stands). C sequestration increased with the age of the stands as well as the AGB, Below Ground Biomass (BGB) and total carbon (TC). Ecological services payment varied from 1277.04±5.61 to 3309.69±8.22 $/ha in the *Mangifera* stands.

Table 5. Biomass and ecological services of the studied sites

Sites	AGB (Mg C/ha)	BGB (Mg C/ha)	TC (Mg C/ha)	VCO_{2eq} (Mg/ha)	VE (Dollar/ha)
5-year-old	24.28±0.11^{b}	10.51±0.04^{b}	34.79±0.15^{b}	127.70±0.56^{b}	1277.04±5.61^{b}
15-year-old	53.28±0.12^{a}	22.55±0.06^{a}	75.84±0.16^{a}	278.36±0.58^{a}	2783.61±5.80^{a}
22-year-old	64.07±0.16^{d}	26.10±0.05^{d}	90.18±0.22^{d}	330.96±0.82^{d}	3309.69±8.22^{d}
Savannah	18.09±0.03^{c}	8.88±0.01^{c}	26.97±0.04^{c}	99.00±0.17^{c}	990.07±1.79^{c}

Notes: Values affected with the different letters are significantly different in the same column.

Biomasses were found strongly correlated with the species richness, density and basal area ($r>0.5$) (Table 6).

Table 6. Correlation between species richness, density, basal area and biomass

Parameters	AGB (Mg C/ha)	BGB (Mg C/ha)	TC (Mg C/ha)
Ne	r= 0.631 p=0.0000	r =0.767 p =0.0000	r =0.973 p =0.0000
D	r =0.778 p =0.0000	r =0.661 p=0.000	r =0.889 p =0.0000
St	r =0.981 p =0.0000	r =0.735 p =0.0000	r =0.999 p =0.0000

From the dendrogram in Figure 3, three main groups can be recognized. C sequestration potential between species had a similarity of at least 70 %. The group 3 only contained *Mangifera indica* which was different to other species in terms of C sequestration potential.

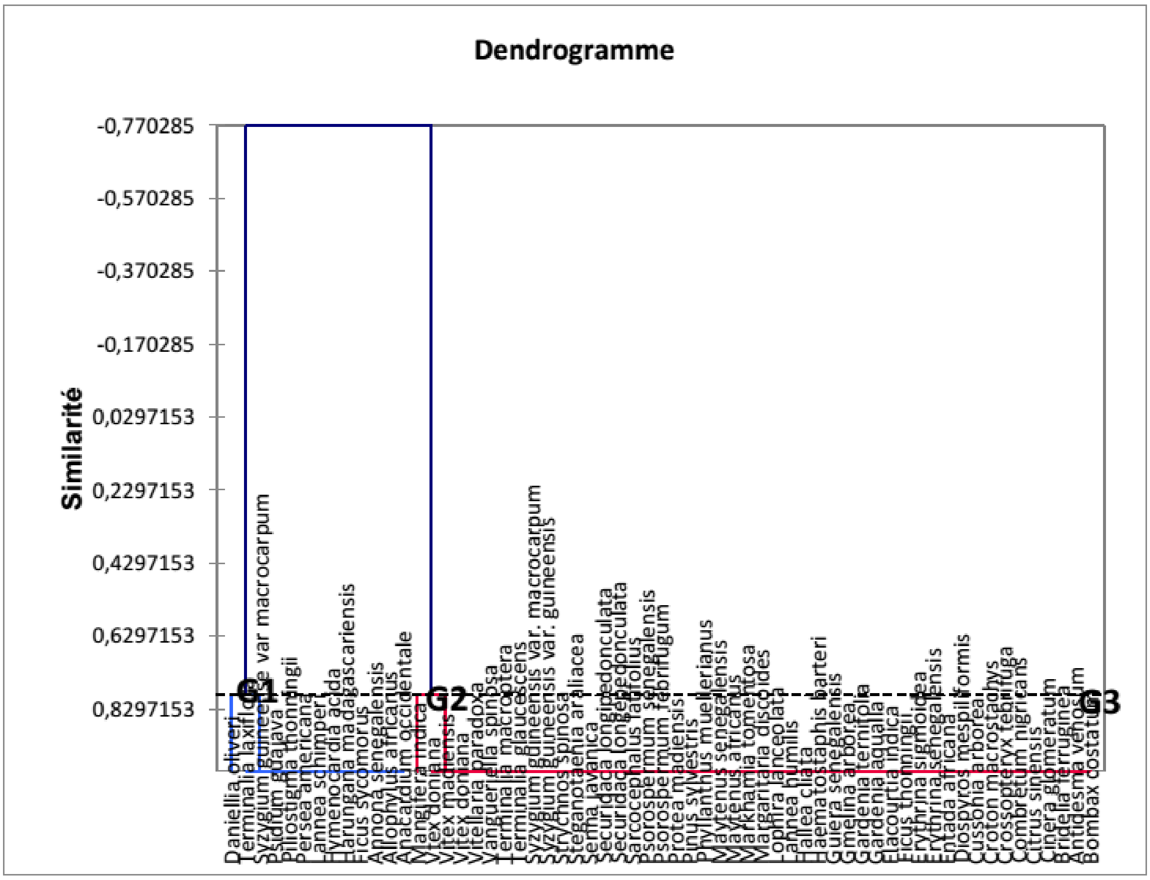

Figure 3. Dendrogram showing affinities of C sequestration.

4. Discussion

4.1 Floristic richness and taxonomic diversity

Our results will be discussed and compared to those of other systems in the tropics. Many authors have focused their investigations on the floristic richness and taxonomic diversity in agroforestry systems in the agricultural mosaics [2,15,20, 34-35]. Their investigations have concluded that agroforestry systems provide important floristic diversity that varies according to the technical and regions. Mango stands in Africa despite their richness are less diversified than unlogged forest. Young stands (5-year-old stands) for example; with 22 species had 12.45 % of the richness of plant diversity (387 individuals). Old stands (22-year-old stands), with 26 species represented 23.46 % of the plant diversity of all parcels (729 individuals) against 38.46 % in savannah (1195 individuals) with 37 species. In terms of species diversity, the results of inventories in the mango stands showed a less diversity compared to the inventories of [36] which identified 49 species, 21 families and 42 genera in Mevo Mevo- and Nkolabang.

4.2 Stand diversity, density, basal area and ecological importance

Floristic diversity indices are objective criteria for assessing the diversity of plant community. The Shannon diversity index ranged from 1.31±0.006 to 3.07±0.002. This index was high in the terrestrial tropical savannah; this result is comparable with that of many works in Africa and Madagascar [20, 37-42]. However, these results do not agree with those of [43] which show that grazing significantly reduced diversity. Densities ranging from 387±5 to 1195±17.2 timbers/ha were not consistent with the values generally found in some tropical forests in the tropics [44-47]; this observation could be due to the anthropogenic pressure. In the literature we found that the basal area of several plots of 1 ha in the rainforests of some countries in the tropics is between 30.7 m²/ha and 45.75 m²/ha (DBH≥10 cm) [45]. However, our results show the basal area values significantly lower than those observed in many forest in the tropics. For example, for all four plots, total basal area ranges from 3.55 m²/ha to 14.53 m²/ha. These values were lower than those obtained by [35] in cocoa stand in the southern part of Cameroon. It is worth mentioning that the basal area of our study sites increased with the diameter classes. Oldest stands were most represented in terms of value of the basal area than Savannah.

4.3 Carbon stocks and sequestration potential

Total stocks ranged from 26.97±0.04 to 90.18±0.22 Mg C/ha with the lowest values for savannah and the highest for the oldest *Mangifera* stands. Sequestration potential ranged from 99.00±0.17 to 330.96±0.82 Mg CO_{2eq}/ha with the lowest value for savannah. These values were higher than the results achieved in young secondary forests of Congo and in cashew stands from north Cameroon [19; 48]. We also found a good result for carbon stocks compared with many other works in several agrosystems in the tropics [2-20, 40-41, 49].

Ecological service payment ranged from 990.07±1.79 to 3309.69±8.22 $/ha. The economic value achieved in this work increased with the age of the stand. We found 1277.04±5.61 $/ha in young stands (5-year-old stands); 2783.61±5.80 $/ha in medium stands (15-year-old stands); and 3309.69±8.22 $/ha in oldest stands (22-year-old stands) against 990.07±1.79 $/ha in the control.

5. Conclusion

Even though we found the largest species diversity in savannah, the agro-phytodiversity achieved in this work was remarkable. Many species already endangered in natural savannah were found in the understories of *Mangifera* stands such as *Vitellaria paradoxa* (VU), *Afzelia africana* (VU), *Erythrina senegalensis* (LC), *Detarium microcarpum* (LC) and *senna spectabilis* (LC) catalogued in the IUCN red data list. Agroforestry systems could be a centre of refuge for threatened species. Agroforests in Africa is not only a good ways of biodiversity conservation, but it is also true carbon sinks at the time when natural ecosystems are under degradation. The ecological service linked to the carbon sequestration offers an opportunity of financial benefits in the event of payment for environmental services provided by these types of land covers. This work could help implementing the process of the Clean Development Mechanism (CDM) with the main goal to help the smallholders of such agrosystems to come out their poverty; one of the main sustainable development goals of the millennium.

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References

[1] Lal, R. (2004). Soil carbon sequestration to mitigate climate change. *Geoderma*. 123(1):1-22. dx.doi.org /10.1016/j.geoderma.2004. 01.032.

[2] Zapfack, L., Engwald, S., Sonké, B., Achoundong G., andMadong, B.A. (2002). The impact of land conversion on plant biodiversity in the forest zone of Cameroon. *Biodiversity and Conservation*, 11(11): 2047-2061.

[3] Albrecht, A., and Kandji S.T. (2003). Carbon sequestration in tropical agroforestry systems. *Agriculture. Ecosystems & Environment*, 99(1):15-27.

[4] Saint-André, L., MiBou, A.T., Mabiala, A., Mouvondy, W., Jourdan, C., Roupsard, O., Deleporte, P., Hamel, O., Nouvellon, Y. (2005). Age-related equations for above- and below-ground biomass of a *Eucalyptus* hybrid in Congo. *Forest Ecology and Management*, 205, 199-214.

[5] Oelbermann Maren, R., Paul Voroney, Donald C.L. Kass., Andrea M. Schlönvoigt. (2005). Above and belowground carbon inputs in 19-, 10- and 4-year-old Costa Rican Alley cropping systems. *Agriculture. Ecosystems & Environment*, 105(1):163-172.

[6] Lufafa, A., I. Diédhiou, S.A.N. Samba, M. Séné, M. Khouma, F. Kizito, R.P. Dick, E. Dossa, J.S. Noller. (2008). Carbon stocks and patterns in native shrub communities of Senegal's Peanut Basin. *Geoderma*, 146(1):75-82.

[7] Takimoto, A.P.K., Ramachandran, N., Vimala, D.N. (2008). Carbon stock and sequestration potential of traditional and improved agroforestry systems in the West African Sahel. *Agriculture. Ecosystems & Environment,* 125(1):159-166.

[8] Prakash, S., and Lodhiyal, L.S. (2009). Biomass and Carbon Allocation in 8-year-old Poplar Populusdeltoides Marsh Plantation in Tar Agroforestry Systems of Central imalaya. India. *New York Science Journal*, 2(6): 49-53.

[9] Torres, A.B., Marchant, R., Lovett, J.C., Smart, J.C.R., Tipper, R. (2010). Analysis of the carbon sequestration costs of afforestation and reforestation agroforestry practices and the use of cost curves to evaluate their potential for implementation of climate change mitigation. *Ecological Economics*, 69(3):469-477.

[10] Kumar, M.B. (2011). Species richness and aboveground carbon stocks in the homegardens of central Kerala. India. Agriculture. *Ecosystems & Environment*, 140(3):430-440.

[11] Hergoualc'h K., Eric Blanchart, Ute Skiba, Catherine Hénault, Jean-Michel Harmand. (2012). Changes in carbon stock and greenhouse gas balance in a coffee monoculture versus an agroforestry system with in Costa Rica. *Agriculture. Ecosystems & Environment*, 148:102-110.

[12] Kuyah Shem, Johannes Dietz, Catherine Muthuri, RamniJamnadass, Peter Mwangi, Richard Coe, Henry Neufeldt. (2012). Allometric equations for estimating biomass in agricultural landscapes: I. Aboveground biomass. *Agriculture. Ecosystems & Environment*, 158:216-224.

[13] Thangata, P.H., and Hildebrand, P.E. (2012). Carbon stock and sequestration potential of agroforestry systems in smallholder agroecosystems of sub-Saharan Africa: Mechanisms for 'reducing emissions from deforestation and forest degradation' (REDD+). *Agriculture. Ecosystems & Environment*, 158:172-183.

[14] Zapfack, L., Noiha, N.V., Dziedjou, K.P.J., Zemagho, L., Fomete, N.T. (2013). Deforestation and Carbon Stocks in the Surroundings of Lobéké National Park (Cameroon) in the Congo Basin. *Environment and Natural Resources Research*, 3(2):78-86.

[15] Somarriba, E., R. Cerda, L. Orozco, M. Cifuentes, H. Dávila, T. Espin, H. Mavisoy, G. Ávila, E. Alvarado, V. Poveda, C. Astorga, E. S., Deheuvels, O. (2013). Carbon stocks and cocoa yields in agroforestry systems of Central America. *Agriculture. Ecosystems & Environment*, 173:46-57.

[16] Kemeuze, V.A., Mapongmetsem, P.M., Sonwa, D., Fongnzossie, E., Nkongmeneck, B.A. (2015). Plant diversity and carbon stock in sacred groves of semi-arid areas of Cameroon: case study of Mandara mountains. *International Journal of Environment,* 6(2): 308-318.

[17] Manfo, D.A., Tchindjang, M., Youta, H.J. (2015). Agroforestry systems and conservation of biodiversity in a high anthropized medium: case of Obala. *Revue Scientifique et Technique Forêt et Environnement du Bassin du Congo,* 5: 22-34.

[18] Zapfack, L., Chimi Djomo,C.. Noiha Noumi, V., Zekeng, J. C..Meyan-ya Daghela, G. R. Tabue Mbobda, R. B. (2016). Correlation between Associated Trees. Cocoa Trees and Carbon Stocks Potential in Cocoa Agroforests of Southern Cameroon. *Sustainability in Environment,* 1(2): 2470-6388.

[19] Jiagho, E.R., Zapfack, L., Kabelong, B.R.P.L., Tsayem-Demaze, M., Corbonnois, J., Tchawa P. (2016). Diversity of timbers around the national park of Waza (Cameroon). *la revue électronique en sciences de l'environnement*, 6(1):17200-17249.

[20] Noiha, N.V., Zapfack, L.,Awé, 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,* 36(3): 277-288.

[21] Anonymous. (2016b). Program strategy of UN collaboration on the reduction emission from forest deforestation and degradation in developping countries: 2011-2015. Genève: Maison Internationale de l'Environnement. 1p.

[22] Liénou, G., Mahé, G., Olivry, J.C., Naah, E., Servat, E., Sigha-Nkamdjou, L., Sighomnou, D., NdamNgoupayou, J., Ekodeck, G.E., Paturel, J.E. (2008). Solid matter fluxes in suspension in Cameroon: review and synthesis in ecosystems scale; climatic diversity and anthropogenic actions. *Hydrological Sciences Journal*, 50 (1) :111-124.

[23] Letouzey, R. (1985). Phytogeographical map of Cameroon at 1/500 000. Sahelian and soudanian domains. IRA (Herbier National). Yaoundé. Institute of international map of vegetation. Toulouse. pp.1-26.

[24] Jayaraman, K. (1999). *A statistical manual for forestry research*. Forestry research support programme for Asia and the Pacific, 242p.

[25] Hu, D., Zeng, F., Peng, W., Wang, K., Zhang, H., Liu, L., Song, T. (2015). Carbon Storage in a *Eucalyptus* Plantation Chronosequence in Southern China. *Forests,* 6, 1763-1778. https://doi.org/10.3390/f6061763.

[26] Frontier, and Pichod-Viale, D. (1992). Ecosystem: structure, fonctioning, evolution. Masson. Collection d'écologue 21. Paris.

392 p.

[27] Ngueguim, J.R., Zapfack, L., Youmbi, E., Riera, B., Onana, J., Foahom, B., Makombu, J.G. (2009). Floristic diversity under canopy in forest plantations of Mangombe-Edea (Cameroon). *Biotechnologie. Agronomie. Société et Environnement*, 1(14) : 167-176.

[28] Adjonou, K., Djiwa, O., Kombate, Y., Kokutse, A.D., Kokou. K. (2010). Study of spacial dynamics and structure of dry dense relic forests in Togo: implications for a sustainable management of protected areas. *Int. J. Biol. Chem. Sci*., 4(1): 168-183.

[29] Chave, J., Andalo, C., Brown, S., Cairns, M.A., Chambers, J.Q., Eamus, D.,Fölster, H., Fromard, F., Higuchi, N., Kira, T., Lescure, J.P., Nelson, B.W., Ogawa, H., Puig, H., Riéra, B., Yamakura, T. (2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia,* 145: 87–99.

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

[31] Chavan, B.L., and Rasal., G.B. (2012). Carbon sequestration potential of young A reticulate and Annona squamosa from University campus of Aurangabad. *International Journal of Physical and Social Sciences*, 2(3):193-198.

[32] FAO. (1997). State of the world's forest. World end publication. Oxford. UK. 1-5 pp.

[33] Ecosystems marketplace. (2016). State of the voluntary carbon market. Ecosystem Services & Management. 25p.

[34] Mapongmetsem, P.M., Nkongmeneck, B.A., Rongoumi, G., Dongock Nguemo, D., Dongmo, B. (2011). Impact of land use systems on *Vitellaria paradoxa* conservation in soudano-guinean savannahs. *International Journal of Environmental Studies*, 68(6): 851-872.

[35] Noiha, N.V., Zapfack, L., Mbade, L.F. (2015a) Biodiversity Management and Plant Dynamic in a Cocoa Agroforests (Cameroon). *International Journal of Plant and Soil Science*, 6(2):101-108.

[36] Fotsa, L. (2011) Floristic diversity of Mevo-mevo and Nkolabang forests (Cameroon). Master degree thesis, Universityof Yaoundé, 65 p.

[37] Rakotoarimanana & Grouzis. (2006). Impact of bush fire on the specific richness and diversity of a *Heteropogon contortus* savannah in south-west of Madagascar (Sakaraha region). *Candollea*, 61(1):167-188.

[38] Fournier, T., Pavan, L., Tarrade, A., Schoonjans, K., Auwerx, J., Rochette-Egly, C., Evain-Brion, D. (2000). The role heterodynes in the regulation of human trophoblast invasion. *Anny AcadSci*, 973, 26–30.

[39] Koita, B., and Bodian, A. (2000). Evolution of vegetal diversity with time in the soudano-sahélian zone, *in Floret & Pontanier*, l, 459-466.

[40] Noiha, N.V., Zapfack, L., Ngueguim, J.R., Tabue, M.R.B., Ibrahima, A., and Mapongmetsem, P. M. (2015b). Sequestered standing carbon stock in selective exploited timbers grown in tropical forest: a case study from the national park of Lobeke (Cameroon). *Journal of Botanical Sciences*, 4(2):19-24.

[41] Noiha, N.V., Awe, D.V.,Nyeck, B., Tabue, M.R.B., and Zapfack, L.(2018a). Vegetation structure, carbon sequestration potential and species conservation in four agroforestry systems in Cameroon (Tropical Africa). *Acta BotanicaBrasilica*, doi:10.1590/0102-33062017abb0279.

[42] Noiha, N.V., Zapfack, L., Hamadou, M.R., Awe, D.V., Witanou, N., Nyeck, B., Ngossomo, J.D., Tabue, M.R.B., Mapongmetsem, P.M. (2018b). Floristic diversity, carbon storage and ecological services of eucalyptus agrosystems in Cameroon. *Agroforest Systems.* doi 10.1007/s10457-017-0130-5.

[43] Hiernaux, P. (1998). Effects of grazing on plant species composition and spatial distribution in rangelands of the Sahel. *Plant Ecol*, 33:387–399.

[44] Hertel, T.W., Rose S., Tol R. (2009). Economic Analysis of Land Use in Global Climate Policy. *Routledge Press*.34p.

[45] Culmsee, H., Leuschner, C., Moser, G., Pitopang, R. (2010). Forest aboveground biomass along an elevational transect in Sulawesi, Indonesia, and the role of Fagaceae in tropical mountain rain forests. *Journal of Biogeography*, 37 (5):960-974.

[46] Jagoret, P. (2011). Analysis and evaluation of agroforest system complexes on the long term: Application to cultural systems based on cocoa in centre Cameroon natural and cultivated ecosystems fonctioning, Montpellier SUPAGRO, 236 p.

[47] Moneye, J. J. (2004). Contribution to the study of timber potential of agroforests based on cocoa in humid dense forest zone of Cameroon: cases of Lékié, Mefou-Afamba and Mvila divisions. Master degree. UDs, Cameroun. 66p.

[48] Mosango, M. (1991). Contribution to botanical and biogeochemical study of forest ecosystem in tropical region (îleKongolo, Zaïre). Belgium J Bot,124(2):167–194.

[49] Dona, A, Fonseca, M.B., Burrell, A., Gay, H., Henseler. (2016). The objective of this paper was to describe the clinical features, the management and the outcome of nine small breed dogs affected with lateral patella luxation referred during the period between , *Open Vet J*, 6 (3): 255-258.