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Carbon Sequestration Potential and Economic Value in Agroforestry Parkland to *Tectona grandis* L. f. (Verbenaceae) in Central Africa: A Case Study to Department of Poli (Northern Region in Cameroon)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The vegetation and the afforestation of agricultural land non-forest represent a potential increase in carbon stocks which could, under certain conditions and within certain limits, compensate part of the emissions resulting from the use of fossil fuels and deforestations. Quantification of stocks of

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biomass and carbon dioxide contained in agroforestry systems has become an international priority within the framework of the implementation of REDD+ mechanism. Estimates of stocks of carbon in woody biomass, dead organic matter, belowground biomass, litter, herbaceous and lianas plant biomass were incorporated in allometric equation based on non-destructive method. The total carbon stock evaluated in the parkland of *Tectona grandis* was 207.34 ton/3ha out of which woody biomass accounted for 130.19 ton/3ha belowground biomass (40.4 ton/3ha), dead organic matter (22.85 ton/3ha), litter (9.09 ton/3ha), herbaceous plant biomass (2.28 ton/3ha) and lianas (2.53 ton/3ha). The aboveground biomass therefore contributed approximately 62.80 % of the total stock of carbon assessed. This show the considerable contribution of *Tectona grandis* parkland to climate change mitigation in Cameroon.

Keywords: Agroforestry parkland; tectona grandis; carbon sequestration potential; economic value; poli (Cameroon).

1. INTRODUCTION

In the global carbon cycle, the biomass is an important element of the blocking, significantly the carbon sequestration and is used to quantify the basins and the changes of the gas from the terrestrial biosphere in the atmosphere associated with the terrestrial coverage [1,2,3]. The sequestration of carbon in the terrestrial ecosystem is called absorption of CO_2 from the atmosphere by photosynthesis. She is a mechanism to eliminate the carbon from the atmosphere in the storing in the biosphere [4,5,6]. The sequestration of carbon in agro-ecosystems in growth is known to be a cost-effective option to mitigate global warming and global climate change [7,8,9,10]. The estimates of carbon stocks and changes in stocks in the biomass of trees (above and below the ground) are necessary to study the climate change in the framework of the United Nations Framework Convention on Climate Change [11,12]. The production of biomass under different forms plays an important role in the sequestration of carbon in the trees. Aboveground biomass, belowground biomass, dead wood litter and soil organic matter are the major carbon pools any ecosystem [13,3,14]. The increase in emissions of carbon is a major concern for the whole world as well addressed in the Kyoto Protocol [15,16,17,18].

To cope in the warming of the planet, several countries have, in the framework of the Framework Convention of the United Nations on Climate Change, signed in 1997 an international treaty, the Kyoto Protocol, a treaty that entered into force in 2005 and which aims to reduce emissions of greenhouse gases [19], [20,21]. This Protocol recognizes that plantations are the best carbon sinks by storing atmospheric carbon contained in CO_2 [19]. For this Clean Development Mechanisms (CDM), such as the mechanism for the reduction of emissions resulting from the degradation and the degradation of plantations (in abstract REDD+), have been established; to encourage the developing countries covered by large expanses of plantations, to keep intact their massif of plantations through a financial remuneration outcome of carbon credits [20]. This would allow the States concerned to estimate the potential social benefits, environmental but especially economic in the case of payment for environmental services provided by these various wells of the fact of their preservation. Hence the interest of this study which will contribute to the conservation and preservation of the biodiversity of agroforestry Parks for local development measures and mitigation measures to climate change.

2. MATERIALS AND METHOD

2.1 Study Area

The study was carried out in Department of Poli, Northern region of Cameroon, in central Africa (Fig. 1). It is bounded in the South by the Adamawa region, to the east by the respective departments of Benue and the Mayo-Rey and to the west by the commune of Béka [22]. It has an area estimated at 10.000 km^2 comprising 266 villages and a total population of 50,000 inhabitants. The climate is of type soudanian to nuance wet. It is characterized by two distinct seasons more or less contrast. A dry season ranging from 4 to 5 months (November to April), a rainy season which extends from 6 to 7 months (May to October) [22]. The average rainfall increased from 1600 mm to 1210 mm. Concerning the temperatures, the average is located at 27°C for the months most and 32°C

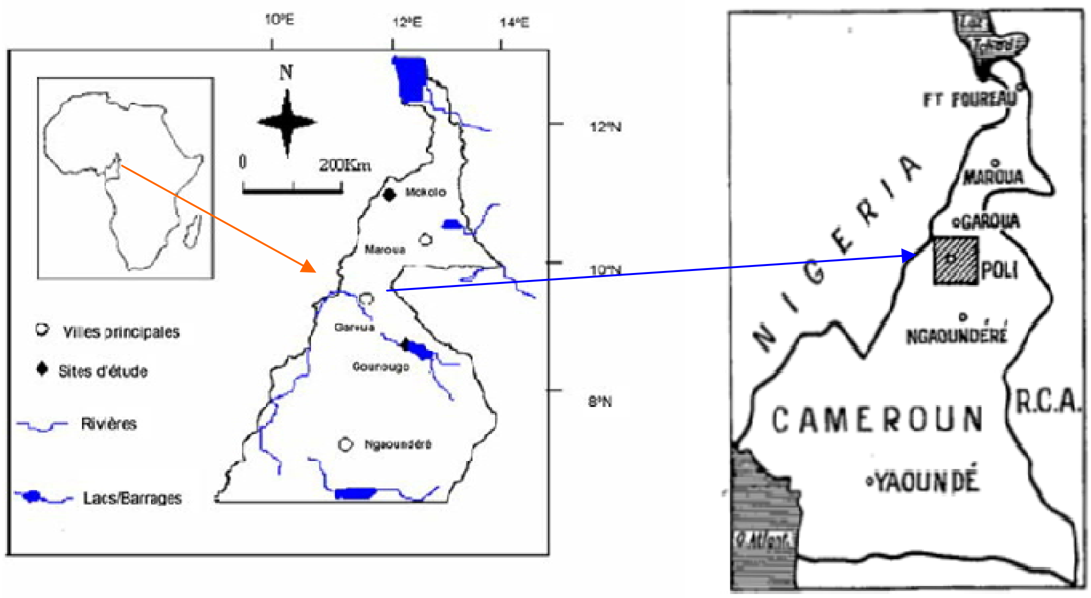

Fig. 1. Map of study site location

for the warmer months [23]. The area is watered by a wind which blows from the north toward there are called harmattan with the formation of a brunette hair. The terrain is a peneplain dotted chains of mountains of unequal importance. The vegetation is a savannah to tree degraded facies [24]. Agriculture is the main activity of the populations of the region. Farmers' agriculture is subsistence (corn; peanut and mil) [10].

2.2 Data Collection

Data were collected in quadrats of 25 x 25 m² (North-South direction) or 625 m² to surface not variable have been installed in the park to *Tectona grandis* of ages varies, Shrub savannah and in a degraded area at the end to make a comparison. Geographic coordinates determined the aid of GPS for each shaft part of the sample to determine its geographical position on the ground. In the 5 sub-quadrats established with the help of the Son and of the compass, all woody a DBH ≥ 3.5 cm were systematically measured and counted using a meter-ribbon to 1.30 m above the ground for large trees and 50 cm above ground l for shrubs. The uses of quadrats were used in line with the results of a floristic inventory carried out in the area [26], [10]. The plant samples were collected, weighed, dried at a temperature of 70°C for 72 hours and then weighed again in order to determine the dry matter. For the lianas, a model incorporating only the diameter was used [27]. The variables taken into account were that the case, the circumference, total height, as well as the condition of the shaft. The sampling of dead wood is done in two categories:

- **For wood death on foot**: The DBH was measured by making use of the methods relating to live trees and the height was measured using the decameter. The calculation of the volume of dead wood on foot using [25] formula: $V = \pi * h * f * (dhp/2)^2$. Where: V =volume of dead wood on foot (m^3); DBH: diameter at breast heigh (m); h: height of dead wood on foot (m); f = form factor (0.627).
- **The dead wood lying in the ground:** This was measured using Line intersection method presented by [28] while the volume of the dead wood was calculated using [29] formula: $V = \pi^2 (\sum di^2) / 8L$. Where; V =volume of woody debris ($M^3.ha^{-1}$); d*i* : diameter of each woody debris sampled (m); The: length of the quadrat (m) = 100 m in the case of our study. The conversion of the results obtained from the volume to mass was done by fixing the value of the density of the wood to 0.47 $KgMS.m^{-3}$ [30]. The passage of the dry mass to the stock of carbon was done using [31] equation: Stock of Carbon in the dead wood = quantity of dry matter (MS) x 0.5.For estimates of emissions of carbon, the

compartments measured were the aboveground biomass, dead wood, and underground biomass. The quantification of the biomass is made by using several allometric equations cited in the literature:

- **Aboveground biomass (AGB):** Wood biomass was measured using have been determined according to the allometric equation developed by [32] for the tropical climates dry: (AGB) =-Expo (2.9489+2.2201*ln(Dbh)+ 0.6945*ln(H))). where AGB: aboveground biomass in kilogram (kg), Dbh: diameter at breast height in centimeters (cm), h: total height (m). 3.5 < Dbh (Cm) <65.5From this biomass, the quantity of carbon (TC/ha) was estimated by multiplying this biomass by a conversion factor of 0.47 [26], [10] followed by conversion to tones of carbon per ha.
- **Biomass of Herbaceous:** B = PHT x MS/100 with PHT = Wet Weight Total At field, Ms (%) = dry matter, B = biomass [33], [34].
- **Biomass of the lianas:** EXP (α+β1 (ln (d)), whereα and β1 are constants and are respectively 0.07 and 2.17[27].
- **Belowground biomass (BGB)**: The belowground biomass was estimated according to the allometric equation developed by [35], [36]: BGB =Expo (-1.0587 + 0.8836*ln (AGB)).
- **Estimate of the stock of carbon content in the litter:** It is generally estimated at 7% of aboveground biomass [37].
- **The stock of carbon in the total biomass** has been evaluated from the following equation: This= B × FC [38], [39] with this = carbon stored in the total biomass (t C/ha), B =Biomass (t/ha) and Fc = 50= fraction of carbon (%).

2.3 Quantity of CO_2 and Economic Value

Given the economic stakes linked to the carbon stock we have estimated the financial cost of the carbon content in the park to Tectona grandis studied. The total stock of carbon evaluated in tones of Carbon by hectares has been converted into the equivalent amount of CO_2 absorbed by using the ratio 44/12 corresponding to the ratio CO_2/C. Several markets of carbon are put in place since the years 2000. However, we opted for the prices of the markets of CDM, of voluntary markets and of the REDD+. The average selling price of the forest credit is 3 euro/teq CO_2 for the CDM; 4.7 euro/teq CO_2 for the voluntary markets [40] and 100euro/teq CO_2 (high value) for the REDD+ [41].

2.4 Analysis of Data

The data have been encoded in the excel software and then analyzed thanks to software Statgraphics Plus 5.0 Testing the significance and correlation were achieved thanks to ANOVA and the Kruskal-Wallis test at 0,001.

3. RESULTS AND DISCUSSION

The carbon in woody species varies significantly between the different plots studied (*df = 4, F = 75.84, p-value < 0.001*). The maximum value of 52.23 ±1.29 tC/haof carbon stock in woody species was observed in the plots of 15-20 years. It then decreased significantly from 45.54 ± 2.21 tC/ha in the parcel of 10-15 years to32.42 ± 1.54 tC/hain parcel of 5-10 years, then to 12.52 ± 0.21 tC/ha in the Shrub savannah and finally 5.29 ± 0.01 tC/ha to in the degraded area (Table 1). The carbon stocks of wood products in the plots to *Tectona grandis* of various ages are largely superior to those obtained in Shrub savannah and the degraded area.

The herbaceous represent the compartment with least carbon stock. In effect, the carbon stocks of herbaceous are very dynamic particularly the parcels of different ages, and therefore strength correlated with the age of the plots studied. The statistical analysis made with the Kruskal-Wallis test reveals highly significant difference (*df= 4, F = 65.57, p-value < 0.001*) of carbon stocks of herbs between the sites studied. The carbon stock of herbs is maximum in the Shrub savannah (2.23 ± 0.023 tC/ha), and then gradually decreases in plots of 5-10 years (1.25 ± 0.002 tC/ha), in those of 10-15 years (0.78 ± 0.003 tC/ha), in those of 15-20 years (0.25 ± 0.002 tC/ha) and finally in the degraded area (0.11 ± 0.00 tC/ha) (Table 1). The carbon stocks of herbaceous in the Shrub savannah are highly superior to those of the parcels of land to *Tectona grandis* of various ages whishing turn are of a value of superiorities to that of the area degraded.

The averages of carbon stocks of dead wood vary from one site to another, and present an average less high in the degraded area (0.93 ± 0.001 tC/ha) and higher in the Shrub savannah (12.89 ± 0.08 tC/ha). The statistical analysis made with the Kruskal-Wallis test reveals highly significant difference of carbon stocks of dead wood between the sites studied (*df= 4, F = 95.54, p-value* < *0.001*) (Table 1). The carbon stocks in dead wood in the Shrub savannah are also highly superior to those of the parcels of land to *Tectona grandis* of various ages who in turn are also of a value of superiorities to that of the degraded area.

The averages of carbon stocks of the lianas also varied with sites. In effect, the carbon stocks of the yarns are very dynamic particularly in natural environments (Shrub savannah), and therefore had no strong correlation with the age of the plots. The Kruskal-Wallis test reveals highly significant difference (*df= 4, F = 55.97, p-value* < *0.001*) of carbon stocks of the lianas between the sites. And are lower in degraded area (0.04 ± 0.00 tC/ha) and compared to Shrub savannah (2.27 ± 0.001tC/ha) tC/ha) (Table 1).

The litter's carbon varied significantly between the plots studied (*df = 4, F = 85.54, p-Value* < *0.001*). The highest carbon stock in the litter is observed in plots of 15-20 years (3.65 ± 0.004 tC/ ha). Followed by 3.18 ± 0.001 tC/ha obtained in 10-15 year old plot and2.26 ± 0.005 tC/ha in 5-10 year plot. It also decreased significantly from 0.87 ± 0.00 tC/ha in the shrub savanna to 0.37 ± 0.002 tC/ha in the degraded area (Table 1). Carbon litter stocks in *Tectona grandis* plots of varying ages are much higher than those of the two controls (shrub savannah and degraded area).

The averages stocks of belowground carbon also varied significant between the plots studied (*df= 4, F = 98.78, p-value* < *0.001*). The belowground carbon of stocks are maximum in the plots of 15-20 years (18.78 ± 0.78 tC/ha), then decline gradually in the parcels of 10-15 years (12.12 ± 0.03 tC/ha), plots of 5-10 years (9.5 ± 0.22 tC/ha), in the Shrub savannah (3.99 ± 0.002 tC/ha) and finally in the degraded area (1.27 ± 0.004 tC/ha) (Table 1). The belowground of carbon stocks in the plots to *Tectona grandis* of varied ages are also higher than those of the two witnesses (Shrub savannah and the degraded area).

The total carbon stock varied significantly between the different plots studied (*df = 4, F = 79.74, p-value* < *0.001*). The highest total carbon stock is observed in the plots of 15-20 years (85.2 ± 4.12 tC/ha) (Table 1).The stocks of total carbon in the plots to *Tectona grandis* of various ages are higher than those obtained In Shrub savannah and the degraded area.

Tectona grandis plots of 5 to10 years, the amount of carbon is higher in the diametric class 20-30 cm. However, in the diametric class > 30 cm, this quantity is very low. In 10 to 15 year-old *Tectona grandis* plots, the diametric class 30-40 cm has a very high and very low carbon amount in the range of 10-20 cm and also in the diametric class > 40 cm. Similarly, in 15 to 20-year-old*Tectona grandis* plots, the diametric class; 60-70cm, 70-80cm and 80-90cm has a very large and very low amount of carbon than diametric class's < 60 cm and diametric class's > 90 cm. The analysis of the histogram (Fig. 2) shows that the shrub savannah and the degraded zone considered as the two controls a large amount of carbon in the 10-20 cm and 20-30 cm diametric class compared to the plots to *Tectona grandis* of varied ages which store considerable quantities of carbon in the diametric class's >30 cm. The range of 70-80 cm is the class with the highest value of the amount of carbon belonging to the *Tectona grandis* plots of 15 to 20 years relative to the other plots, due to the aboveground and belowground biomass, important elements in the assessment of the total carbon stock (Fig. 2). The distribution of the total carbon stock in the diameter class has the appearance of an asymmetric closed curve with a predominance of the diametric class 70-80 cm in amount of carbon.

Table 2 shows the correlation between the number of species and the density and basal area and carbon stocks in the various sites studied. It is clear that the correlation between the carbon stocks and the number of species or the density is low ($r < 0.5$). By contrast, the correlation between the carbon stock and the basal area is very high in relation to the total carbon, ($r = 0.94$; $p = 0.005$), the aboveground carbon ($r = 0.97$; $p = 0.001$) and belowground carbon ($r = 0.91$; $p = 0.002$). The correlation seems very low between the basal area and the carbon in the Herbaceous plants ($r = 0.020$; $p = 0.0003$) or that of the Litter ($r = -0.18$; $p = 0.0000$) or that of the dead wood ($r = -0.48$ $p = 0.0000$) (Table 2). In the end the correlation between the economic value and the different stocks of carbon is very highly significant and strong ($r<0,05$; $p < 0.001$).

In total, 207.34 ton/3ha obtained in the whole of the parcels of land of *Tectona grandis* studied (Table 3). This value corresponds to a sequestration of carbon dioxide of 760.92 tCO_2/ha. Economically, this corresponds to the carbon price CDM (2282.85 Euros/3ha), the price carbon voluntary market (3576.4 Euros/3ha) and at the price of REED carbon (76093.78 Euros /3ha) in the whole of the parcels of land to *Tectona grandis* studied (Table 3).

The quantity of CO_2 is the highest 15 to 20 year-old *Tectona grandis* plot with average value of 312.68 ± 2.25 tCO_2/ha. This is followed by 250.47 ± 4.02 tCO_2/ha obtained10-15 year-old plot, 197.77± 3.42 tCO_2/ha in 5-10 year-old plot, 127.61± 2.28 tCO_2/ha in the Shrub savannah and 29.4 ± 1.32 tCO_2/ha in the degraded area (Table 3).

The statistical analysis shows that there is a significant difference in the economic value between the sites (*F=98.54; df =4; p < 0.001*). It is also clear from the Table 3 that the economic value is very important in the parcel of 15-20 years at the price CDM carbon (938.1 ± 4.67 Euros/ha), or a price or prices carbon voluntary market of 1469.61 ± 4.14 Euros /ha, or a price or prices of reed carbon of 31268.4 ± 100.12 Euros/ha.

We note a gradual flow of the price of carbon between the plots to *Tectona grandis* of varied ages studied. The economic value is very high on the unit price of carbon REED+ compared to the price of the CDM and the voluntary market. The Kruskal-Wallis significance testing show that there is significant difference the economic value between the sites (*F=87.89, df=4; p < 0.001*) (Table 3). This amount of CO_2 being the value of the carbon of carbon if it is sold on the market, it decreases therefore gradually backgrounds with the more important stocks of carbon to the backgrounds with weaker stocks that is to say of the parcel of 5-10 years toward the parcel of 15-20 years in passing successively by the Shrub savannah and to the degraded area (Table 3).In total, 207.34tC/ha obtained in the whole of the parcels of land to *Tectona grandis* studied (Table 3). This value corresponds to a sequestration of carbon dioxide of 760.92 tCO_2/ha. Economically, this corresponds to the carbon price CDM (2282.85 Euros/ha), the price carbon voluntary market (3576.4 Euros/ha) and at the price of REED carbon (76093.78 Euros /ha) in the whole of the parcels of land to *Tectona grandis* studied (Table 3).

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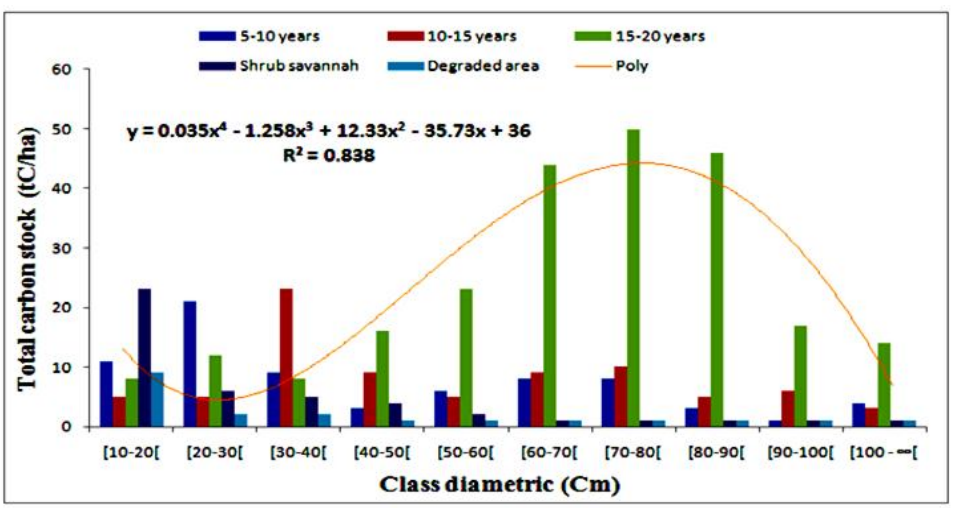

Fig. 2. Distribution of total carbon stock by diameter classes

Table 1. Carbon stock (ton/ha) in the different compartments of the park to *Tectona grandis* and two witnesses (Shrub savannah and degraded area)

Reservoirs of carbon	Park to *Tectona grandis*				Witnesses	
	5-10 years	**10-15 years**	**15-20 years**	**Total**	**Shrub savannah**	**Degraded area**
Carbon in the Wood Products	32.42 ± 1.54[c]	45.54 ± 2.21[d]	52.23 ±1.29[a]	130.19 ton/3ha	12.52 ± 0.21[e]	5.29 ± 0.01[b]
Carbon in the herbs	1.25 ± 0.002 [c]	0.78 ± 0.003 [d]	0.25 ± 0.002 [a]	2.28 ton/3ha	2.23 ± 0.023[e]	0.11 ± 0.00 [b]
Carbon in the dead wood	7.23 ± 0.02[c]	5.65 ± 0.01[d]	9.97 ± 0.06[a]	22.85 ton/3ha	12.89 ± 0.08[e]	0.93 ± 0.001[b]
Carbon in the lianas	1.23 ± 0,004[c]	0.98 ± 0.003 [d]	0.32 ± 0.002 [a]	2.53 ton/3ha	2.27 ± 0.001[e]	0.04 ± 0.00 [b]
Carbon in the litter	2.26 ± 0.005[c]	3.18 ± 0.001[d]	3.65 ± 0.004[a]	9.09 ton/3ha	0.87 ± 0,00[e]	0.37 ± 0.002 [b]
Belowground carbon	9.5 ± 0.22[c]	12.12 ± 0.03d	18.78 ± 0.78[a]	40.4 ton/3ha	3.99 ± 0.002 [e]	1.27 ± 0,004[b]
Total Carbon	53.89 ± 2.07[c]	68.25 ± 1.87[d]	85.2 ± 4.12[a]	207.34 ton/3ha	34.77 ± 1.01[e]	8.01 ± 0.05[b]

The values assigned to the same letter are not statistically different at the threshold of probability of 1 %

Table 2. Correlation between a few parameters and the carbon stocks

Parameters	Correlation coefficient (*r*)						
	Carbon Total	**Aboveground Carbon**	**Belowground Carbon**	**Carbon in the herbs**	**Carbon of Littery**	**Carbon of the lianas**	**Carbon of the woodDeath**
Number of species	0.43 (p = 0.003)	0.44 (p = 0.005)	0.25 (p = 0.0000)	0.93 (p = 0.0000)	0.079 (p = 0.0000)	0.27 (p = 0.0000)	0.19 (p = 0.0000)
Density	0.46 (p = 0.003)	0.39 (p = 0.0000)	0.42 (p = 0.007)	-0.11 (p = 0.016)	0.09 (p = 0.017)	0.03 (p = 0.017)	0.39 (p = 0.017)
Basal area	0.94 (p = 0.005)	0.97 (p = 0.001)	0.91 (p = 0.002)	0.020(p = 0.0003)	-0.18 (p = 0.0000)	-0.15 (p = 0.0000)	-0.48 (p = 0.0000)
Economic Value	0.999(p < 0.001)	0.979(p <0.001)	0.998(p <0.001)	0.990(p < 0.001)	0.996(p <0.001)	0.997(p<0.001)	0.998(p < 0.001)

Table 3. Carbon Stocks, rate of CO_2 and different prices of carbon in the sites studied

Parameters	Park to *Tectona grandis*				Witnesses	
	5-10 years	**10-15 years**	**15-20 years**	**Total**	**Shrub savannah**	**Degraded area**
Total Carbon	53.89 ± 2.07[c]	68.25 ± 1.87[d]	85.2 ±4.12[a]	207.34	34.77 ± 1.01[e]	8.01 ± 0.05[b]
Rate of CO_2 (tCO_2/ha)	197.77± 3.42[c]	250.47 ± 4,02[d]	312.68 ± 2.25[a]	760,92	127.61± 2.28[e]	29.4 ± 1.32[b]
Carbon of Price CDM	593.32 ± 5.51[c]	751.43 ± 9.23[d]	938.1 ± 4.67[a]	2282,85	383 ± 2.54[e]	88.2 ± 2,12[b]
The carbon of price voluntary markets	929.55 ± 7.09[c]	1177.24 ± 11.03[d]	1469.61 ± 4.14[a]	3576,4	599.74 ± 5.76[e]	138.16 ±1.37[b]
Carbon of Price REDD+	19777.63 ± 55.89[c]	25047.75 ± 21.01[d]	31268.4 ± 100.12[a]	76093,78	12760.59 ± 80.23[e]	2939.67 ± 34.04[b]

The values assigned to the same letter are not statistically different at the threshold of probability of 1%

We note a gradual flow of the price of carbon between the plots to *Tectona grandis* of varied ages studied. The economic value is very high on the unit price of carbon REED+ compared to the price of the CDM and the voluntary market. The Kruskal-Wallis significance testing show that there is significant difference the economic value between the sites (*F=87.89; df=4; p < 0.001*) (Table 3). This amount of CO_2 being the value of the carbon of carbon if it is sold on the market, it decreases therefore gradually backgrounds with the more important stocks of carbon to the backgrounds with weaker stocks that is to say of the parcel of 5-10 years toward the parcel of 15-20 years in passing successively by the Shrub savannah and to the degraded area (Table 3).

Analysis hierarchical basis of species as a function of the economic value (price of carbon REED +) in each site studied.

The hierarchical classification bottom-up of surveys obtained following the index of similarity confirms the different each site studied. At the threshold of the similarity coefficient of approximately 95.58%, the analysis shows that the species form six groups listed in the dendrogram. Group 1 includes 10 species. The group 2 present 21 species. The Group 3 includes 13 species. The group 4 present 20 species. The group 5 present 8 species. The group 6 present 11 species. The economic value is the primary determinant of the groups (*H= 115.87; p < 0.001*), with a clear separation between species to broad economic values of other species to low economic values.

The group 2 is more rich in species with Strong Values economically than the other five groups (1; 3; 4; 5; 6), and is located in the first branch of the cluster. We translated which more the sequestration of carbon dioxide of carbon is high over its economic value is considerable. The CAH includes very clearly the species as a function of their economic value. These 6 groups formed three complex with the following similarities, (G1-G6): 92.89%; (G2-G3): 91.67% and (G4-G5): 85.98% dependent in their economic value (Fig. 3).

4. DISCUSSION

The result of the carbon in the wood show that the stock of carbon in 15-20 years was higher than those of 5-10 years and 10-15 years and the two witnesses (Shrub savannah and degraded area). This result is content in the meantime 10 and 60 tC/ha of values obtained by [33], to the Interval 40-60 tC/ha given by [42], and the 11-63 tC/ha obtained by [25]. By contrast does not corroborate to that obtained by [33] who found a carbon stock of 5.046 tC/ha in the aboveground biomass of a park to sheaf butter of the North-Cameroon; to 57.34 tC/ha obtained by [43] in Young secondary forests of the Congo, to the 186.92 tC/ha degraded secondary forests of the region of the Center Cameroon [44], the values 13-42 tC/ha obtained by [34] the 7-25 tC/ha obtained by [45], the values 40-60 tC/ha given by [42] to the interval 12-33 tC/ha given by [10] in an agro-ecosystem to cashew, to 11-26 tC/ha obtained

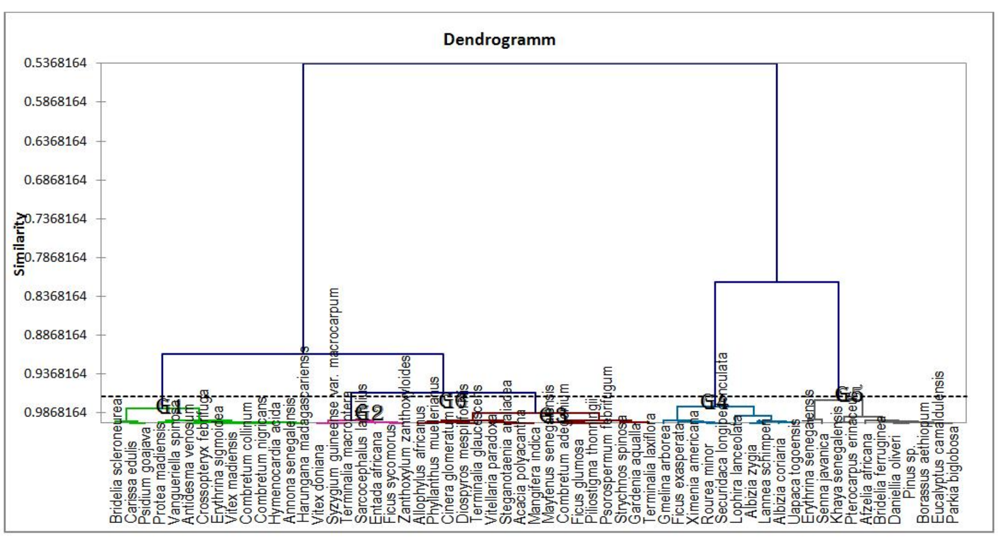

Fig. 3. Dendrogram of species as a function of the economic value in each study site

by [46] in a agro-ecosystem to Eucalyptus and also to those obtained in Agro-ecosystems at the center of the Himalayas in India, in agro-ecosystems of the humid tropical forests of low altitude in Costa Rica and in young stands to Annona reticulate and *Annona squamosa* the university campus of Aurangabad [47],[48], [6], the values obtained by [49] in agro-ecosystems to Cashew 16 years of age (7.17 tC/ha) and 22 years (21.73 tC/ha) in Burkina Faso , to the values obtained by [50] The palm groves of 15 years (99 tC/ha) in Ivory Coast and also to the values obtained by [50] in the palm groves of 20 years (73 tC/ha). This difference is related to the sampling methodology and the type of allometric equation used which could which explain the variations of carbon stocks of wood obtained in the tropical zone [51],[52],[53],[54],[55],[56].The carbon stocks of wood the most important are found in the plots of 15-20 years could be explained by biomass increment from a plant growth undisturbed by man. The carbon stock of wood products in the whole of the parcels of land to *Tectona grandis* is 130.19 tC/ha. This value is significantly higher than the witnesses (Shrub savannah and degraded area) with respectively 12.52 ± 0.21 tC/ha and 5.29 ± 0.01 tC/ha. These low values of carbon stocks of wood products in the Shrub savannah and the degraded area compared to plots to *Tectona grandis* can be summarized by the strong anthropogenic interventions which is explained by the fact that the aerial parts of trees are exploited quickly and/or prejudicially affected by accidental fires but also with the increase in the exploitation of forest resources for the production of wood and coal.

The Herbaceous represent the compartment the least provided in carbon. In the whole of the parcels of land to *Tectona grandis*, the carbon stock of herbaceous is 2.28 tC/ha which does not differ to the one of the Shrub savannah which has 2.23 tC/ha. These results do not corroborate the values obtained by [26] in the old fallow land (1.02 ± 0.64 tC/ha), primary forests (0.76 ± 0.34 tC/ha), swamps (0.75 ± 0.28 tC/ha), secondary forests (0.73 ± 0.32 tC/ha), young summerfallow (0.65 ± 0.23 tC/ha), and the fields of mixed cultures (0.56 ± 0.29 tC/ha) in Cameroon, the values obtained by [57] in the secondary forests (0.54 tC/ha), primary forests (0.18 tC/ha) and swamps (0.08 tC/ha) , to the values obtained by [48] in the plantations of *Vochysia guatemalensis* and *Hieronyma alchorneoides* from 0 to 16 years of age in Costa Rica and The value (0.40 ± 0.06 tC/ha) obtained by [34] in the parks to Shea Butter and locust tree. This is explained by the fact that the closure of the forest to negatively influence the carbon reservoir of the herbaceous stratum. Thus, forest dynamics increases the carbon stocks in the tree stratum and shrub layer to the detriment of the herbaceous stratum. And also there is less projected shadow on the ground, which facilitates the growth of herbaceous vegetation. By against those parcels of 10-15 years (0.78 ± 0.003 tC/ha), corroborated the results obtained by [26] in primary forests (0.76 ± 0.34 tC/ha), swamps (0.75 ± 0.28 tC/ha), secondary forests (0.73 ± 0.32 tC/ha), the results obtained by [58] in clearings in 15 years with respectively 0.71 tC/ha and 0.78 tC/ha. This stock of carbon in the herbaceous obtained in the plots to Tectona grandis (2.28 tC/ha) and the Shrub savannah (2.23 tC/ha) is also similar to the results obtained by [59] in a savannah to kifafa (or pseudo-steppe to *Aristida similis*) in Madagascar (2.6 tC/ha).

The carbon stocks of dead wood obtained during the present study differ between the three plots to *Tectona grandis* studied and tend to increase parcel of 5-10 years to the parcel of 15-20 years. And it can be noted as [60] and [61], that the stocks of carbon in the dead wood increase with the increase in the stock of carbon in wood. In the whole of the parcels of land to *Tectona grandis*, the parcel of 15-20 years holds the largest stock of carbon in the dead wood (9.97 ± 0.06 tC/ha). This result is close to 9.45 ± 6.6 tC/ha obtained by [61] in a swamp forest of the Likouala (North Congo). By against does not corroborate those of [62] and [63] in the forest zone tempered where they have obtained respectively, 1.1 tC/ha each and the values 0.32 ± 0.21 tC/ha and 2.35 ± 0.31 tC/ha obtained by [34] in the parks to Shea Butter and locust tree. These differences in carbon stocks of dead wood noted could explain by [64] which emphasize that the carbon stocks of dead wood vary depending on the sites and the methods of study used. The carbon stock of dead wood total in the whole of the three plots to *Tectona grandis* studies is to 22.85 tC/ha which is largely superior to those of the two witnesses: Shrub savannah (12.89 ± 0.08 tC/ha) and the degraded area (0 ,93 ± 0.001 tC/ha). It may be assumed that this is due to the presence of a greater number of trees in plots to *Tectona grandis* of varied ages, where the presence of a greater number of fallen trees to the ground. The reason for which the parks to *Tectona grandis* store more carbon in this component is certainly due to the fact that the farmers are involved very little in this type of system, contrary to the Shrub savannah and the degraded area where fallen trees on the ground are most often harvested (for the purposes of wood for heating and the manufacture of coal).

The carbon stocks are very dynamic particularly in natural environments (Shrub savannah), and therefore strongly do not correlated to the age of the plots studied. In the Shrub savannah (2.27 ± 0.001 tC/ha), this stock is considerable in relation to the other plots. In contrast in the degraded area (0.04 ±0.00 tC/ha), this stock is very low where the reason for the strong anthropogenic interventions which is explained by the fact that these vines are exploited quickly and/or prejudicially affected by accidental fires but also with the increase of The exploitation of forest resources for care in traditional medicine.

The litter, mainly composed of leaves, varies from one site to another. The carbon stocks of the litter are high in plots of 15-20 years (3.65 ± 0.004 tC/ha) by reports to other plots. This result seems logical in view of the fact that the parcels of 15-20 years closer to a forest ecosystem where a certain thickness of humus was able to accumulate with the time. This result does not corroborate the values obtained by [26] in the old Summerfallow (5.56 ± 3.64 tC/ha, the fields of mixed cultures (4.91 ± 2.54 tC/ha), primary forests (4.37 ± 1.95 tC/ha), young Summerfallow (2.91 ± 1.27 tC/ha) and finally in the swamps (2.43 ± 1.05 tC/ha), the values obtained by [57] in secondary forests (4.48 tC/ha), primary forests (1.49 tC/ha) and finally in the swamps (2.43 ±1.05 tC/ha) and 1.89± 0.07 tC/ha obtained by [34] in the parks to Shea Butter and locust tree. But that of 10-15 years (3.18 ± 0.001 tC/ha) corroborates to the value obtained by [26] in the secondary forests (3.27 ± 0.49 tC/ha). By against the parcels of 5-10 years closer to the values obtained by [26] in the swamps (2.43 ± 1.05 tC/ha) and [57] in the swamps (2.43 ± 1.05 tC/ha). The stock of carbon in the whole of the parcels of land to *Tectona grandis* is 9.09 tC/ha, which is higher than those found in the two witnesses: Shrub savannah (0.87 ± 0.00 tC/ha) and the degraded area (0.37 ± 0.002 tC/ha). This could be explained by two main reasons: in effect, the litter of plantations comes, in addition of cultures, of wood left on foot, the park which is adjacent to this last and Brownfield sites resulting from the clean which precedes his put in place. In addition, although the rate of illumination is more important in the savannah and in the degraded area, the rate of moisture is less high in the Parks; this significantly affects the speed of decomposition of the organic matter that will be more important in the parks studied than in the two witnesses. The fall of the sheets of *Tectona grandis* in soil can explain that the humus is more important in these parks studied. These values are similar to those obtained in other research [65] and [33].

The belowground carbon of stock is very high in the plots of 15-20 years (18.78 ± 0.78 tC/ha). This result does not support the work of several authors: [66], [19], [49], [34], [8], [67], [68], [25] [46], [10], [69]. This difference is likely linked to the methodology of counting used. Relatively low levels of the stock of carbon in the soil in the two witnesses (Shrub savannah and degraded area) can be explained by the average quality of the physical properties of the soil of our environment to study. The main factors of variation of carbon stocks in agroforestry soils are climate, the dominant petrol, in link with the type of humus, and qualitative characteristics (their pedogenic type) and quantitative soil (clay content and depth of soil). The stock of carbon in the whole of the three plots to *Tectona grandis* studied is of 40.4 tC/ha. This value is greater than the two witnesses (Shrub savannah and degraded area). This difference could be explained mainly in part by the different textures and biochemical compositions of the soil and also the fact that in the two witnesses (Shrub savannah and the degraded area), anthropogenic factors (bush fires, cuts of wood, put culture on burning) and biophysical factors (erosion, stripping surface layers, mechanical action land clearing and the oxidation of organic matter) which destroy and reduce refunds organic center toward the ground. In fact, the dynamics of carbon storage in soils depends on agroforestry changes of uses of soils (deforestation, afforestation...), the climate and then sylvicultural practices increasing the activity mineralisation of soil micro-organisms (labor, drainage, fertilization).

The stock of total carbon obtained in the whole of the parcels of land to *Tectona grandis* studied (207.34tC/ha), which is far superior to the two witnesses. This superiority could also be explained by the diversity of woody species which are not necessarily the same in the various sites studied. According to [45], the storage capacity of the carbon in the agroforestry system varies between 12 and 228 tC/ha with a mean value of 95 tC/ha. The value obtained in our study is included in this interval. In effect, the quantity of carbon sequestered by the agroforestry system depends largely on the culture system implementation, the structure and the function of the latter [34]. This also depends on the species included in the agroforestry system and the system of management of this last. These results do not corroborate those of [43], [42], [70],[71] ,[66],[34],[8],[26],[72],[67]; [68],[25] ,[46], [69] ,[10] ,[61],[73],[74],[75] This difference is likely linked to the methodology of counting and equations allometric used. And also to the parameters taken into account by the authors and the influence of the geographical area studied. By contrast, this result is similar to the 206.84 tC/ha obtained by [67] in the plantations of mango tree of Aurangabad in India and the 206.4 tC/ha obtained by [76] in the temperate forest in France. This result is also contained in the interval 17.93-365.87 tC/ha and 32.91-671.36 tC/ha obtained by [77] in plantations to *Tectona grandis* of India, to the Interval 16.78- 524.22 tC/ha given by [77] in plantations to coconut trees of India. The carbon stocks total obtained in plots of 5-10 years (53.89 ± 2.07 tC/ha) , of 10-15 years (68.25 ± 1.87 tC/ha) and 15-20 years (85.2 ± 4.12 tC/ha) are higher than those obtained by [10] in the plantations in the cashew of 0-10 years (14.51 tC/ha), 10-20 years (34.78 tC/ha) and of more than 20 years (40,02 tC/ha) in Cameroon; [69] in the plantations of neems of 0-10 years (12.10 tC/ha), 10-20 years (40.58 tC/ha) and more than 20 years (28.24 tC/ha) at (Cameroon); [46] eucalyptus plantations in 0-10 years (10.3 ± 0.088 tC/ha), 10-20 years (16.47 ± 0.196 tC/ha) and over 20 years of age (2 1.27 ± 0.13 tC/ha) in Cameroon; [77] in plantations to teak of 5 years (23.00 tC/ha) ,10 years (27.33 tC/ha) ,15 years (29.51 tC/ha) ,20 years (35.84 tC/ha) in India. This is due to the different geographical areas studied, to the method of sampling, to allometric equations used by the authors, at the DBH, to the basal area, to the age and density of trees of plantations chosen and studied. The low of the stock of total carbon in the degraded area (3.15 ± 0.01 tC/ha) is due to the many anthropogenic disturbances. This result is lower than those of [43] obtained in the Democratic Republic of the Congo (6.63 tC/ha), [68] in the Sudano-Sahelian region of Cameroon (13.15 tC/ha), [46] (13.39tC/ha) in area of high Guinean trays of Cameroon, [69] in the Sahelian zone of Cameroon (13.68 tC/ha).

The study of the structure diamétrique reveals that the trees DBH ≥ 70 cm of our study area contribute to 35.78% in carbon storage. Our values are close to those found by many authors in the tropical zone [78],[79]. These values of our area of study show that the contribution to carbon storage of more than 30 per cent by the trees of DBH ≥ 70 cm [80] is only possible for land. The differences noted in the contribution to the storage of carbon by the trees of DBH ≥ 70 cm is explained by the diversities intra-interspecific and high ecosystem in tropical area. The distribution obtained better fits with a polygonal function whose equation is: $y = 0.023x^4 - 1.258x^3 + 12.33x^2 - 35.73x + 36$ and $R^2 = 0.838$. This distribution can be explained by the fact that the trees of large diameters store more carbon than the Trees of small diameter and that in spite of the effect of the abundance, the DBH is the most important factor in terms of sequestration. Individuals of diamétrique class 70-80 cm have sequestered more carbon. For a group of given taxon, the amount of carbon is amplified by the strength of the individuals who represent the taxon having of the large capacity of carbon sequestration. Taken individually, the DBH is the only important factor of variation of sequestered carbon.

The correlation tests show that there is a highly significant correlation between the carbon stocks and the basal area of agro-ecosystems ($r> 0.05$; $p=0.0000$). The wood from large diameters occupies a basal area too important, which is proportional to the circumference of the trunk of the tree. Therefore more a tree has a large circumference, the more he occupies a basal area important and receiver a large quantity of carbon. The sequestration potential for a wood is intimately linked to its diameter. The woods from large diameter have a great potential of carbon sequestration in relation to the wood from small diameter. The correlation between the stocks of carbon and the economic value is very strong ($r> 0.05$; $p=0.0000$). Where the carbon stock is proportional to the economic value. Therefore more a plantation receiver a large quantity of carbon over its economic value is great too. The economic value is the primary determinant of the groups ($H= 115.87$; $p < 0.001$), with a clear separation between species to broad economic values of other species to low economic values. We translated which more the sequestration of carbon dioxide of carbon is high over its economic value is considerable. The CAH includes very clearly the species as a function of their economic value. These 6 groups formed three complexes with the following similarities, (G1-G6): 92.89%; (G2-G3): 91.67%

and (G4-G5): 85.98% dependent in their economic value.

In total, 207.34ton/3ha obtained in the whole of the parcels of land to *Tectona grandis* studied. This value corresponds to a sequestration of carbon dioxide of 760.92 tCO_2/ha. Economically, this corresponds to the carbon price CDM (2282.85 Euros/ha), the price carbon voluntary market (3576.4 Euros/ha) and at the price of REED+ Carbon (76093.78 Euros/ha) in the whole of the parcels of land to *Tectona grandis* studied. This justifies including their major role contributory in the sequestration of carbon. If this is marketed on the market, it grows with the age of the parcels therefore gradually environments degraded recently toward the environments less degraded with the stocks most High. The correlation between the stocks of carbon and the economic value is very strong and highly significant ($P < 0.05$), this shows that these different plantations are of the large reservoirs of carbon and may justify the use of a judicious combination of agricultural crops and woody (agroforestry) in order to enhance the carbon stocks totals and consequently the quantity of CO_2 in the degraded ecosystems such as agroforestry systems. We note a gradual flow of the price of carbon between the plots to *Tectona grandis* of varied ages studied. The economic value is very high on the unit price of the REED+ carbon by report to the price of the CDM and the voluntary market. These results do not corroborate those of [26] in the south of Cameroon, [68] in the Sudano-Sahelian region of Cameroon, [46] in the Sudano -Guinean of Cameroon, [69] in the Sahelian zone of Cameroon, [10] in the Sudano-Sahelian region of Cameroon.

5. CONCLUSION

This study main objective was to estimate the potential of carbon sequestration and the economic value in the various components of an agroforestry Parkland of *Tectona grandis* in the Sudano-Sahelian region of Cameroon. The main results show that this park agroforestry activities stores a significant amount of carbon are 207.34ton/3ha of which 130.19ton /3ha for the biomass of woody, 40.4 ton/3ha for the belowground biomass, 22.85 ton/3ha for the dead organic matter, 9.09 ton/3ha in the litter, 2.28 ton/3ha for the herbaceous and 2.53 ton/3ha for the lianas. These results therefore assert the role of contributory parks to *Tectona grandis* in the fight against the climate change mitigation in Cameroon. At the end these results also constitute an important informative value to the plan economic, ecological and dynamics to serve as a basis for guiding any program of action for the conservation and management of such a park agroforestry activities. It would be judicious to which that services for agricultural development should be interested in the conservation and enhancement of such an agroforestry parkland activities for a sustainable exploitation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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