FLORISTIC STRUCTURE AND CARBON SEQUESTRATION POTENTIAL OF ACACIA SENEGAL (L.) WILLD. (FABACEAE) IMPROVED FALLOWS IN FAR NORTH REGION OF CAMEROON

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ABSTRACT: *Agroforestry systems through their capacity to sequestrate carbon can contribute to climate change mitigation. This study aimed to evaluate the carbon storage potential of improved fallows with Acacia senegal in the Far North Region of Cameroon. Three categories of fallow were defined according to the planting age. The biomass of trees, bushes, and herbaceous was estimated in 21 sample plots. Soil carbon was also estimated. 08 woody species belonging to 4 families were identified. The most abundant species was Acacia senegal with 97 % of the individuals. Carbon stocks registered are 80.17 ± 33.64 tC ha^{-1} in the 7-11years old fallows, 101.10 ± 14.19 tC ha^{-1} in fallows of 12-16 years and 103.96 tC ha^{-1} in those over 17 years old. Soil is the main carbon reservoir with values ranging from 67.78 tC ha^{-1} to 89.24 tC ha^{-1}. Statistical test shows that there is no significant difference between carbon stocked with the different ages (P > 0.05). The amount of CO_2 absorbed gives an ecological value of $ 2942.24 ± 1234.77 ha^{-1} for fallows aged 7-11 years; $ 3710.37 ± 520.77 ha^{-1} for fallows aged 12-16 years and $ 3815.33 ± 947.60 ha^{-1} to those over 17 years. Improved fallows with Acacia senegal have good carbon sequestration potential and their inclusion in environmental services payments under the clean development mechanism would represent an opportunity to revive the creation of Acacia senegal plantations.*

KEYWORDS: Carbon, Improved Fallow, Environmental Service, Acacia Senegal, Cameroon

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INTRODUCTION

Climate change is one of the major concerns of the international community because of its threats on the sustainability of the global environment. In Africa, these threats include more variability in annual precipitation, more severe climatic events, including acute floods and droughts, particularly in countries suffering already an advanced level of desertification and land degradation (Thiam *et al*., 2014). Africa is particularly vulnerable to climate change because of geographical exposure, low incomes and greater dependence on climate-sensitive sectors such as agriculture (Stern, 2007; FAO, 2007). Agriculture and land-use change are responsible respectively for about 13% and 17% of total emissions of greenhouse gases due to human activities (FAO, 2008). These emissions are mainly due to poor agricultural practices, conversion of forests to cropland and soil degradation (Murphy *et al.*, 2009).

Agroforestry is a land-use system where perennial woody species are deliberately associated with annual crops and/or animals in order to optimize the ecological and economic interactions of the different components (Nair, 1993). It can help address certain environmental threats especially in tropical countries where forest destruction is a major issue (Torquebiau *et al*., 2002). One of the potential solutions to land degradation is to promote the utilization,

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regeneration and planting of a native underutilized legume tree such as *Acacia senegal* (Harmand *et al.*, 2012). Agroforestry systems also play an important role in carbon sequestration. Most agroforestry systems have higher carbon stocks than agricultural monocultures, and expansion of agroforestry practices could raise the carbon stocks of Africa's terrestrial systems (Albrecht & Kandji, 2003). Agroforestry systems such as parklands, live fences and home gardens store between 0.2 and 0.8 tC/ha/year, while improved fallows store between 2.2 and 5.8 tC/ha/year (Luedeling *et al*., 2011). Lieunang (2013) estimated between 167 and 364 tC/ha, the amount of carbon stored by improved fallow in the western region of Cameroon. In the eastern region, Temgoua *et al*. (2018) found an average of 107 tC/ha in cocoa based agroforestry systems. This carbon sequestration potential of agroforestry systems offers an opportunity for their consideration in the clean development mechanism and payment for environmental services.

In the Sudanian zone of Cameroon which faces serious environmental problems such as the disappearance of vegetation cover and soils degradation, agroforestry projects of *Acacia senegal* plantation in the form of improved fallows have been initiated since the middle of the 1980s. Some authors showed that *Acacia senegal* improved fallows, contribute to the regeneration of degraded soils (Harmand *et al*., 1997; Abdou *et al*., 2013). They also provide wood with production estimated at 39.6 m^3/ha (Kissi *et al*., 2013). Gum arabic is one of the major product of these fallows (Palou Madi *et al*., 2010), with production ranging from 50 to 250 kg/ha/year (Harmand *et al*., 2012). Despite the keen interest of local population, the surface area planted increased rapidly between the years 1999 and 2003, and then declined since 2003 due to the low production and slump of gum arabic (Palou Madi *et al*., 2010). This currently represents a threat to the sustainability of *Acacia senegal* improved fallows in the region.

Researches on *Acacia senegal* improved fallows mainly focused on their contribution to soil fertility (Abdou *et al*., 2013) and their gum arabic and wood productivity (Harman *et al*., 2012; Kissi *et al*., 2013). Few works have been conducted to assign their sequestration potential and ecological services. There is a need to check for ecological services they provide so that they could be valued in the context of payment for environmental services and carbon stock sold as CO_2 emission offsets. The present study aims to estimate the carbon storage potential and the ecological value of *Acacia senegal* improved fallows.

MATERIAL AND METHODS

Study area

The study was carried out in the Far North region of Cameroun within two divisions: Mayo-Danay and Mayo-Kani (Figure 1). This region is located between 10° and 13° North and 13° and 16°East. The climate is Sudano Sahelian dry tropical type, characterized by a long dry season that last at least seven months and a short rainy season that usually last only four months (Jebkalbe, 2010). Rainfall is characterized by inter-annual variability with maximums greater than 1000 mm and minimums below 600 mm and a variability in rainfall distribution over the year (Donfack, 1993). Temperatures vary from 20°C to more than 45°C. The main types of soils encountered in this region are: ferruginous tropical soils, vertisols, lithosol, and hydromorphic soils in the lowlands. The vegetative type of the Far North region of Cameroon is dry savannah. It falls within the thorny steppes sector, periodically flooded plains and shrubby and grassy savannah (Letouzey, 1985). The herbaceous and woody species of this savannah have multiple uses: firewood, building materials, tools, medicines, etc. The economy of the region is based on livestock and agriculture (Jebkalbe, 2010).

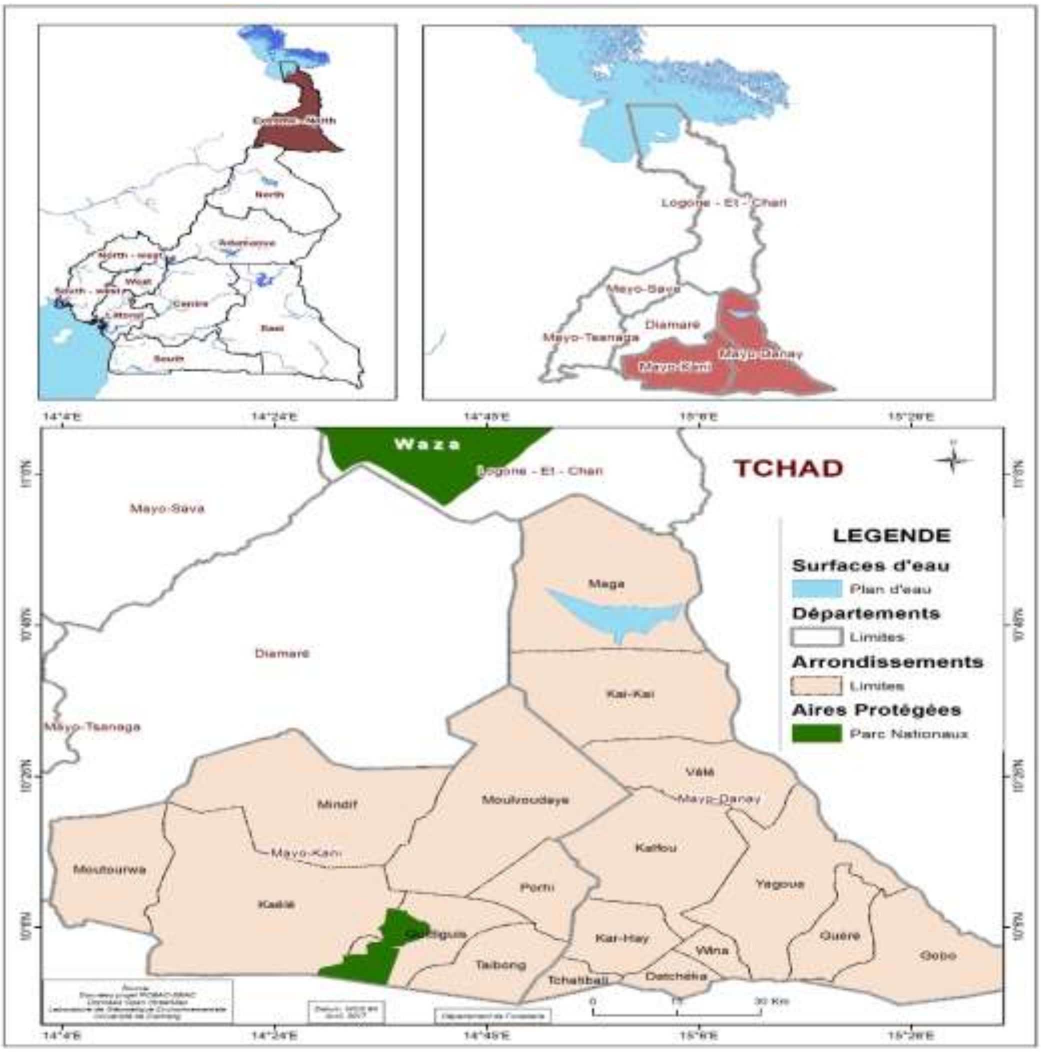

Figure 1. Localization of the study zones in the Far North Region of Cameroon

Data collection

Data were collected in fallows of different ages. Trees categories of fallow were defined according to the plantation age: 7-11 years; 12-16 years and 17 -21 years. A total of 21 designs were sampled. The number of plots per age vary from 6 to 8. In each plot, an experimental design consisting of 3 concentric square plots was used. The tree biomass was estimated in plots of 2500 m² (50 m x 50 m), those of bushes in plots of 100 m² (10 m x 10 m), and that of herbaceous plots in 1m ² (1 m x 1 m) as shown by figure 2. A square block of 15 cm side and 15 cm deep was used to extract soil sample at the center of each 1 m x 1 m subplot.

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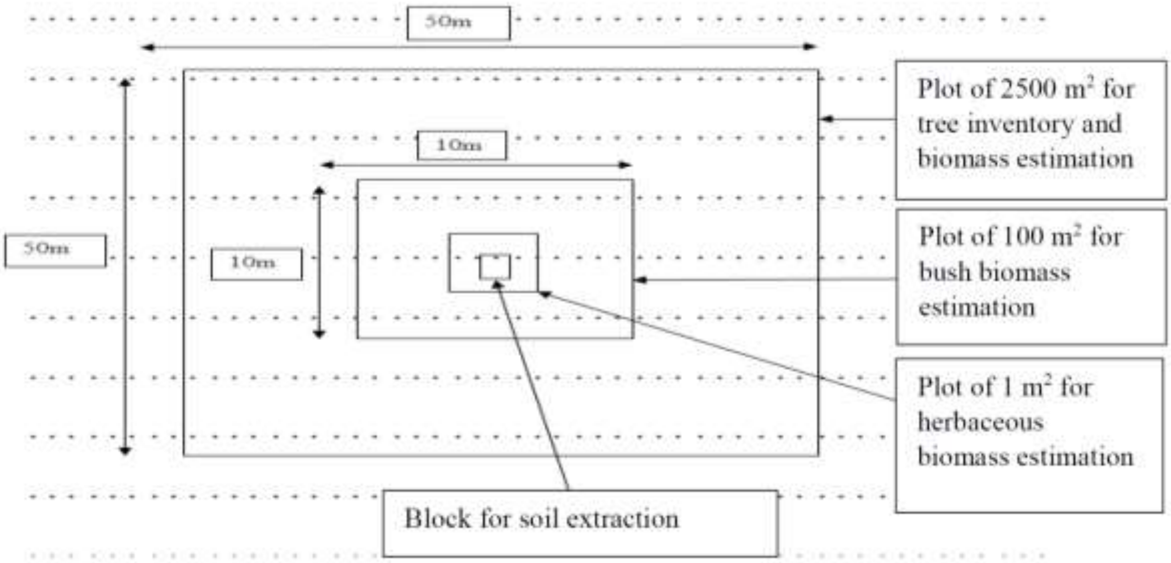

Figure 2. Sampling method for data collection

In the 50 m x 50 m plots, all woody individuals with at least 10 cm diameter at 0.5 m from the ground were counted. The inventory took into account the floristic composition (different species present in the plots), the circumferences of trunks at 0.5 m from the ground and the trees' heights measured by a graduated pole. In plot of 10 m x10 m plots, all bushes were cut to the ground and weighed. A subsample was taken and its wet mass determined by weighing. All herbaceous plant in the 1 m x 1 m subplot were cut to the ground. The total herb mass was determined by weighing and a subsample taken. This subsample was then dried in an oven and the dry mass noted down.

To estimate the bulk density of the soil, the total wet mass of soil sample was determined by weighing. Samples were then dried in the laboratory in an oven at 105°C for 48 hours until the dry mass became constant.

To obtain the percentage of organic matter, the dry matter was brought to the muffle furnace until the complete disappearance of carbonaceous particles. Samples were burned to a cinder at 550°C. After calcination, capsules were cooled down and weighed. For each sample three repetitions were made and the average considered.

DATA ANALYSIS

Floristic structure of fallows

The characterization of the floristic structure was done by determining parameters such as: the woody floristic richness, the diametric structure, the density and the survival rate of trees.

Species richness is the number of species in a stand. Number of family and number of woody species present in each plot was determined as well as the number of individuals of each species.

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Density (D): The density is the number of individuals per hectare. It is evaluated by the formula:

$$D = N/S \qquad (1)$$

With: D the density (stems/ha), N the number of stems present on the considered surface and S the area considered (ha).

Diametric structure of woody species: The trees were divided into diameter class, and histograms of distribution of the stems were developed to characterize the diametric structure of the vegetation. Five classes of amplitude equal to 5 cm diameter were established. These classes were [5–10[, [10–15[, [15-20[, [20-25[, [25 and more.

Survival rate: The survival rate is the ratio of the number of dead trees to the number of trees planted.

Biomass and Carbon stocks estimation

Aboveground biomass

The tree biomass (Bt) was estimated according to the specific allometric equation for *Acacia senegal* developed by Smektala *et al.* (2002) in the savannah zone of Northern Cameroon:

$$Bt = 443{,}929 \text{ x } C^{2{,}3783} \qquad (2)$$

Where: Bt is the aboveground trees biomass (kg) and C the circumference of the tree at 0.5 m from the ground (m).

For the estimation of bushes biomass (Bb) and herb biomass (Bh), the following equation was used:

$$Dry\ mass = \left(\frac{\text{Dry mass of subsample}}{\text{Fresh mass of subsample}}\right) * \text{Fresh mass of entire sample} \qquad (3)$$

Total aboveground biomass (AGB) is the sum of the tree biomass (Bt), bushes (Bb) and herbs (Bh). It was calculated according to the formula:

$$\text{AGB} = \text{Bt} + \text{Bb} + \text{Bh} \qquad (4)$$

Belowground biomass

Estimation of below ground biomass followed the guideline established by Kaire *et al.* (2013). It is obtained using the equation:

$$BGB = \exp^{(-1{,}0587+0{,}8836*\ln\ (\text{AGB}))} \qquad (5)$$

Where: BGB is the belowground biomass (kg) and AGB the aboveground biomass (kg).

Carbon from biomass

From this biomass, the amount of carbon stock (kg/ha) is obtained by multiplying the biomass by a conversion factor of 0.5 (Kaire *et al.*, 2013); then it is converted into ton of carbon per hectare (tC/ha).

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$$C = (AGB + BGB) \times 0.5 \quad (6)$$

Where: C is the carbon stock of biomass (tC/ha), AGB the aboveground biomass (kg), and BGB the belowground biomass.

Soil Carbon (tC/ha)

Amount of soil carbon was estimated from the bulk density of soil and organic matter content according to the following formula:

$$Cs = (\mathrm{Db} * \%\mathrm{OM} * 0{,}58 * \mathrm{H})/100 \quad (7)$$

Where Cs is the amount of soil carbon, Db, bulk density of soil and H, depth of the block of soil and OM the organic matter content.

The bulk density of the soil is calculated from the total dry mass, the depth and the side of the block of soil dug in the following manner:

$$\boldsymbol{Db} = \mathrm{MST}/(\mathrm{L}^2 * \mathrm{H}) \quad (8)$$

Where: Db is the bulk density (g/cm^3), MST, total dry matter, L, side of soil block (cm); H, depth of the block (cm).

The organic matter of the sample is calculated according to the formula:

$$\%OM = \left(\frac{(\mathrm{Ms}-\mathrm{Mc})}{\mathrm{Ms}}\right) * 100 \quad (9)$$

Where: % OM is the percentage of organic matter in the sample, Ms, mass of the sample after drying at 105°C and Mc, mass of the sample after calcination at 550°C.

Total amount of carbon

Total carbon stock (tC/ha) is the sum of the amount of carbon of all the components (above-ground and below-ground biomass and soil).

$$TC = C_{AGB} + C_{BGB} + C_S \quad (10)$$

Where TC is total carbon; C_{AGB}, carbon from the aboveground biomass, C_{BGB}, carbon from the belowground biomass and C_S, soil carbon.

Ecological value

Estimated total carbon stock (tC/ha) was converted into equivalent tons of CO_2 (tCO_2/ha) absorbed using the ratio 44/12 corresponding to ratio CO_2/C. To obtain the monetary value, the equivalent tons of CO_2 were multiplied by the average price of carbon credit estimated at \$10/tCO_2 (Ecosystems Marketplace, 2016).

Statistical analysis

Data analysis was performed with SPSS 20.0 software. One-way analysis of variance (ANOVA) was used to find whether the age of fallow has an effect on floristic structural parameters, biomass, carbon stock and ecological value.

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RESULTS AND DISCUSSION

Floristic characteristics of fallows

Eight (08) woody species belonging to 7 genera and 4 families were identified in fallows (table 1). The most represented family is the Fabaceae with four species (*Acacia Senegal*, *Acacia seyal*, *Faidherbia albida* and *Prosopis africana*). The dominant species is *Acacia senegal* with 97.70% of the individuals, followed by *Azadirachta indica* (1.15%), *Faidherbia albida* (0.63%) and *Balanites aegyptiaca* (0.24%). Although the main fallows species is *Acacia senegal*, other species are introduced and/or preserved for their socio-economic values (wood production, food and medicinal value). The Number of species present in fallows is similar to that of 5 to 9 found by Wala *et al.* (2005) in the agroforestry parklands of Doufelgou in Togo.

Table 1: Woody floristic richness of fallows

Species	Family	Percentage of individuals (%)
Acacia senegal L. (Willd.)	Fabaceae	97.70
Azadirachta indica A. Juss	Meliaceae	1.15
*Faidherbia albida (*Del.) A. Chev.	Fabaceae	0.63
Balanites aegyptiaca (L.) Del.	Balanitaceae	0.24
Acacia seyal Del.	Fabaceae	0.096
Eucalyptus camaldulensis Dehnh.	Myrtaceae	0.096
Hyphaene thebaica (L.) Mart.	Arecaceae	0.049
Prosopis Africana (Guil et Perr.) Taub.	Fabaceae	0.049

Structural parameters of fallows

Structural parameters such as densities, heights and diameters of the different fallows are recorded in table 2.

Table 2. Structural parameters of *Acacia senegal* improved fallows

Age category (years)	Planting density (trees/ha)	Current density (tree/ha)	Survival rate (%)	Average height (m)	Average diameter (cm)
[7-11]	621±177a	400 ±137a	62±0.14b	4.07±0.98a	12.5±2.2a
[12-16]	552 ±179a	352±78a	64±0.14b	5.05±1.00a	13.2±4.1a
[17-21]	550 ±129a	462±157a	79±0.06a	5.34±1.39a	13.7±4.2a

Values within the column followed by the same letter are not significantly different ($P > 0.05$)

Initial planting densities vary from 417 to 834 trees/ha with averages within age categories ranging from 550 to 621 trees/ha. There is a large difference in planting spacing that range

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from 4 m x 3 m to 5 m x 5 m. Although plantations with 4 m x 4 m spacing are the most common, some farmers do not respect this recommendation. Current densities are lower than planting densities due to the death of some trees. Survival rate is greater than 60% with the highest value (79 %) observed for [17– 21] years old fallows. In most cases, the refilling that consists of replacing dead trees was not done after planting. Survival rate of trees of [17-21] years old fallows is similar to that of 80 % found by Harmand *et al*. (2012). This gives a reason to believe that the first plantations made in the region have benefited from better technical supervision by the forestry and research services. This was not the case for the youngest plantations.

The heights of trees range from 4 to 5.34 m and diameters from 12.5 to 13.7 cm. Trees of [12-16] and [17-21] years old fallows recorded the best performances in diameter and height. However there is no significant difference in the age categories ($P > 0.05$). The small variation would be due to the fact that *Acacia senegal* reaches its optimum of growth around the age of 12. The average heights are similar to those of 4.2 and 5 m obtained by Thiam *et al*. (2014) in Senegal respectively for 9 and 12 years old trees. They are also in the range of 4 to 6.30 m reported by Harmand *et al*. (2012) for trees 8 to 13 years after planting.

The diametric structure of the vegetation resulting from distribution of trees into five classes of 5 cm diameter interval is presented in figure 3.

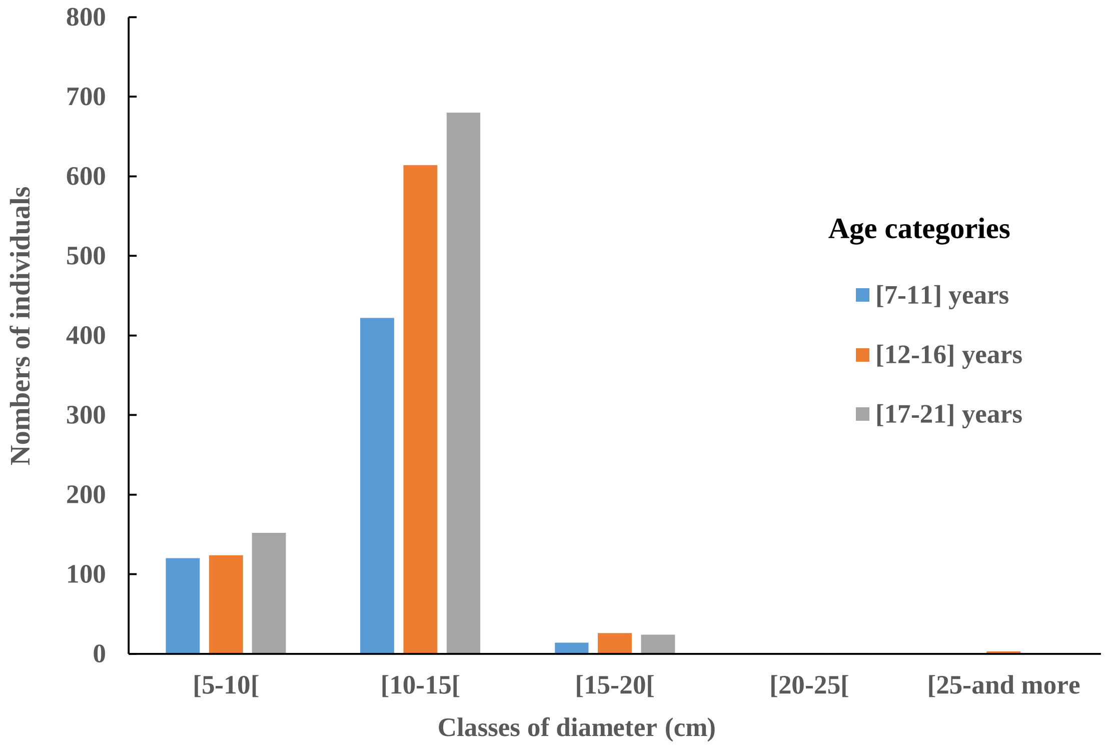

Figure 3: Diametric structure of *Acacia senegal* improved fallow

Overall, the distribution of trees within the different diameter classes showed bell-shaped form with distribution at the left side indicating a predominance of individuals with small diameters

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in the stands. The most abundant individuals were found in the diametric class of [10-15 [cm. This class corresponds to the average diameter class. The diameter classes which dominate the studied populations is a characteristic of Sudano sahelian vegetation. Trees of larger diameters are rare. Trees with diameters greater than 20 cm are very few (6 individuals) and belong to species beside *Acacia senegal*, notably *Balanites aegyptiaca* and *Eucalyptus camaldulensis*.

Aboveground and belowground biomass of fallows

Aboveground biomass was assessed for trees, bushes and herbaceous plants. It is highest (36.21 t/ha) for the age category [17-21] years old and lower for the age category [12-16] years old (19.18 ± 6.66 t/ha) as shown in table 3.

Table 3. Aboveground and belowground biomass of *Acacia senegal* fallows

Age category (years)	Biomass (t/ha)		
	Aboveground biomass AGB (t/ha)	Belowground biomass BGB (t/ha)	Total
[7-11]	19.80 ± 11.66	4.77 ± 2.51	24.53±14.17
[12-16]	19.18 ± 6.66	4.53 ± 2.45	23.71±9.20
[17-21]	36.21 ± 26.12	8.51 ± 5.94	44.47±32.01

Values within the column followed by the same letter are not significantly different (P > 0.05)

Table 3 shows that the amount of belowground biomass varies from 4.53 t/ha to 8.51 t/ha. The lowest amount of biomass in fallows of age category [12-16] years is related to the density of trees that is also lower in this age category. Analysis of variance showed however, that, there was no significant difference in total biomass ($p > 0.05$) in the different age categories. This amount of biomass is lower than that of 356.13 t/ha and 776.47 t/ha found by Lieunang (2013) respectively in *Acacia angustissima* and *Calliandra calothyrsus* improved fallows in western Cameroon. This difference is related to the estimation method used, but especially to the very high density of these fallows (more than 5000 stems/ha). Table 4 shows the distribution of aboveground biomass in the different pools.

Table 4. Distribution of aboveground biomass (t/ha) in different pools

Pools	Biomass (t/ha)	% Aboveground biomass
Trees	30.83±19.73a	96.17a
Bushes	0.41±0.33b	1.29b
Herbaceous	0.81±0.76b	2.54b
Total	32.06±20.40	100

Values within the column followed by the same letter are not significantly different (P > 0.05)

Tree biomass was higher than that of bushes and herbaceous plants. It is 30.83 ± 19.73 t/ha and represents 96% of total aboveground biomass. That of bushes is the lowest, 0.41 ± 0.33 t/ha, representing 1.29% of total biomass. The three pools of biomass differed significantly ($p < 0.05$). The difference in biomass composition is largely due to the vegetation structure of the fallows with greater abundance of tree species.

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Carbon storage

The amount of carbon was evaluated in aboveground and belowground biomass and in soil (table 5).

Table 5. Carbon stock in different storage pools

Age category (year)	Carbon stock (tC/ha)			
	Aboveground Carbon	Belowground Carbon	Soil Carbon	Total
[7-11]	10.01±5.15a	2.38±1.25a	67.78±29.69a	80.17±33.64a
[12-16]	9.60±5.65a	2.26±0.86a	89.24±9.68a	101.10±14.19a
[17-21]	18.11±7.21a	4.25±2.24a	81.60±16.37a	103.96±25.82a

Values within the column followed by the same letter are not significantly different (P > 0.05)

The aboveground carbon stock varies from 9.60 tC/ha for fallows of [12-16] years old to 18.11 tC/ha for those of [17-21] years old. These values are in the range of 7 to 43 t C/ha reported by Albrecht and Kandji (2003) for fallows and 11 to 32 tC/ha found in cashew agro-ecosystems by Noiha *et al*. (2017) in Northern Cameroon. The belowground carbon stock varies from 2.26 to 4.25 tC/ha. There is no significant difference between aboveground and belowground carbon stock at different ages. The large amount of carbon stored in the systems is found in tree biomass and soil. The soil has accumulated significant amounts of carbon range from 67.78 tC/ha to 89.24 tC/ha. Soil carbon accounts for more than 2/3 of the total amount of carbon in different fallow age categories. This carbon results from the decomposition of leaves, branches, fruits, and root rot over the years.

The total carbon stock varies from 80.17 to 103.96 tC/ha. Although the trend is seen to be an increase in carbon stocks with age, this variation is not significant ($p>0.05$). Our results corroborate those of Palm *et al*. (2000) who reported a carbon stock of 64 to 131 tC/ha for 25 years old fallows in the humid tropics. However, our results are lower than those of Lieunang (2013) due to the very high density of trees and shrubs in fallows land in western Cameroon, which gives them a higher biomass.

Ecological value of *Acacia senegal* improved fallows

Amount of CO_2 absorbed from the atmosphere by *Acacia senegal* improved fallow is presented in table 6.

Table 6: Amount of CO_2 absorbed and ecological value of *Acacia senegal* improved fallows

Age category	Carbon stock (tC/ha)	Amount of CO_2 (tCO_2/ha)	Ecological value (US$/ha)
[7-11]	80.17±33.64a	294.22±123.45a	2942.24±1234.77a
[12-16]	101.10±14.19a	371.03±52.07a	3710.37±520.77a
[17-21]	103.96±25.82a	381.53±94.75a	3815.33±947.60a

Values within the column followed by the same letter are not significantly different (P > 0.05)

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Table 6 shows that the amount of CO_2 absorbed varies from 294.22 tCO_2/ha for fallows of [7-11] years old to 381.53 tCO_2/ha for those of [17-21] years old. Ecological value corresponding to carbon sequestration ranges from $ 2942/ha for fallows from [7-11] years old to $ 3815.33/ha for those of [17-21] years old. Statistical tests show that the difference is non-significant ($p > 0.05$) in the different age categories. This ecological value is higher than that of cashew agrosystems (Noiha *et al*., 2017) but is lower than that of Eucalyptus agrosystem (Noiha *et al*., 2018) and *Acacia angustissima* and *Calliandra calothyrsus* improved fallows (Lieunang, 2013).

The amounts of money that would result from the sale of carbon stored in *Acacia senegal* improved fallows as CO_2 emission offsets are higher than the revenues that would be derived from the sale of wood and gum arabic estimated by Kissi *et al*. (2013) at $ 1300 and $ 930/ha, respectively. These amounts are economically significant and could be considered in case of payment for environmental services under the clean development mechanism as a good source of income for fallow landowners, but also an incentive for sustainable management of trees and the revival of *Acacia senegal* plantations in the Sudanian zone of Cameroon.

CONCLUSION

Acacia senegal improved fallows are agroforestry systems that are not very diversified in woody species. Farmers in addition to *Acacia senegal* introduce in fallows a reduced number of species for food, medicinal and wood production. Over the years, fallows have accumulated a large amount of carbon in plant biomass and soil. They contribute to the fight against climate change. The ecological value of fallows is greater than the production of gum arabic and firewood. The ecological service linked to carbon sequestration offers a possibility of financial benefits in case of payment for ecosystem services. Farmers through the clean development mechanism projects could have access to the carbon credit market. This option would be an opportunity to improve the living conditions of farmers and an incentive for the plantation of *Acacia senegal* which is in decline due to the slump of gum arabic.

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