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Carbon storage potential of agroforestry parkland in Cameroon

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Research Article

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ABSTRACT

This study assessed the carbon storage and CO_2 sequestration potential of four agroforestry parklands in Cameroon. Data of vegetation, dead wood, herbs, litter, soils and fine roots were collected using systematic sampling methods, laying 192 quadrats each with 50m × 50m for trees and dead wood, 1m × 1m sub-quadrats for herbs, 0.5m × 0.5m sub-quadrats for litter biomass, 0.25 m × 0.25 m sub-quadrats for soil sample and volume of 0.2 m² × 0.2 m × 0.2 m³ for fine roots. Aboveground biomass carbon (AGC), belowground biomass carbon (BGC), Soil Organic Carbon (SOC), general carbon stock (TC) have been predicted the usage of allometric equations. The result revealed that, the general carbon stock followed this order: *Adansonia digitata* (142.50 ± 3.6 Mg C/ha) > *Anogeissus leiocarpus* ([illegible]0.46 ± 2.01 Mg C/ha) > *Pterocarpus lucens* (88.57 ± 1.73 Mg C/ha) > *Terminalia laxiflora* (55.29 ± 0.84 Mg C/ha). The CO_2eq sinks followed this order: *Adansonia digitata* (522.97 ± 13.32 Mg CO_2/ha) > *Anogeissus leiocarpus* (442.08 ± 7.37 Mg CO_2/ha) > Pterocarpus lucens (325.05 ± 6.34 Mg CO_2/ha) > *Terminalia laxiflora* (202.91 ± 3.08 Mg CO_2/ha).This study showed that the agroforestry parkland plays a role as a carbon sink.

Keywords: Agroforestry parklands; Carbon sinks; Climate change; REDD+; Cameroon

INTRODUCTION

Agroforestry parks provide a wide range of ecosystem services that are essential to sustain life on this planet and support the livelihoods of millions of people worldwide [1]. Agroforestry parks help stabilize the climate [2]. The crucial role of forest parks in mitigating and adapting to climate change is now widely recognized [3,4]. Agroforestry parks contribute significantly to mitigating climate change through their carbon absorption and storage functions [5,6]. They play an important role in reducing climate-related risks and vulnerabilities and in adapting people and ecosystems to climate change and other natural disasters [7]. The role of plant forest parks in mitigating climate change has become a central focus of international climate change agreements [8,9].

Reducing emissions from deforestation, forest degradation, sustainable forest management, conservation and enhancement of forest carbon stocks (REDD+) has emerged as a promising option for forest-based climate change mitigation in developing countries [10,11]. Under the REDD+ program, developed countries encourage developing countries to preserve their forests and thus reduce greenhouse gas emissions [6,11]. One of the essential requirements of carbon-based forest management is the measurement, reporting and verification of forest carbon stocks [12].

Agrosystems, as described in many works, can thus provide a mitigation solution to mitigate climate change [13]. Agrosystems are refuges for endogenous species threatened by anthropogenic activities caused by natural ecosystems [14]. Sustainable management of agricultural systems is commendable; Apart from their many known uses that benefit the population, their role in the climate change mitigation process is still unknown to our knowledge. These practices can also lead to the implementation of the Clean Development Mechanism (CDM) for poor populations, contributing to poverty reduction one of the Millennium Development Goals.

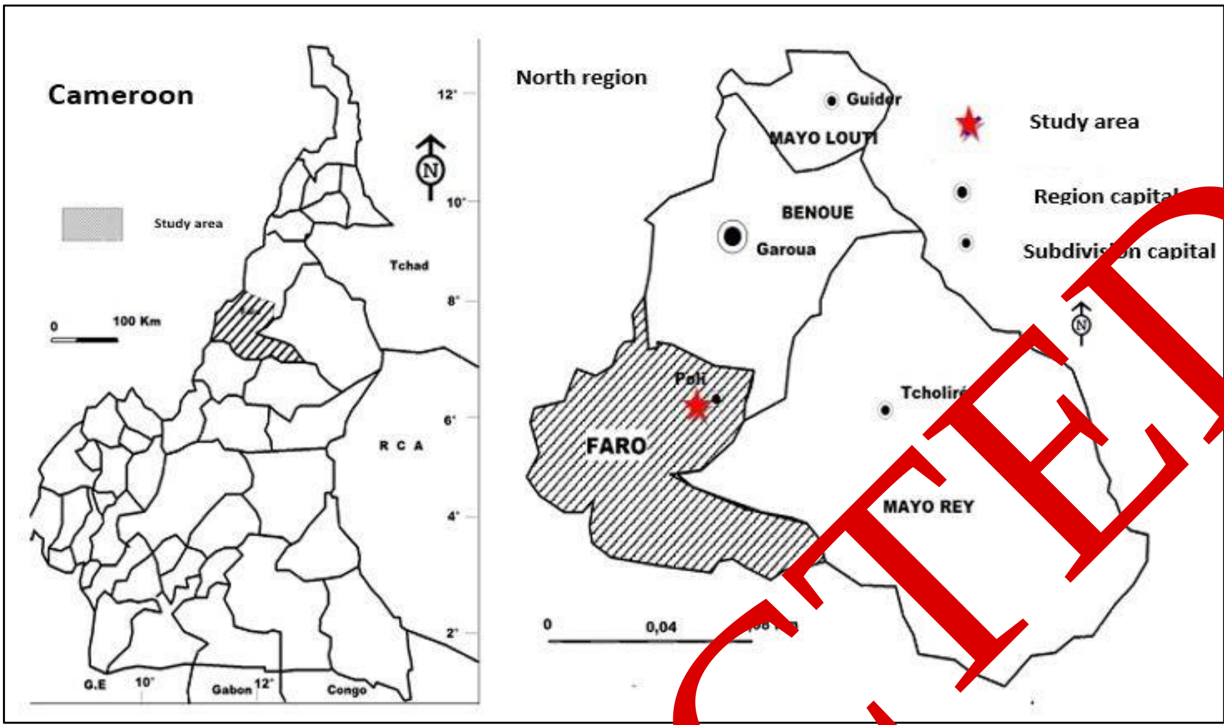
Studies carried out on the different agroforestry systems in Cameroon reveal that they are in continuous degradation due to climatic, anthropogenic factors and cultural practices [6]. This state of affairs is explained by a lack of policy to promote these agroforestry systems and the implementation of conservation strategies for these species. The results of this degradation make agroforestry parklands, in the long run, potential sources of greenhouse gas emissions when they should normally constitute carbon sequestration zones. Faced with these problems, it is therefore urgent to develop conservation and management strategies for these forest resources. The current study was carried out to estimate the carbon storage potential of four agroforestry parklands in Cameroon.

MATERIALS AND METHODS

Study area

The study was carried out in the North part of Cameroon, in the Faro sub-region, specifically in the Poli district. The Poli district is located at latitude 8°28'32 N and longitude 13°14'27" E [15]. The area of Poli district is 8045 km^2 [16]. The terrain consists of Vokre mountain (2000 m), Papé, Ninga, Mayfoula (975 m). The soils are feralitic and planosols with thick horizons. The climate is of the Sudanese type with humid shade. The Pole district has an average annual precipitation of 1200 mm and an average annual temperature of 25 °C. Vegetation is dominated by shrubby savannas to tree degenerate facies as shown in Figure 1 [16-19].

Figure 1. Location map of the study area.



Experimental setup and vegetation sampling (tree, shrubs and dead wood)

Data collection took place between June and December 2024. In total, 192 dendrometric surveys were carried out in the Poli district (i.e. 48 surveys x 4 species x 1 zone) according to the four agroforestry parkland (*Adansonia digitata*, *Anogeissus leiocarpus*, *Pterocarpus lucens* and *Terminalia laxiflora*). 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 [20]. For this study, four treatments (*Adansonia digitata*, *Anogeissus leiocarpus*, *Pterocarpus lucens* and *Terminalia laxiflora*) were considered.

A total 192 quadrats each with 50 m × 50 m (covering 48 ha) was sampled and inventoried in the *Adansonia digitata* (n = 48 plots), *Anogeissus leiocarpus* (n = 48 plots), *Pterocarpus lucens* (n = 48 plots) and *Terminalia laxiflora* (n = 48 plots). The quadrats were plotted over a ground distance of 2500 m², using a GPS and a compass. Along the quadrats, all woody trees of Dbh ≥ 5 cm were counted in both areas. This inventory system applies to the model used by [21]. The inventories of trees, dead wood and shrubs were carried out by measuring their circumference with a measuring tape. The dendrometric data focused on the measurement of the diameter at breast height (dbh) of the bark using a measuring tape and the height of a clinometer. Thus, the circumferences of four agroforestry parklands were measured using a tape measure at 1.30 m from the ground. Circumference values were then converted to diameter (dbh) using the formula: dbh = C/ π where C = circumference, dbh = diameter at breast height, and π = 3.14.

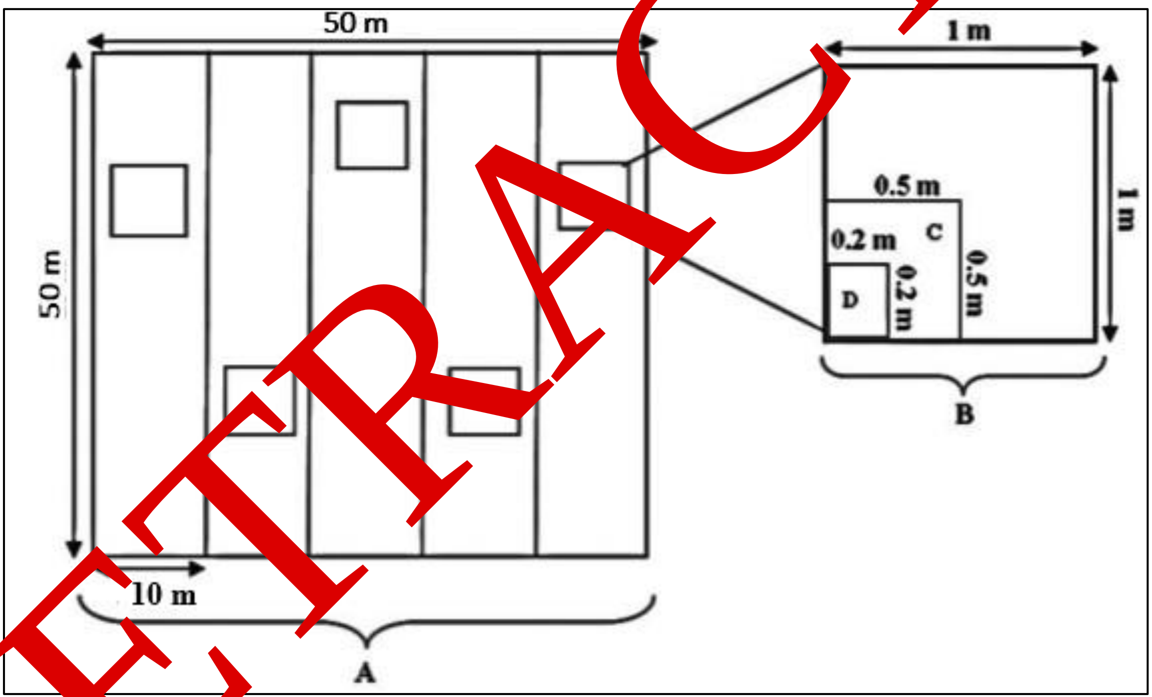
Collection of herbaceous, litter, soil and fine roots

A destructive sampling method was used to quantify herbaceous and litter biomass. Herbaceous plants were sampled in sub-quadrats (1 m × 1 m). All emergent herbaceous vegetation in the quadrats was cut above ground, weighed and a pooled sample was taken from each sub-quadrat to determine oven dry weight in the laboratory [22].

Litter was taken from sub-quadrats (0.5 m × 0.5 m) and the combined waste was collected. To determine moisture content, samples are quickly returned to the laboratory where they are reweighed, dried at 70°C for 24 hours to constant weight and then reweighed.

Soil samples were collected from five 0.2 m × 0.2 m sub-quadrats. Fine roots were extracted from the soil with a trowel in a volume of 0.2 m² × 0.2 m² × 3 m², then washed and sealed in envelopes to dry in the laboratory. These samples are taken from four main profiles at 0 cm - 10 cm, 10 cm - 20 cm, 20 cm - 30 cm and 0 cm - 30 cm depth. Each depth of soil was collected with a machete and trowel and then immediately placed in a sealed bag in the cooler shade to prevent evaporation. Soil samples were taken to determine bulk density. The soil sample was then air-dried and then oven dried at 105°C for 24 hours at the Garoua Agricultural Research Multipurpose Station. Bulk density was measured using the core method and soil organic carbon was determined using the Walkley–Black oxidation method as shown in Figure 2 [23,24].

Figure 2. Inventory sampling method for woody trees and biomass estimation of different carbon pools.



Note: Inventory of woody trees with DBH ≥ 5 cm on survey plots of 50 m × 50 m (A), plots of 1 m × 1 m to evaluate the biomass of the herbs (B),the biomass of the litter was evaluated in a plot of 0.5 m × 0.5 m (C), and soil biomass in 0.2 m × 0.2 m (D) plots.

Estimation of carbon storage

Aboveground carbon stock (AGCs): The biomass of woody species was evaluated according to the allometric equation developed by for dry tropical climates: AGB= expo [(-1.996+2.32ln (DBH))]; in this formula AGB is aboveground biomass (kg), DBH is diameter at breast height (cm) [25]. To convert the above ground dry biomass to carbon, 50 % of all trees biomass were assumed the carbon stock. So based on the aboveground carbon stock calculated as follows [29]: AGCs= AGB*0.5; in this formula AGCs is aboveground carbon stocks (Mg C/ha).

Belowground Carbon Stock (BGCs): The aboveground biomass of woody trees thus calculated is used to deduce the belowground biomass according to the allometric equation developed by [26]. It is recommended by for dry areas (rainfall < 1500 mm). The equation is as follows: BGB = exp [(-1.0587+0.8836 In (AGB))]; in this formula BGB is belowground biomass (Kg); AGB is aboveground biomass (Kg). From this biomass, the amount of carbon (Mg C/ha) was obtained by multiplying this biomass by a 50 % conversion factor [22,27].

Herbaceous and litter carbon stock: The percentage of dry matter of herbaceous and litter was determined according to the French standard NFM03-002, according to the following formula: DM = (DW/WW)*100; where DM = Quantity of dry matter (%); DW = dry weight of the sample after three days in the oven at [illegible]°C (g); WW=wet weight of the sample measured in the field (g). Herbaceous and litter Biomass were computed using the formula: B= (TWW*DM)/100; where B = biomass (g); TWW = Total wet weight in measured in the field (g); DM = percentage of dry matter (%) [28]. The carbon stock (carbon content) for the dry biomass of herbs and litters is 50 % of the total dry biomass of the quadrate [29].

Dead wood carbon stock: Dead wood biomass was computed using the formula: BDW= [0.13 (DBH) 2.32–5.5 %]; where BDW= dead wood Biomass (Mg C/ha); DBH=Diameter at breast height of dead wood (cm). The dead wood carbon stock was computed by multiplying the total biomass of the dead wood by 0.[illegible] [23].

Soil Organic Carbon (SOC): Soil bulk density was computed using the formula: BD = (W)/ (V); where BD: Bulk density (g/cm^3); W: Weight of dried soil (g); V: Volume of the core (cm^3). The soil organic carbon stock was calculated using the formula as shown below: SOCs = % C × [illegible] × sd; where SOCs= Soil organic carbon stock per unit area (Mg C/ha), % C= Carbon concentration (%), sd= Soil depth ([illegible]) and BD: Bulk density (g.cm^{-3}) [30,31].

Total carbon stock: The total carbon stock of four agroforestry parklands will be obtained by summing all assessed stocks: TC = AGC + BGC + LC + HC+ DWC+ FRC+ SOCs; in this formula TC: general carbon stock; AGC: Aboveground carbon; BGC: Belowground carbon; LC: Litter carbon; HC: Herbaceous carbon; DWC: Dead wood carbon; FRC: Fine roots carbon (Mg C.ha-1); SOCS: soil organic carbon stock. The total carbon stock evaluated in Mg C/ha was converted to the equivalent amount of CO^2 absorbed using the 44/12 ratio corresponding to the CO^2/C ratio [31]. The determination of the ecological value was based on the following formula: TéqCO2 = TC×FCC where TC is the total carbon stock and CFC is the conversion factor of carbon to CO^2 equivalent=44/12 or 3.67.

Data analysis

All statistical analyzes were performed with STATGRAPHICS plus version 5.0 software for Windows. One-way Analysis of Variance (ANOVA) was used to compare floristic parameters, mean carbon storage and stand sequestration potential using the Duncan test. A p-value = 0.05 was used to reveal statistical significance.

RESULTS AND DISCUSSION

Aboveground carbon

Carbon stocks contained in aboveground (80.07 ± 0.63 Mg C/ha) and belowground (16.67± 0.14Mg C/ha) biomass are higher in *Adansonia digitata* agroforestry parks. The analysis of variance shows significant differences in the carbon stocks contained in aboveground (F=22.83; p=0.003<0.05) and belowground (F=38.63; p=0.012<0.05) biomass between the four agroforestry parks studied. Our results show above-ground carbon

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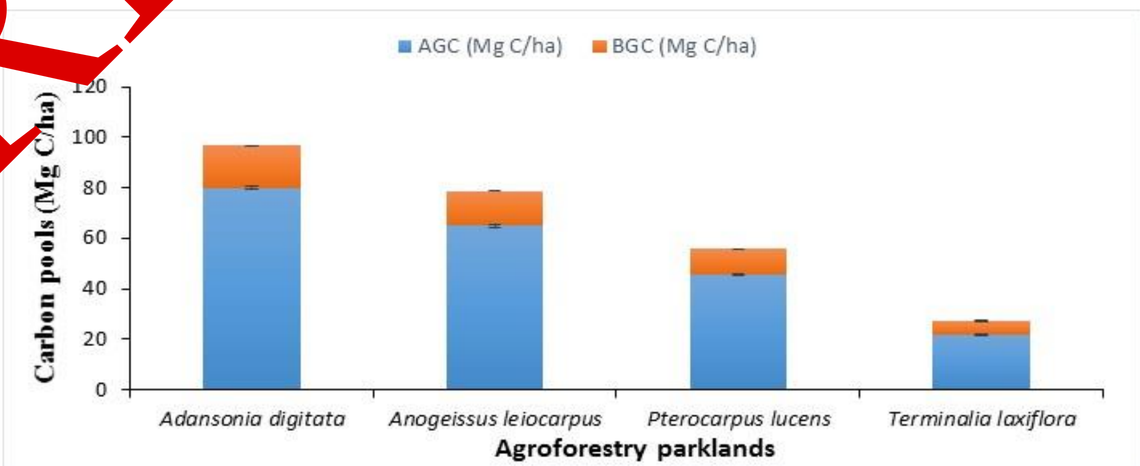
stocks vary according to the different agroforestry parklands studied. *Adansonia digitata* agroforestry parkland sequestered more aboveground carbon stocks (80.07 ± 0.63 Mg C/ha) compared to *Anogeissus leiocarpus* (64.98 ± 0.49 Mg C/ha), *Pterocarpus lucens* (45.57 ± 0.27 Mg C/ha) and *Terminalia laxiflora* (21.89 ± 0.19 Mg C/ha). The differences between the aboveground carbon stocks of four agroforestry parklands would be due to the difference in diameter at breast height (Dbh), basal area and density which influences the biomass produced by a species. This confirms the observations of according to which the more the tree grows (length and circumference), the more carbon it sequesters [32]. Our results obtained in this study are different from those of who found an aboveground carbon stock of 31.64 Mg C/ha (Boundiali), 21.82 Mg C/ha (Ferkessédougou), 95.68 Mg C/ha (Ouangolodougou), 58.33 Mg C/ha (Tengrela) of Vitellaria paradoxa agroforestry parklands in the Northern Côte d'Ivoire; who found an aboveground carbon stock of 43.39 Mg C/ha in the Tectona grandis agroforestry parkland in the Northern region of Cameroon; who found an aboveground carbon stock of 54.46 Mg C/ha in Eucalyptus saligna agroecosystems in the Adamawa-Cameroon region, who found an aboveground carbon stock of [illegible].50 Mg C/ha in Gmelina arborea agrosystems in the Adamawa region of Cameroon [15,33-35]. This difference in our results to those of the cited authors is related to the counting methodology, the allometric equations used and the climatological conditions of the study environments.

Belowground carbon

The *Adansonia digitata* agroforestry parkland sequestered more belowground carbon stocks (16.67± 0.14 Mg C/ha) compared to *Anogeissus leiocarpus* (13.86 ± 0.1[illegible] Mg C/ha), *Pterocarpus lucens* (10.13± 0.08 Mg C/ha) and *Terminalia laxiflora* (5.30 ± 0.04 Mg C/ha). The variations in belowground carbon stocks between the different agroforestry parklands studied could be explained mainly in part by the different textures, biochemical compositions of the soils and the maturity of the trees in each agroforestry parklands studied. Our results are different from those of who found belowground carbon stocks of 6.99 Mg C/ha in the *Albizia lebbeik* plantations and 3.93 Mg C/ha in the *Delonix regia* plantations in Aurangabad (India); who found an belowground carbon stock of 13.46 Mg C/ha in the *Tectona grandis* agroforestry parkland in the Northern region of Cameroon and who found an belowground carbon stock of 4.25 ± 0.74 Mg C/ha in *Vitellaria paradoxa* and *Parkia biglobosa* agroforestry systems in the Sudanian zone of Benin [32,36,37]. The differences in our results with the cited authors could be explained by the use of different allometric equations, root characteristics of the species studied and the soil conditions in which the species are planted as shown Figure 3.

Figure 3. Aboveground and belowground carbon stocks of four agroforestry parklands.



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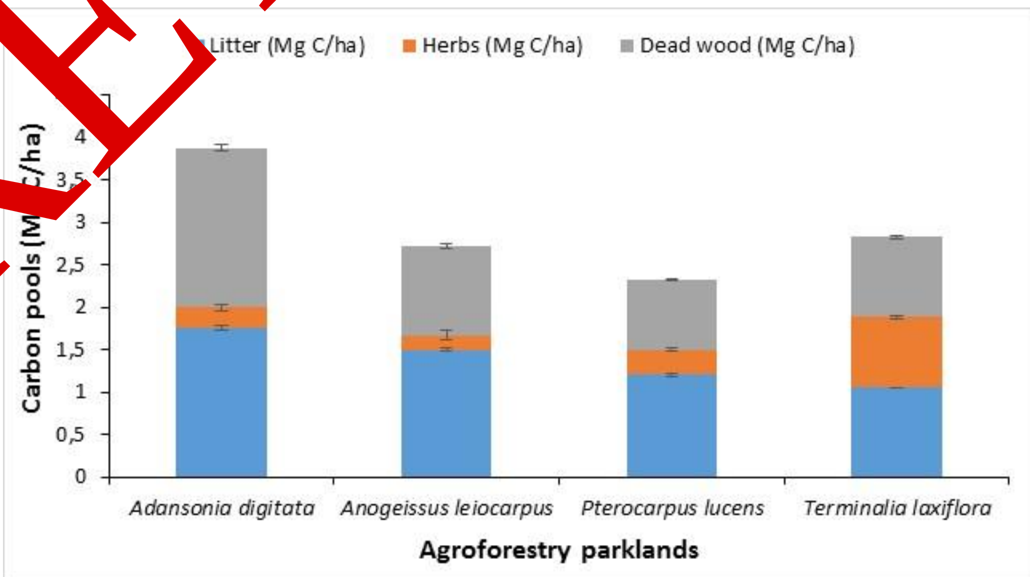
Litter and deadwood carbon

The highest carbon stocks contained in leaf litter (1.75 ± 0.03 Mg C/ha) and deadwood (1.88 ± 0.04 Mg C/ha) biomass were recorded in *Adansonia digitata* agroforestry parklands. However, the highest carbon stock contained in the herbaceous biomass is recorded in *Terminalia laxiflora* agroforestry parklands. The analysis of variance shows that there is no significant difference in the carbon stocks contained in leaf litter ($F=0.14$; $p=0.077>0.05$), dead wood ($F=0.77$; $p=0.058>0.05$) biomass between the four agroforestry parklands studied. The high value leaf litter carbon stock obtained in the *Adansonia digitata* agroforestry parkland could be justified by the fall of leaves, fruits and twigs on the ground, which may explain why humus is more important in these agroforestry parklands. Our results are different from those who found an litter carbon stock of 3.03 Mg C/ha in the *Tectona grandis* agroforestry parklands in the Northern Region of Cameroon and who found an litter carbon stock of 1.89 ± 0.07 Mg C/ha in the *Vitellaria paradoxa* and *Parkia biglobosa* agroforestry systems in the Sudanian zone of Benin. The different values observed in this study and the authors quoted can be explained by the different sampling methodologies and the silviculture management methods of these agroforestry parklands [15,38].

Herbaceous carbon

The result of the herbaceous carbon stock obtained in the *Terminalia laxiflora* agroforestry parkland could be explained by the opening of the canopy of the young agroforestry parkland which easily let the penetration of light into the undergrowth of this agroforestry parkland which favors the herbaceous development. Our results are much lower than those of who found 3.91 ± 0.15 Mg C/ha (Central Benin); 4.47 ± 0.13 Mg C/ha (Far North of Benin); 4.06 ± 0.30 Mg C/ha (North-East of Benin); 4.01 ± 0.24 Mg C/ha (north-west of Benin); 4.02 ± 0.02 Mg C/ha (South of Benin) for the carbon stock of herbaceous plants in cashew plantations; who found an herbaceous carbon stock of 0.76 ± 0.07 Mg C/ha in the *Tectona grandis* agroforestry parklands in the Northern Region of Cameroon and who found an herbaceous carbon stock of [illegible] ± 0.06 Mg C/ha in *Vitellaria paradoxa* and *Parkia biglobosa* agroforestry systems in the Sudanian zone of Benin [32,39,40]. These differences are explained by the different sampling methodologies and the undergrowth management techniques of these plantations by the peasant farmers as shown in Figure 4.

Figure 4. Leaf litter, herbaceous and dead wood carbon stock under four agroforestry parklands.



Fine roots and soil carbon

The highest carbon stocks of fine roots (1.05 ± 0.07 Mg C/ha) and soil carbon (40.83 ± 1.84 Mg C/ha) are recorded in *Adansonia digitata* agroforestry parklands. The result of the carbon stock of fine roots obtained in the *Adansonia digitata* agroforestry parklands could be explained by the high root density in the soil and the good soil conditions which favor a good capacity for regeneration of the root systems of the species *Adansonia digitata*. Our results obtained in this study do not corroborate several research works in the literature [41,42]. The different values obtained in our study with the cited authors of the literature can be partly explained by the different textures and biochemical compositions of the soils of the agro-ecological environments studied as shown in Table 1.

Table 1. Fine roots, soil carbon stock, total carbon and quantity of CO2 of agroforestry parklands.

Carbon pools (Mg C/ha)	Adansonia digitata	Anogeissus leiocarpus	Pterocarpus lucens	Terminalia laxiflora
Fine roots	1.05 ± 0.07a	0.85 ± 0.05a	0.26 ± 0.[illegible]	0.22 ± 0.02a
Soil carbon stock	40.83 ± 1.84c	38.05 ± 1.23b	30.28 ± 1.14b	25.05 ± 1.04a
Total carbon	142.50 ± 3.63d	120.46 ± 2.01c	[illegible]57 ± 1.73b	55.29 ± 0.84a
Quantity of CO2	522.97 ± 13.32d	442.08 ± [illegible].37c	325.[illegible] ± [illegible].34b	202.91 ± 3.08a
Note: In each lines, values assigned the same letter are not statistically different (p>0.05; Duncan's test)				

Total carbon

The general carbon stock is higher in the *Adansonia digitata* agroforestry parklands (142.50 ± 3.6 Mg C/ha) than in the *Anogeissus leiocarpus* (120.46 ± 2.01 Mg C/ha), *Pterocarpus lucens* (88.57 ± 1.73 Mg C/ha) and *Terminalia laxiflora* (55.29 ± 0.84 Mg C/ha) agroforestry parklands. The variation in the total carbon stock in the different agroforestry parklands would therefore be due to the variation in the dendrometric (Dbh) and structural (density and basal area) characteristics of agroforestry parklands. According to the carbon storage capacity of agroforestry system varies between 1[illegible] and 228 Mg C/ha with an average value of 95 Mg C/ha [42]. The values obtained during this search are included in this interval. Our results obtained in this study are different from those of who found an total carbon stock of 1[illegible]0 Mg C/ha (Boundiali), 13.48 Mg C/ha (Ferkessédougou), 58.73 Mg C/ha (Ouangolodougou), 35.65 Mg C/ha (Tengrela) of *Vitellaria paradoxa* agroforestry parklands stands in the Northern Côte d'Ivoire and who found an total carbon stock of 34.7 Mg C/ha, 20.1 Mg C/ha, 8.4 Mg C/ha and 3.9 Mg C/ha in the *Adansonia digitata*, *Parkia biglobosa*, *Sterculia setigera* and *Vitelaria paradoxa* agroforestry parkland in the Sudanese tropical region of Togo. Our results are also located in the range 23 to 374.13 Mg C/ha reported by in *Pinus kesiya* plantations in Bukidnon (Philippines), in the range 17.93 to 365.87 Mg C/ha and 32.91 to 671.36 Mg C/ha obtained by in *Tectona grandis* plantations in India, in the range 16.78t o 524.22 Mg C/ha given by in coconut tree plantations in India, in the range 8.657 to 193.32 Mg C/ha reported by found in cashew plantations in Northern Côte d'Ivoire. But remains different from those of who found in *Picea crassifolia* (469 Mg C/ha), *Larix gmelinii* (375 Mg C/ha), *Populus simonii* (330 Mg C/ha), *Pinus tabuliformis* (281 Mg C/ha) plantations in a semiarid temperate region of Northwest China [32,44-47]. These differences would be related to the density, the basal area, geographical environment, management method, allometric equation used for the species and the methodology used.

Amount of CO2

Throughout this study, the amount of CO_2 in the four agroforestry parklands studied varies from 202.91 ± 3.08 Mg CO2/ha to 522.97 ± 13.32 Mg CO_2/ha. This result only confirms the difference in aboveground and belowground biomass values obtained in agroforestry parklands. Based on these values, agroforestry parklands can offset carbon dioxide emissions from anthropogenic activities. These results obtained during this research are not close to those of similar work carried out by which show that cashew agrosystems have a CO_2 sequestration capacity of around 327.47 ± 2.07 Mg CO_2eq/ha, those of Eucalyptus (859.33 ± 10.01 Mg CO_2eq/ha), those of ne[illegible] (296.70 ± 1.98 Mg CO_2eq/ha) and those of Cocoa plantations (539.87 ± 8.01 Mg CO_2eq/ha) [39,40]. Similarly found in the Selbé-Darang locality (Adamawa region) that the potential for CO_2 sequestration in the [illegible]e reforestation sectors at Gmelina arborea was 85.05 ± 16.05 Mg CO_2eq/ha (site 1), 83.39 ± 18.65 Mg CO_2eq/ha (site 2), 90.41 ± 15.01 Mg CO_2eq/ha (site 3) with an average CO_2 sequestration potential of 86.28 ± [illegible]6.57 Mg CO_2eq/ha. In the Far North region of Cameroon, found 463.72 Mg CO_2eq/ha for Moringa oleifera agrosystem stands [48,49]. The ecological values found in these studied agroforestry parklands are very encouraging. It is necessary for the services in charge of rural development to sensitize the populations for better management of these plantations with a view to reducing greenhouse gases.

CONCLUSION

The general objective of this work was to assess the carbon storage potential of agroforestry parkland in Cameroon. The results of this work showed that, the total carbon stock followed this order: *Adansonia digitata* (142.50 ± 3.6 Mg C/ha) > Anogeissus leiocarpus (120.46 ± 2.01 Mg C/ha) > Pterocarpus lucens (88.57 ± 1.73 Mg C/ha) > Terminalia laxiflora (55.29 ± 0.84 Mg C/ha). Therefore, the result of this study showed that agroforestry parklands have a great potential to contribute to carbon sequestration. Therefore, these agroforestry parks must be carefully managed so that they can fulfill their role in reducing CO_2 emissions.

CONFLICT OF INTERESTSTATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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