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Comparison of carbon stocks in *Acacia senegal* and *Acacia seyal* stands in Chari - Baguirmi region (Chad)

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Abstract

Acacia senegal and *Acacia seyal* have an important role in environmental balance in arid and semi-arid regions of sub-Saharan Africa through their carbon sequestration. However very little information on the carbon stock of the gummeraies are available. The purpose of this study is to estimate the carbon stock of *Acacia seyal* and *Acacia Senegal* stands in Chari-Baguirmi region of Chad. In each of two Acacia stand, the carbon stock was estimated in 18 plots of 50 m x 50 m, by the indirect method. The experimental design was a randomized block with 18 repetitions. The two (02) Acacia stands were the treatments. Soil carbon was estimated in 54 plots of 47.10 m^2, at three depth levels (0-30, 30-60 and 60-90) in each of the 2 Acacia stands. The results show that the aboveground and root carbon stock were significantly higher in *Acacia seyal* stand (14.77 and 3.45 tC/ha) than in *Acacia Senegal* stand (8.04 and 2.02 tC/ha). On the other hand, the soil carbon stock was not differed significantly between the 2acacia stands (123 and 102 tC/ha) but varied with soil depth. The carbon stock was influenced by the types of Acacia stands for the plant compartment, but not the soil type in Baguirmi department.

Keywords: *Acacia senegal*, *Acacia seyal*, Carbon stock, Chari-Baguirmi, Chad.

Introduction

Gum trees, including *Acacia senegal* and *Acacia seyal*, belong to the family Mimosaceae according to the classical classification, or Fabaceae according to the phylogenetic classification. Globally, African species dominate in the Sahelian zone (Giffard, 1965). They grow on different types of soils (Bodil *et al.*, 2005) and are endowed with ecological plasticity that allows them to grow in several ecological zones (Nongonierma, 1978). This ecological plasticity gives the Acacia genus an increased environmental interest in drylands because its hardiness put it at the forefront of indigenous species for land use planning and the fight against desertification (Fagg *et al.*, 1990). Moreover, not only for restoring the fertility of degraded soils thanks to their nitrogen fixing power and their easily degradable litter, but they also contribute in solving the problems of climate change by the fixing of carbon dioxide.

In Chad, the area of distribution of gum trees is the dry intertropical zone, located between latitudes 11° and 17° north, and between isohyets 150 mm and 900 mm/year (Baohoutou, 2007). The Chari-Baguirmi region is one of the 9 regions of the production of gums in Chad. The two main species cultivated in this region are *Acacia senegal* and *Acacia seyal*. However, the first species that produces hard gum grows on sandy soils of ancient dunes and the second that produces crumbly gum prefers clay soils and clay-siliceous often flooded during the rainy season (Cabot, 1965). It invades abandoned land and can be found in scattered groves in the Sahelo-Sudanian zone of Chad (Cabot, 1965). The two species not only play a major socio-economic role for the Chadian populations, especially those in the Chari-Baguirmi region by supplying firewood, energy, medicine, food products of men and animals, sources of reviews, etc. (Gueye *et al.*, 2012), but also that of the environment, since these vast sets of gums represent a carbon reservoir potential that can contribute significantly to the carbon balance of soil and atmosphere, and flow of it (Delmas *et al.*, 1991). However, gum trees have long been ignored, and most of the available carbon balance data are generally for forest ecosystems (Houghton, 1995).

The gummy savannas of Chad, particularly those in the Chari-Baguirmi region, as well as the other Sahel gummy savannas, have not been spared from anthropogenic pressures and climatic hazards (Coulibaly, 1989). Because population growth has led to overgrazing, overexploitation of gum trees, a reduction of their regeneration by trampling and increased and anarchic harvesting of wood in the gums, because gum trees produce very good firewood (Obeid and Seif El Din, 1971). Added to this are the episodes of drought, which caused hecatombs among the gum trees in the Sahel countries, particularly in Chad, including the Chari-Baguirmi region (Coulibaly, 1989).

In order to evaluate the contribution of gum trees and the impact of their degradation on the global carbon cycle and the amount of soil organic matter, it is essential to acquire data as sources of carbon. The aim of this study is to estimate the carbon stored in the *Acacia senegal* and *Acacia seyal*, which are important of the natural vegetation of the Chari-Baguirmi region.

Materials and Methods

Study site

This study was conducted in the Baguirmi Department of the Chari-Baguirmi Region (Figure 1). The study area covers an area of 15.300 km² and stretches in length between 10° 34' and 12° 26' North and between 15° 48' and 17° 40' East. The climate is Sahelian, with a rainy season (June-October) and a dry season (November-May). The average annual precipitation is 636.23 mm, the average annual temperature is 35° C (Baohoutou, 2007). The dominant soils are subarid brown soils on sandy materials, poor in mineral nutrients, soils hydromorphouslimono-clay or sandy-clay dominated by congestion and halomorphic soils (Cabot, 1965). The vegetation of the Chari-Baguirmi region is a shrub savanna with the characteristics of the Sahelian zone where prickles predominate. The dominant species are *Acacia senegal*, *Acacia seyal*, *Acacia nilotica*, *Acacia albida*, *Balanites aegyptica*, *Prosopis africana*, *Ziziphus mauritiana*, *Ziziphus spina-christi*, etc. (Cabot, 1965).

To characterize the carbon pool in the savannas of the Chari-Baguirmi region, two predominant facies of this vegetation were selected. It is a gummy savanna with *Acacia senegal* and a gummy savanna with *Acacia seyal*, located on sites of the same topography, but with different physiognomy, structure and specific vegetation composition. These sites are not disturbed.

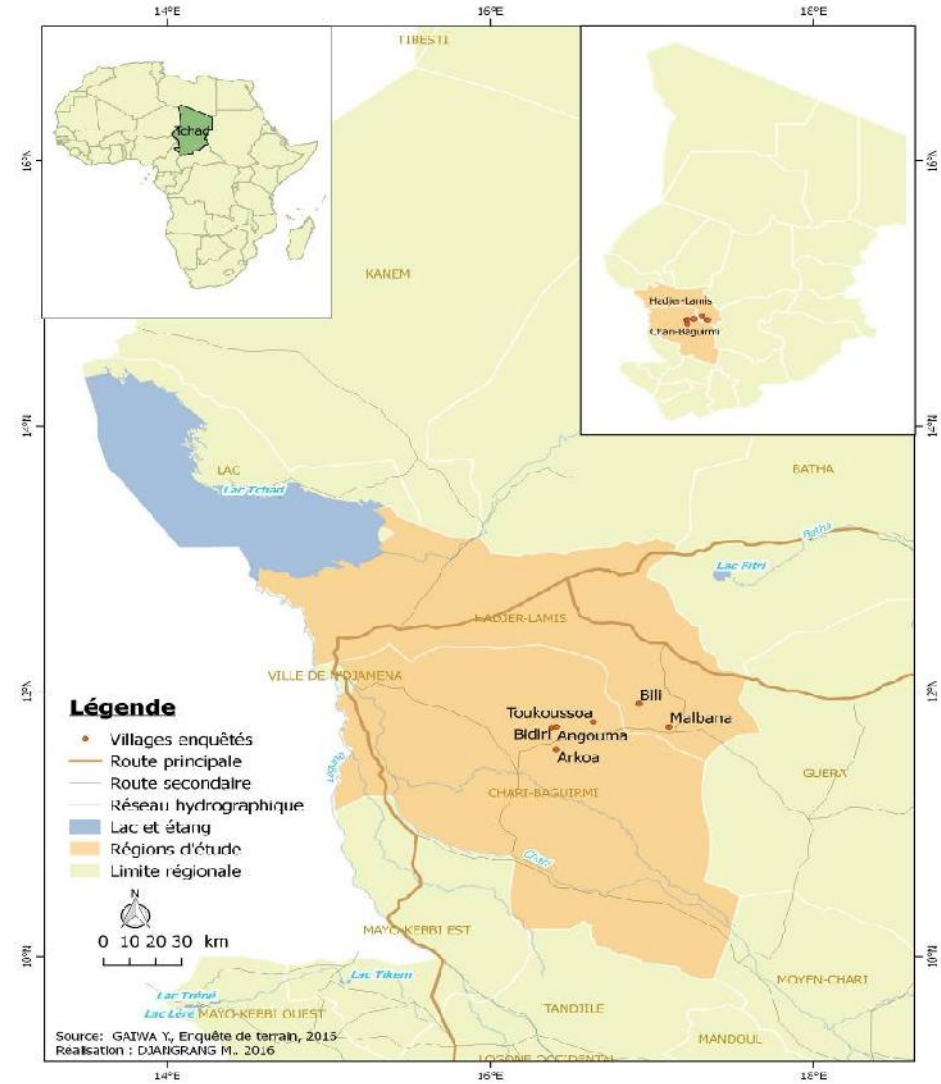

Figure 1: Map of the study area

Measuring biomass

The phytomass measurement was carried out in eighteen (18) plots of 2500 m2 (50 m x 50 m) in each type of gum sands. To minimize spatial heterogeneity, the plots were not far apart. In these plots, the biomass of trees, shrubs, roots and soil density were determined according to the method of Anderson and Ingram (1993). During the determination of biomass, floristic composition and specific names were determined. The experimental device used is a completely randomized block with 6 repetitions. The types of the gums (*A. senegal* and *A. seyal*) are the treatments and the plots the repetitions. The experimental unit consists of 3 plots.

Aboveground biomass

The biomass of the trees was estimated in plots of 2500 m^2. All trees with a breast height diameter (DBH) greater than or equal to 5,01 cm and a height greater than or equal to 3 m were considered as all trees. The trees have been inventoried. Their diameter at breast height (at 1.3 m from the ground) was measured respectively with a tape measure. The biomass of the trees was estimated by the indirect method, using an allometric model, taking into account the parameters of the tree (DBH sound). Among the equations used, that used by FAO (1997) and Saidou *et al.* (2012) was chosen because it was developed under Sahelian climate conditions and the coefficient of determination between tree biomass and diameter is highly significant (R2 = 0.987):

Ba (Kg) = exp (-1.996 + 2.32 * Ln (D))

Where Ba is the biomass of trees in kilograms, D is the DBH (cm) of the tree. This biomass was then expressed in tonnes per hectare (t/ha).

The biomass of shrubs and regenerations was estimated in plots of 2500 m^2. All trees with a diameter greater than 5 cm in diameter and all those with a diameter at base less than 4 at 5 cm were considered to be all-woody shrubs. The height of the shrubs varies between 2.99 m and 1.5 m and that of the rejects is between 1.49 m and 0.3 m. These shrubs have been inventoried. Their basal diameter was measured using a tape measure and that of the rejects by calipers. Shrub biomass was estimated by the indirect method, using an allometric model, taking into account the parameters of the shrub (DBH sound). Among the equations used, the one used by Segura *et al.* (2005) and Saidou *et al.* (2012) was chosen because it was developed under Sahelian climate conditions and the coefficient of determination between shrub biomass and diameter is highly significant (R2 = 0.987)

Bs = exp (-1.27 + 2.20 IogD)

Where Bs is the shrub biomass in kilograms, D is the diameter (cm) of the shrub.

Belowground biomass

Root biomass was estimated by the indirect method, using an allometric model developed by Cairns *et al.* (1997) who showed that from the above-ground biomass, the biomass of the roots (Br) can be obtained by the following equation:

Br (Kg) = exp (-1.0587 + 0.8836 * Ln (Bt))

Where Br is the biomass of the roots and Bt is the total biomass of the trees in kilograms. This biomass of the roots was then expressed in tonnes per hectare (t/ha).

Soil sampling

In each of the eighteen (18) plots of 50 x 50 m of each gum plantation, three (3) circular subplots of 15 m in diameter were delineated. In each sub-plot, four soil blocks 2.15 dm^3 [((0.955 dm) 2/4) x 3.14 x 3 dm] were extracted using 9.55 cm diameter auger, three soil depth levels (0-30, 30-60 and 60-90 cm). These four blocks were blended to form a single composite sample for each level of soil depth. After wet weighing, a subsample of 700 g was taken to calculate the water content and bulk density of the soil.

All soil subsamples (54 = 18 x 3) were returned to the soil-water-plant analysis laboratory of the Chadian Institute for Agronomic Research for Development (ITRAD) in Ndjamena, Chad, in sacks. in plastics to be dried in oven at 105 ° C for 48 hours, that is to say until a constant dry weight. The water content (TE %) of soils relative to the dry mass of all subsamples was calculated according to the following formula TE (%) = [(MH-MS) / MS] x 100; where MH is the wet mass and MS is the dry mass.

From the water content of the soil subsamples, the total dry masses of the soil samples were calculated as follows: MST = 100 x MHT/(100-TE), where MST is the total dry mass and MHT is the total wet mass.

From the STS soil samples, the bulk density of the soil (D, kg.m-3) was calculated as follows: D = MST/(sxe) where s is the auger surface and e is the depth of the auger each of the three levels.

Chemical analyses

Soil samples after reduction to powder using a Micro Hammer Mill Culatti mill, equipped with a 2 mm filter, were analysed in the laboratory mentioned above. The carbon concentration was determined by the Walkley-Black (2003). For vegetation, the 50% value of the currently accepted carbon concentration (Kotto-Samé *et al.*, 1997) and recommended by the IPCC (2003) was used.

Estimation of the amount of carbon

From the biomass (B) of the vegetation (fraction, component or category), soil density (D) and their carbon concentrations, the carbon quantities were calculated as follows:

QCv = B x C for vegetation
QCs = D x C x h for the soil

Where QCv is the amount of carbon in the vegetation, expressed in t / ha, QCs is the amount of soil carbon, h is the soil depth and is the carbon concentration (expressed as a percentage of dry mass).

The total amount of carbon in each gum plantation was simply obtained by summing the amounts of carbon from all components (aerial, root) of each type of vegetation and soil.

QC total = QC aerial + QC root + QCsoil

Data analyses

A Student provided a test of significance of biomass and carbon between gums lands (Acacia stands). These tests were conducted through SPSS software version 18.0.

Results and Discussion

Structure of the gum tree stands

Table (1) presents the parameters of the structure of the gums. These parameters vary according to gum plantations. The density of *Acacia seyal* (418 ind./ha) was significantly (P <0.001) higher than that of *Acacia senegal* (224 ind./ha). It follows from these results that in both gums, trees dominate, whose vegetation is deteriorating. The density obtained in the two gum plantations is lower than those reported by Kissi (2011) in plantations with *Acacia senegal*(0.40 ha) at 15 years old, which is 576 trees / ha in northern Cameroon. It is also lower than that found by Temgoua (2018), which varies between 417 to 834 trees / ha in gummy fallows in Far-North Cameroon. In both gums, the stand is homogeneous (98.79% and 97.94%). The survival rate of our two gums (95.91 and 91.18%) is still higher than that mentioned by Temgoua (2018) in fallows aged 17 to 21, whose survival rate is greater than 60%, the highest is 79%. This survival rate obtained is also higher than that found by Harmand *et al.* (2012), which is 80% in *Acacia senegal* plantations in northern Cameroon.

Table1: Parameters of the structure of the gum

Gommeraies	Densities(ind.ha)			Parameters	
	Trees	Shrubs	Total	Height	DHP
A. senegal	206 ± 30,81	18 ±5,36	224±31,27	6,27 ±0,98	14,11
A. seyal	367 ± 85,49	51 ±11,84	418±90,33	7,23 ±1,01	13,28
t-value	6,86***	9,83***	22,47***	2,64*	1,29 ns

ns: not significant; * P<0,05; *** P < 0,001.

The height of *Acacia senegal* gum trees varies from 0.5 to 13.4 m with an average of 6.27 m and that of *Acacia seyal* is from 0.5 to 12 m with an average of 7.23 m (Table 1). There is no difference between the average height of two gums. Those results are superior to these reported by Ismaila (1994). According to him, the gum is a shrub that does not often exceed 6 meters high. The average heights obtained are always higher than those of Thiam *et al.* (2014), which vary between 4.2 and 5 m in Senegal respectively on trees aged 9 to 12 years and those of Harmand*et al.* (2012) in the range of 4-6.30 m on 8-13 year old trees in the *Acacia senegal* plantation in the Sudanian zone of Cameroon. Kissi (2011) noted that the gums are hardly more than 7 meters high. The differences observed between our study and those of the previous authors are explained by the fact that they studied plantations contrary to our study which is carried out in natural stands.

The diameter at breast height (DHP) of *Acacia senegal* gum plantation varies between 1.23 and 31.21 cm with an average of 14.11 cm and that of *Acacia seyal* gum plantation is from 1.32 to 33.51 cm with an average of 13.28 cm. There is no significant difference between the averages DBH of two gums. Our values are in agreement with those of Pierre (2005) who showed that the DHP of gums can exceed 30 cm in diameter. Temgoua *et al.* (2018) reported DHP values ranging from 12.5 to 13.7 cm (figure 2).

The diametric structure of two gums trees revealed a bell curve distribution or normal distribution, with dominance of individuals in the class of 10 to 15 cm. Individuals of small and large diameters are poorly represented. These results can be explained by the pressure of the animals on the young plants due to their small sizes or by the anarchic exploitation of the old individuals by the producers of the gum.

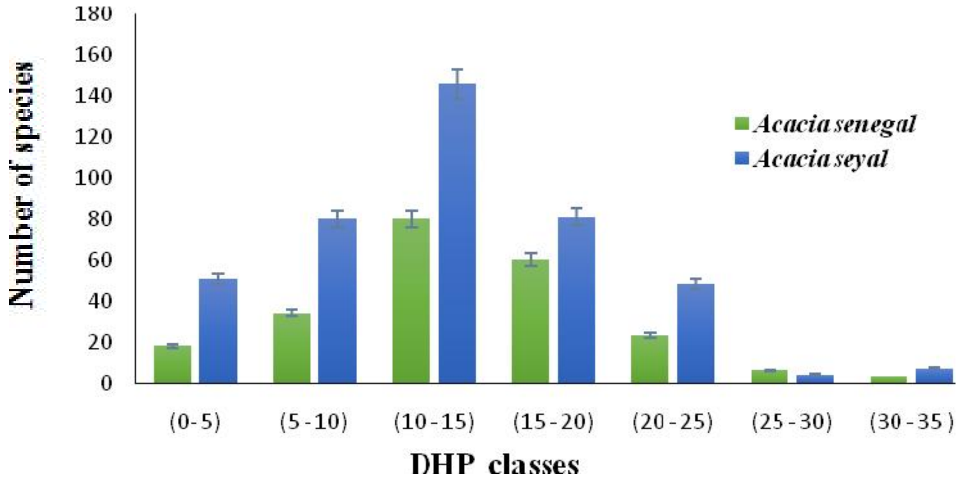

Figure 2: Diametric structure of gum

Plant biomass

Tree biomass varied significantly (P<0.001) between species (Table 2). It is higher in *Acacia seyal* (29.49 t/ha) than in *Acacia senegal (*16.05 t/ha). This indifference is due to the attack suffered by the *Acacia senegal* during the operations of the bleeding, which leads to the decrease of the production.

Biomass shrubs of two species (*A. senegal* and *A. seyal*) are very low (0.03 and 0.04 t / ha) compared to trees (Table 2) and represent between 0.14 and 0, 19% of the total aerial biomass. This low shrub biomass can be explained by higher anthropogenic pressures on shrubs than on trees. In fact, overgrazing, cutting and bush fires are mains factors. Between the two species, there is no significant difference for biomass.

Total aerial biomass was 16.08 and 29.53 t/ha for *Acacia senegal* and *Acacia seyal* (Table 1), respectively, and different (P <0.001) between gum plantations. The total aerial biomass of *A. seyal* is greater than one and a half times that of *A. senegal*. Stands of *A. senegal* are much more in demand by riparian populations for the high production of great quality energy wood than those of *A. seyal* which produce low quality gum. In addition, the density of the *Acacia senegal* (224 plant/ha) stand is lower than that of the *Acacia seyal* stand (418 plant/ha).

The biomass values obtained in our study are among the low values reported by Temgoua *et al*. (2018) for *Acacia senegal* in fallow land dominated 97.70% by *Acacia senegal* and 0.09% by *Acacia seyal* in the savannahs of the Far northern Cameroon region. Indeed, the values reported by these previous authors vary between 19.18 and 36.21 t/ha respectively for fallows of 12-16 and 17-21 years. Similarly, Kissi *et al.* (2013) found a total aerial biomass of 66.96 t/ha for a plantation of *Acacia senegal* in the Sudanian savannahs of Ngong, North Cameroon region. These low values obtained in our study are explained by the fact that our study is carried out in the Sahelian zone with low productivity. In addition, stands of Acacia are much in demand in the Sahel by animals for fodder and man for energy wood and work and the production of gum by anarchic bleeding that decimate these stands. Beside this there is also the impact of recurrent bush fires. On the other hand, in the studies of Temgoua *et al.* (2018) and Kissi *et al.* (2013) are the peasant plantations of *Acacia senegal* been maintained and rationally exploited and maintained at a density varying between 352 and 462 individuals per hectare.

Root biomass varies between Acacia stands (Table 2). It is 4.03 and 6.90 t/ha respectively in the *A. senegal* and *A. seyal* stands. They are very low in relation to total biomass and represent 18.94% and 21.37% of total plant biomass. These values of the total root biomass of the gums are found in the lower part of the values (0.3 - 30 t/ha) reported by Serpentier and Ouattara (2000) for the savannahs under a tropical climate with a long dry season. Temgoua *et al.* (2018) reported slightly lower values for underground biomass than ours. They are from 4.52 to 8.51 t/ha for fallow ages between 12-16 and 17-21 years in the savannahs of the Far North Cameroon region. Like above-ground biomass, *Acacia seyal* plant root biomass was significantly (P<0.001) higher than that of *Acacia senegal*. This pressure from riparian harvesting also affected the underground part of *Acacia senegal* stands.

The total biomass of Acacia is variable from 20.12 to 36.44 t/ha, respectively, for the *Acacia senegal* and *Acacia seyal* stands (Table 2). These values are slightly lower than those reported by Temgoua *et al.* (2018) for fallow land dominated by *Acacia senegal* and *Acacia seyal* stands in Far North Cameroon. These slight differences are due to the different anthropic pressures on stands in two regions of two countries (Chad and Cameroon).

Table 2 : Biomass of plants

Gommeraies	Trees	Shrubs	AGB	BGB (roots)	Total biomass
A. senegal	16,08 ± 2,98	0,03 ± 0,011	16,11 ± 2,99	4,03 ± 0,662	20,12 ± 3,64
A seyal	29,53 ±4,88	0,04 ± 0,018	29,57 ± 4,89	6,90 ± 1,005	36,44 ± 5,89
t-value	9,11***	2,73*	9,08***	9,27***	9,12***

* P<0,05; *** P < 0,001.

Plant carbon

The aerial carbon stock sequestered by gum plants varies significantly (P<0.001) between the two stands of *Acacia senegal* and that of *A. seyal* (Table 3). *Acacia seyal* sequestered more carbon (14.77 tC/ha) than that of *Acacia senegal* (8.04 tC/ha). The variation in the carbon stock between the two stands varies according to their density, which is higher in *Acacia seyal* than in *Acacia senegal*. The carbon stock sequestered by trees confirms the important role of ligneous species in carbon sequestration (Jarkko *et al.*, 2000). The carbon stock reported in the studies of Temgoua *et al.* (2018) is in the order of 9.60 to 18.11 tC/ha for the plantations of *Acacia senegal* in Far North Cameroon. Similarly, Kissi *et al.* (2013) found a value of 16.49 tC/ha in a 15-year-old plantation in northern Cameroon. These values are slightly higher than ours and are explained by the fact that our study took place in the natural stands whereas these authors carried out their studies in the well maintained peasant plantations. On the other hand, our results show that the gum plantations store more carbon than the Shea park as Peltier *et al.* (2007) in his studies on the Shea park in North Cameroon (5.046 t C/ha).

The root carbon stock varies between the two species studied (Table 2). It is between 2.02 and 3.45 tC/ha respectively in *Acacia senegal* and *Acacia seyal* gum plantations. Analysis of the variance reveals that there is a significant difference (P<0.001) between the two gums. These values are slightly lower than those reported by Temgoua *et al.* (2018) in fallows dominated 98% by gum trees in the savannahs of Far-North Cameroon (2.26 and-4.25 tC/ha).

The total carbon stock of the plants varies significantly (P<0.001) between the two gum plantations studied (Table 3). It is higher in *Acacia seyal* (18.22 tC/ha) than in *Acacia senegal* (10.06 tC/ha). The carbon stock reported in the studies of Temgoua *et al.* (2018) is in the order of 11.86 to 22.36 tC/ha for *Acacia senegal* plantations in Far North Cameroon.

Table 3 : Plant carbon

Gommeraies	AGC	BGC	Total plant
A. senegal	8,04 ± 1,49	2,02 ± 0,33	10,06 ± 1,82
A seyal	14,77 ± 2,44	3,45 ± 0,50	18,22 ± 2,94
t-value	9,11***	9,24***	9,13***

*** P < 0,001.Aboveground carbon (AGC) and Below ground carbon (BGC)

Soil carbon

The soil carbon stock varies with the type of gum plantation and soil depth (Table 4). This stock decreases with the soil depth in the two gums, from 105.56 to 97.76 tC/ha and from 157.39 to 105.93tC/ha respectively in the *Acacia seyal* and *Acacia senegal* trees. The carbon stock in each of the 3 depths of the soil, as well as the total soil, is higher in *Acacia seyal* than in *Acacia senegal*. These results show that the total soil carbon stock did not differ significantly (P> 0.001) between the two species. Temgoua *et al.*(2018) found in the fallow gum trees of Far-North Cameroon, a value lower than ours, between 67.78 and 89.24. The soil carbon is 87.11 and 91.03% of the total value of the stock in the gum plantation. These results agree with those of Temgoua *et al.* (2018) who reported values of 78.50 to 88.27% for soil carbon in Ngong gummy fallows in North Cameroon.

Table 4 : Soil carbon

Gommeraies	Depth of soil			Total soil
	0-30	**30-60**	**60-90**	
A. senegal	105,56 ± 3,30	102,85 ± 1,40	97,76 ± 2,84	102,06 ± 3,54
A seyal	157,39 ± 4,92	105,93 ± 2,01	105,93 ± 1,94	123,08 ± 26,57
t-value	33,88***	4,86***	9,20***	3,03*

* P<0,05; *** P < 0,001.

Conclusion

The study, which aimed to estimate the carbon stock of gum and soil of the gum plantations in the Chari-Baguirmi region, shows that the aerial, root and soil carbon stock of the *Acacia seyal* (14,77; 3.45 and 123.08tC/ha) are higher than those of *Acacia senegal* (8.04; 2.02 and 102.06tC/ha). The carbon stock decreases with the depth of the soil. Soil is the reservoir of carbon because it represents between 70 and 80% of the total carbon stored in the gums. The *Acacia seyal* stand sequesters more carbon than the *Acacia senegal* one because of their differences in individual density and structure. These results show that, in addition to their important socio-economic role, the gum groves can sequester carbon for the improvement of soil fertility but also for the fight against climate change.

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