Agroforestry parklands and carbon sequestration in tropical Sudanese region of Togo

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Abstract

The aims of this research was to estimate total carbon stock of the agroforestry system in the Sudanese tropical region of Togo. Physical measurements (height, diameter, and tree density) of trees in major agroforestry parklands were carried out on random quadrat (900 m^2) samples. The total biomass carbon stock was computed following the tropical dry area allometric equation as suggested by Brown (1997). Results showed that recorded total carbon stock in agroforestry systems species in the study zone was 81.2 t ha^{-1} with *Adansonia digitata*, *Parkia biglobosa*, *Sterculia setigera* and *Vitelaria paradoxa* tree species respectively accumulated 34.7 t ha^{-1}, 20.1 t ha^{-1}, 8.4 t ha^{-1}, and 3.9 t ha^{-1}. The *A. digitata* parkland (mature one) has shown the highest total carbon stock (16.9 t ha^{-1}), whereas the low values occurred in young parkland (0.23 t ha^{-1}). Among the five parklands of the study zone, high carbon stock accumulated in Diameter at Brest Height (DBH) class ranging from [0-10] to [30-40]. The agroforestry system in the study zone could contribute to improving the functionality of the whole ecosystem by its substantial capacity to sequester carbon. In the context of reducing global warming with the objective to improve country income through the green and clean mechanism of ecosystems; agroforestry systems could be efficiently promoted by adhering to Reducing Emissions from Deforestation and Forest Degradation project (REDD+) and to clean development mechanism (CDM).

Keywords: Agroforestry, above-below ground biomass, carbon stock, Togo

Parcs Agroforestiers et séquestration du carbone en zone tropicale soudanienne du Togo

Résumé

La recherche vise à estimer le stock de carbone total du système agroforestier dans la région tropicale soudanienne du Togo. Les mesures physiques (hauteur, diamètre et densité des arbres) des arbres dans les principaux parcs agroforestiers ont été obtenues par un échantillonnage aléatoire du quadrat (900 m^2). Le stock de carbone de la biomasse totale a été calculé en utilisant l'équation allométrique adaptée aux régions tropicales sèches suggérée par Brown (1997). L'étude a révélé que le stock total de carbone mobilisé par les espèces des systèmes agroforestiers s'élève à 81,2 t ha^{-1}, tandis que les espèces d'*Adansonia digitata*, *Parkia biglobosa*, *Sterculia setigera* et *Vitelaria paradoxa* accumulent respectivement 34,7 t ha^{-1}, 20,1 t ha^{-1}, 8,4 t ha^{-1} et 3,9 t ha^{-1}. Le parc d'*A. Digitata* (mature) a présenté le stock de carbone total le plus élevé (16,9 t ha^{-1}) alors que les faibles valeurs ont été observées dans de jeunes parcs (0,23 t ha^{-1}). Parmi les cinq parcs de la zone d'étude, un stock de carbone élevé est accumulé dans les classes de DHP (Diamètre à Hauteur de Poitrine) allant de [0-10] à [30-40]. Le système agroforestier dans la zone d'étude pourrait contribuer à améliorer la fonctionnalité de l'ensemble de l'écosystème grâce à sa capacité substantielle de séquestration du carbone. Dans le contexte de réduction du réchauffement climatique mis en œuvre afin d'améliorer les revenus nationaux grâce à un mécanisme écosystémique écologique et propre, les systèmes agroforestiers pourraient être efficacement promus en adhérant aux exigences de la REDD + et aux mécanismes de développement propre.

Mots clés: Agroforesterie, biomasse Aero-souterraine, stock de carbone, Togo

INTRODUCTION

The sharp increase in the greenhouse gases in the atmosphere (particularly carbon dioxide) was considered by policy makers as a signal of climate change and led to organize the Kyoto summit (1997). Since the end of the 20th century, a great spontaneous interest on terrestrial carbon mitigation has occurred from different organized communities especially countries' government. Several options were proposed as tentative solutions, but the greatest challenge was to find efficient and low-cost method which can sequester atmospheric carbon without affecting countries' development (Montagnini and Nair, 2004).

Woodland sinks accumulate more carbon than any other terrestrial ecosystem and constitute an important natural means to monitor climate change (Gibbs *et al.*, 2007). However, in areas very sensitive to climate change like Sudanese and Sahel zones, agroforestry systems (which remain an important component of the landscape) are highly wooded in spite of the low percentage in cover of natural wooded vegetation. Agroforestry is commonly defined as a deliberate integration of trees into a field crop or livestock systems, in order to exploit synergies and complementarities between different structural elements of the system (Luedeling and Neufeldt, 2012). The agroforestry system has been known as an integrated approach to sustainable land use because of its production and environmental benefits. The conservation of existing agrosystems or the promotion of establishing it on land less covered by trees has been identified as key strategy to raise carbon stocks on currently productive land without compromising food and fiber production in dry zone of Sudanse regions (Nair *et al.*, 2009; Luedeling and Neufeldt, 2012).

In the ecological zone I of Togo, mainly dominated by savanna ecosystems, agroforestry systems activities are well integrated in socioeconomic landscape. Rural communities still use traditional knowledge to design the parklands. Woodlands are often moved to establish parkland. The

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parkland in most of the cases was a result of long-term land shifting with a selective preservation of few multi-purpose trees in the field. Most of the studies regarding these agrosystems were almost focused on their typology definition (Folega *et al.*, 2018; 2011). Complete research on these agroforestry systems productivity in terms of fruit productivity, biomass productivity or biomass carbon stocked, was not yet carried out. There is a great need to explore the contribution of these agrosystems as carbons sinks as worldwide attention is focused on carbon mitigation process through vegetation components. Estimates and records of the potential of the north Togo parklands as carbon sinks, as a component of reduced emissions from deforestation and forest degradation in the process of clean development mechanism (CDM), could substantially improve local community income and encourage them to promote the agroforestry techniques.

This study proposes was to estimate the above-below ground biomass and carbon stock of agroforestry parklands in Togo through the allometric equation designed for dry tropical zone. It aims particularly at evaluating the biomass carbon stored in agroforestry tree species, which belong to the major agroforestry systems typology of northern Togo.

METHODS

Study area

The study areas belong to the ecological zone I as defined by Ern (1979). It lies between 11°N and, 9°N latitude and between 0°E and 1°E longitude (Figure 1). The area is mainly occupied by spiny and Combretaceae savannas with some shrubs, wooded savanna and riparian and stream forests (Atakpama *et al.,* 2012; Badjana *et al.,* 2011). The elevation of the study area ranges between 200 m and 400 m ASL (Poss, 1996). The study area has the driest tropical climate with annual rainfall inferior to 1500 mm. The rainy season occurs from May to October, but the highest concentration of precipitation is found in August (Badjana *et al.,* 2011). Soils are leached ferruginous covering a cuirass, and hydromorphic sandy, clayey and muddy black soil in the rare valley of the plain (Poss, 1996). Croplands in the zone are almost associated with agroforestry species (*Parkia biglobosa, Vitellaria paradoxa, Adansonia digitata, Lannea spp*…), carefully selected by peasants during the farm establishment and conferred to the region a lead rang in endogenous agroforestry practices (Wala *et al.,* 2005). The sorghum, millet, peanut, cowpeas, maize and yams are the main crops; livestock includes poultry, caprine, cattle, donkey and sheep (Aleza *et al.,* 2015).

Agroforestry parkland in the study area

Agroforestry practices in Sudanese zone are well known by peasant and rural communities. The agroforestry parklands in this area of Togo as in Sahelian area are almost the result of long-term selective shifting of wooded vegetation by peasants (Boffa, 1999; Luedeling *et al.*, 2011; Wala *et al.*, 2005). During the process regarding the establishment of cropland, peasants deliberately preserve and promote the conservation of multipurpose tree species in the field. The process which achieves the design of parklands in the study area almost ends by the maintaining in the cropland of spontaneous edible fruit and/or feedstock tree species (Batawila *et al.*, 2007; Folega *et al.*, 2011). In this context, parkland are almost constituted by a mosaic of multifunction tree species. Agroforestry systems dominated by one or two species could express the oldness of the parkland and the degree of species selection during the different stage of selective shifting by the peasant (Nair, 1993).

In the study areas the following agroforestry systems (Photo 1) could be met:

- Homegarden almost dominated by *Adansonia digitata, Elaeis guineensis, Bligia sapida, Annona squamosa, Carica papaya*; are established around the concessions, and provide to the communities their immediate need.

- The agroforestry system dominated by one of the following species *P. biglobosa, A. digitata, L. microcarpa, V. paradoxa, B. aethiopum, E. guineensis, S. setigera*, and *T. indica* can be also quoted.

- Mixed parkland like *P. biglobosa* and *A. digitata*, *V. paradoxa* and *P biglobosa, V. paradoxa* and *S. setigera* often appeared in the Sudanian zone of the country.

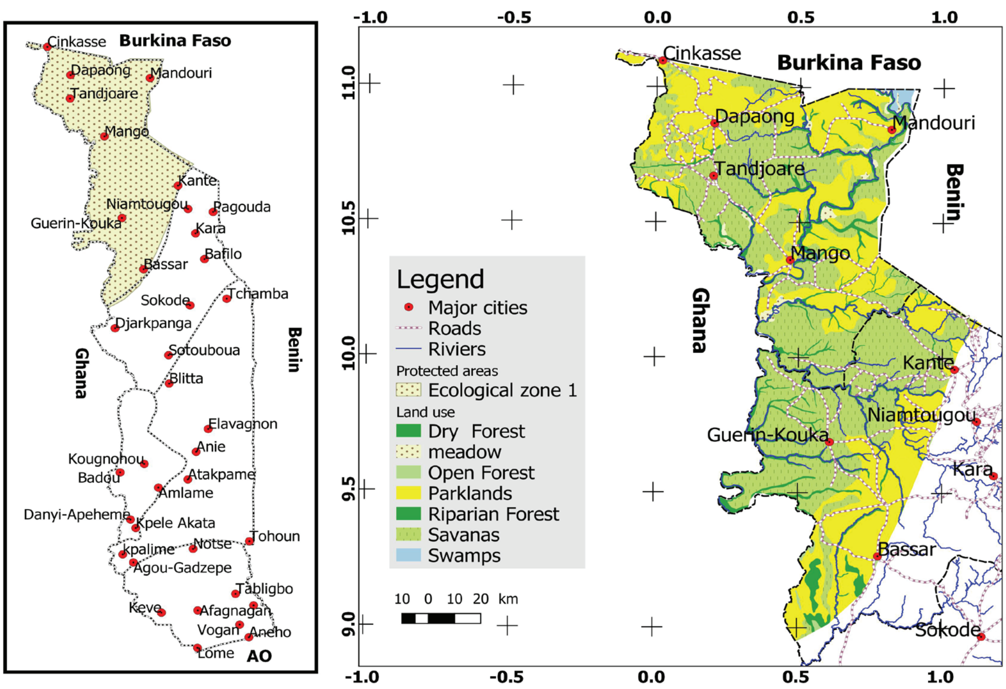

Figure 1: Study area

Data collection

The study was based on field data collection through physical measurement and field observation conducted from August 2009 to October 2010. The sampling was directed toward five major agroforestry parklands. Parklands dominated by *A. digitata*, *P. biglobosa*, *V. paradoxa*, *S. setigera* and young parkland dominated by several agroforestry and dry forest tree species were selected. The frequent major agrosystems present in the landscape and frequent quoted are led by the tree species mentioned above. The first three and the youngest parklands are well known for their economic value and their contribution in raising rural communities' income (Fifanou *et al.*, 2011; Kalinganire *et al.*, 2008; Ræbild *et al.*, 2012). The agroforestry system of *S. setigera*, in spite of having a high economic value potential (gum species) is unknown because of endogenous considerations (malefic tree) attributed by peasants (Atakpama *et al.*, 2012; Betti *et al.*, 2011). The choice of these five major agroforestry systems aims to explore and to assess their contribution in ecosystem carbon productivity balance.

In each agroforestry system, all trees with a circumference ≥ 10 cm at breast height (which is equivalent to 3.18 cm dbh) at 1.3 m from the base were measured in plots of 30×30 m in size (900 m^2). Their height was also measured followed by the identification of their scientific name.

The selection of 900 m^2 as the minimum sample plot area is justified by the fact that recently, it has been successfully used in Togo and its neighboring countries (Nacoulma *et al.*, 2011).

Data processing and analysis

Several allometric equations were identified to be useful for estimating the above ground biomass (AGB) of the individual belonging to the 83 tree species recorded. Both equations are dry tropical areas specific (Brown *et al.*,1989; Chave *et al.*, 2005). The model of equations developed by Brown et al. (1989) was found to be suitable for estimating the AGB (Above ground biomass)of trees' species in the study area. This model was developed and tested in dry deciduous zone which receives about 1200 mm/year of rainfall; but it can be applied to dry tropical areas where the annual rainfall is greater than 900 mm/year. The study area belongs to the dry tropical area where the annual rainfall ranges from 1000 to 1200 mm/year; tree height up to 15 m and, the dbh range from 5 to 40 cm. The climatic and forest structure parameter is well in line with those set by Brown et al. (1989) and could justify the use of this allometric equation in the framework of this study. The formula below was used:

$$Y = exp\,(-1.996 + 2.32\, ln\,(DBH))$$

(R^2 = 0.89, dry transition to moist (rainfall>900 mm))

Where Y is AGB in kg and DBH is in cm.

The allometric model mentioned above was used to determine AGB of each tree. So far literature quoted that this allometric equation almost suitable method for biomass carbon stock estimation in dry tropical areas where annual rainfall is higher than 900 mm (Schroeder *et al.,* 1997).

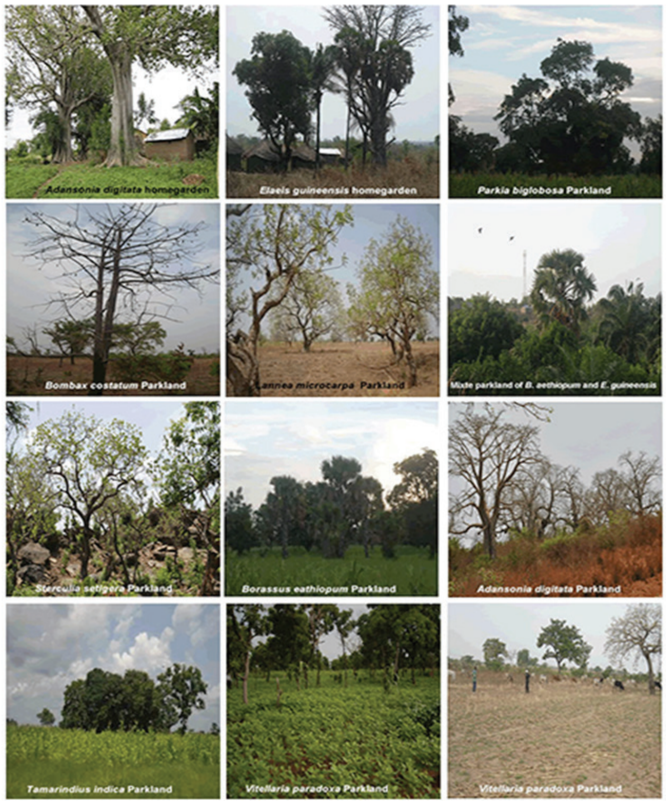

Photo 1: Frequent quoted agroforestry systems photo's in Togo

Below ground biomass (BGB) was calculated considering 15% of the AGB (Macdicken, 1997). The author found that for a conservative estimate of root biomass in forests would not exceed 10–15% of the AGB. Carbon stock as biomass was then calculated considering 55% of the total biomass (Juwarkar *et al.,* 2011). The calculation of carbon stock (CS), as biomass consists of multiplying the total biomass (TB) by the widely used conversion factor (0.55).

For all data of each agroforestry system, tree species average height (H), average diameter (DBH), density (D), basal area (BA), total biomass (TB), and carbon stock (CS) were calculated. Correlations between the above-quoted structure parameters were assessed followed by the comparison of the different agroforestry system types.

RESULTS

The five surveyed agroforestry systems are involved differently in carbon sinking balance. Their involvement is highly linked to their physical characteristics which differ from one to another.

Twenty-seven tree species were recorded inside the plots which belong to *A. digitata* parkland. Tree height ranges from 2 m to 19.5 m, with an average mean of 7.45 m. Tree densities of dominant species are observed among *V. paradoxa*, *B. aethiopum*, *T. indica* and *A. leiocarpa* trees. The parkland contributes 30.8 t ha^{-1} of carbon biomass sink. Trees with high potential of carbon stock are *A. digitata*, *B. aethiopum*, *K. senegalensis*, and *V. paradoxa* (Figure 2).

For *P. biglobosa* parkland, 33 tree species were recorded, with an average height of 7.91 m. High carbon stock is accumulated among *P. biglobosa*, *A. digitata* and *V. paradoxa* species. The average total biomass sequestrated by this parkland is estimated to 5.08 t ha^{-1}. Tree density in the parkland is evaluated to be 3.33 n ha^{-1}.

Twenty-eight tree species were identified to belonging to *V. paradoxa* parkland. The average height, density and basal area were 6.21 m, 6.41 nha^{-1} and 4.97 E-5 m^{2}ha^{-1}. The parkland accumulated a total biomass of 98.4 t ha^{-1} with an average estimated to 3.5 t ha^{-1}. *V. paradoxa, P. biglobosa, A. digitata, S. setigera* and *P. erinaceus* represent the tree species which sequestrated a large amount of carbon biomass in this parkland.

In the *S. setigera* parkland, 46 tree species were recorded. This floristic batch is characterized by an average height, density and basal area of 9.26 m, 1.97 n/ha and 2.08 E-5 m^{2}ha^{-1}. The global amount of carbon biomass sink by this parkland was estimated to be 72.4 t ha^{-1}, although the average total biomass accumulated by perennial ligneous species was 1.57 t ha^{-1}. The species with high potential of carbon biomass sink in this parkland were *S. setigera*, *A. digitata, P. biglobosa, B. aegyptiaca* and *A. indica*.

The young parkland is characterized by 4.66 m, 3.71 n/ha and 7.53 m^{2}ha^{-1} respectively, as average height, density and basal area. Fifty tree species were recorded in this parkland and accumulated a total biomass of 21.6 t ha^{-1}, with an average of 0.43 t ha^{-1}. Dry forest species represent the tree species which sequestrated much biomass carbon; among them can be quoted *P. erinaceus, D. oliveri, S. birrea, S. setigera* and *L. barteri*.

By comparing the average of total biomass and carbon stock in each agrosystem; the *A. digitata* parkland has the highest total biomass and carbon stock (30.8±23.4 and 16.9±12.9 t ha^{-1}, respectively), whereas the low values occurred in young parkland zones (0.43±0.12 and 0.23±0.06 t ha^{-1}). The *V. paradoxa* parkland and young parkland have shown the highest density (6.19±3.54 and 3.71±0.56 nha^{-1}, respectively). However, their basal areas, total biomass and carbon stock remained the lowest among the five agroforestry systems types.

For the five agroforestry parklands, five species at least represent more than 50% of total biomass and carbon stock (Table 1). In *V. paradoxa* parkland, apart from

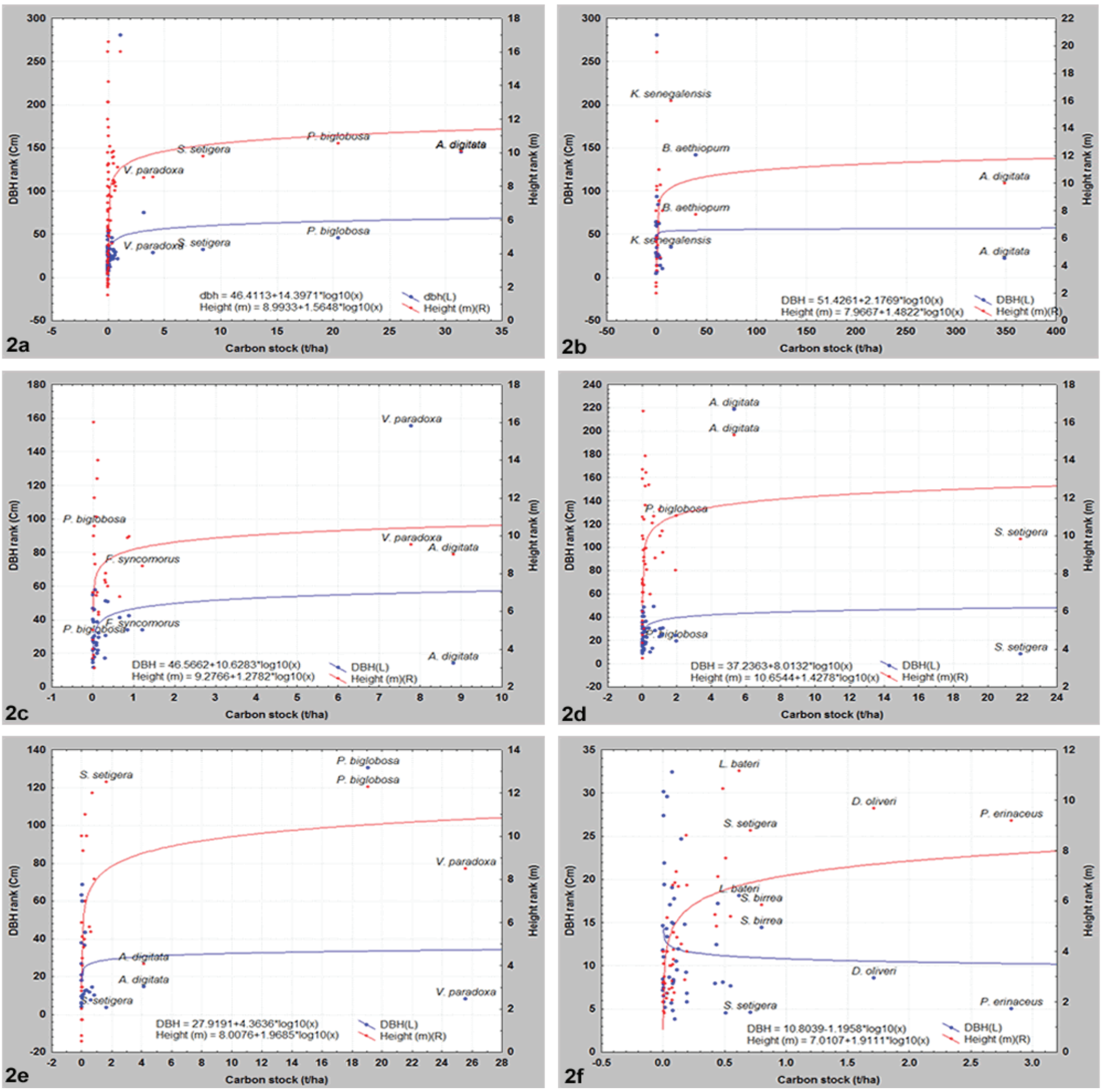

Figure 2. Relationship between tree species carbon stock and dbh and height rank

(2a: whole surveyed landscape, 2b: A. digitata parkland, 2c: P. biglobosa parkland, 2d: S. setigera parkland, 2e: V. paradoxa parkland, 2f: young parkland).

the dominant species, there are other major species (*A. digitata, P. biglobosa* and *S. setigera*). The *P. biglobosa* species did not occur in the batch of the first five species which contribute 50% of total biomass and carbon stock in *P. biglobosa* parkland.

In the study area, the highest total biomass and carbon stock are concentrated in individual tree which belongs to the batch of [40-50] and [>60] dbh classes (Table 2 and Figure 3a). The situation is a little different when exploring the amount of carbon stock per dbh class in the agroforestry parklands taken individually. The highest amount of biomass carbon is observed in [20-30] class in *A. digitata* parkland (Figure 3b), whereas in *P. biglobosa* park, highest biomass carbon values are accumulated in [10-20] and [>60] dbh classes. Some of *S. setigera, V. paradoxa* and young parkland dbh class of [0-10] have shown the highest value of carbon stock. However, in *V. paradoxa* and *S. setigera* parklands class of [>60] accumulated also important biomass carbon (Figure 3d and 3e).

In *P. biglobosa* parkland, it appeared that biomass carbon accumulated by all individuals with [10-20] diameter class is quietly similar to the amount sequestrated by all trees with [>60] diameter class. The same scenario can be observed in *V. paradoxa* parkland (Figure 3).

DISCUSSION

Forest has been recognized as a means to sequester atmospheric carbon dioxide as well as enhancing the global net primary productivity by also reducing CO_2 emissions. Agroforestry systems, in spite of having low ability to sink carbon than forest, present high carbon stock compared to monospecific croplands (IFDC-SWE, 2012). In African humid tropical region, the carbon storage was estimated between 29 and 53 t ha^{-1} (Murthy *et al.*, 2013); but for Cameroon crop-fallows parkland, the maximum amount was estimated to 167 t ha^{-1} in traditional long fallows landscape (Palm *et al.*, 2000).

In this study, the total carbon stock stored by tree tissues in agroforestry parkland has been estimated to be 81.2 t ha^{-1}; it is three times higher than the value obtained for coffee agrosystems growing in the open (22.9 t ha^{-1}) and less to that estimated in shade coffee systems (81 t ha^{-1}) (Dossa *et al.*, 2008). In coffee under shade (Togo) the carbon stock per year was estimated to 6.3 t ha^{-1} (Luedeling *et al.*, 2011), whereas in new parkland in Sahel it is estimated to 0.4 t ha^{-1} (Takimoto *et al.*, 2008). Through the information mentioned above, it highly implies that remarkable payments for carbon stock can be demanded per ha agroforestry system cover.

Table 1: Five species with more than 50% of biomass (t ha^{-1}) among parklands

Agroforestry Parklands	*A. digitata*	*P. biglobosa*	*S. setigera*	*V. paradoxa*	Young parkland
Adansonia digitata	634.6	16.03	9.65	7.53	
Azadirachta indica			2.22		
Balanites aegyptiaca			3.49		
Bombax costatum		1.55			
Borassus aethiopum	71.1				
Daniellia oliveri					3.11
Ficus sycomorus		2.22			
Khaya senegalensis	26.1				
Lannea kerstingii					1.12
Moringa oleifera	8.01				
Parkia biglobosa			3.58	34.7	
Prosopis africana		1.63			
Pterocarpus erinaceus				1.57	5.14
Sclerocarya birrea					1.45
Sterculia setigera			39.8	2.97	1.28
Vitellaria paradoxa	11.67	14.15		46.5	
Total	751.6	35.6	58.8	93.3	12.1
	96.2%	85.8%	79.1%	93.8%	55.7%

Table 2: Tree structure parameters and biomass carbon stock among the agroforestry parklands

Parklands	RS	H (m)		DBH (cm)		D (n/ha)		BA (m²ha^{-1})		TB (t ha^{-1})		CS(t ha^{-1})	
		M/SE	S	M/SE	S	M/SE	S	M/SE	S	M/SE	S	M/SE	S
A. digitata	27	7.45± 0.8	**	50.7±10.6	*	2.83±1.04	**	7.30±5.79	*	28.9±23.4	*	15.9±12.9	*
P. biglobosa	33	7.91±0.53	**	35.0±4.21	***	3.31±2.4	**	5.49±4.23	*	1.25±0.62	**	0.69±0.34	**
S. setigera	48	9.11±0.42	**	28.6±4.33	***	1.88±0.94	*	2.48±1.35	**	1.54±0.84	**	0.85±0.46	**
V. paradoxa	29	5.99±0.68	*	23.5±5.12	***	6.19±3.54	***	0.77±0.45	***	3.43±1.95	**	1.88±1.07	**
Young Parkland	50	4.66±0.34	*	12.3±1.02	**	3.71±0.56	**	0.61±0.16	***	0.43±0.12	**	0.24±0.06	**

RS: Specific richness, H: average height (m), DBH: average diameter (Cm), D: density (n/ha), BA: basal area (m²/ha), TB: total biomass (t/ha), CS: carbon stock (t/ha), S: significant level at 0.005 (variables with the same number of asterisks are similar), M: mean, SE: Standard Error of mean.

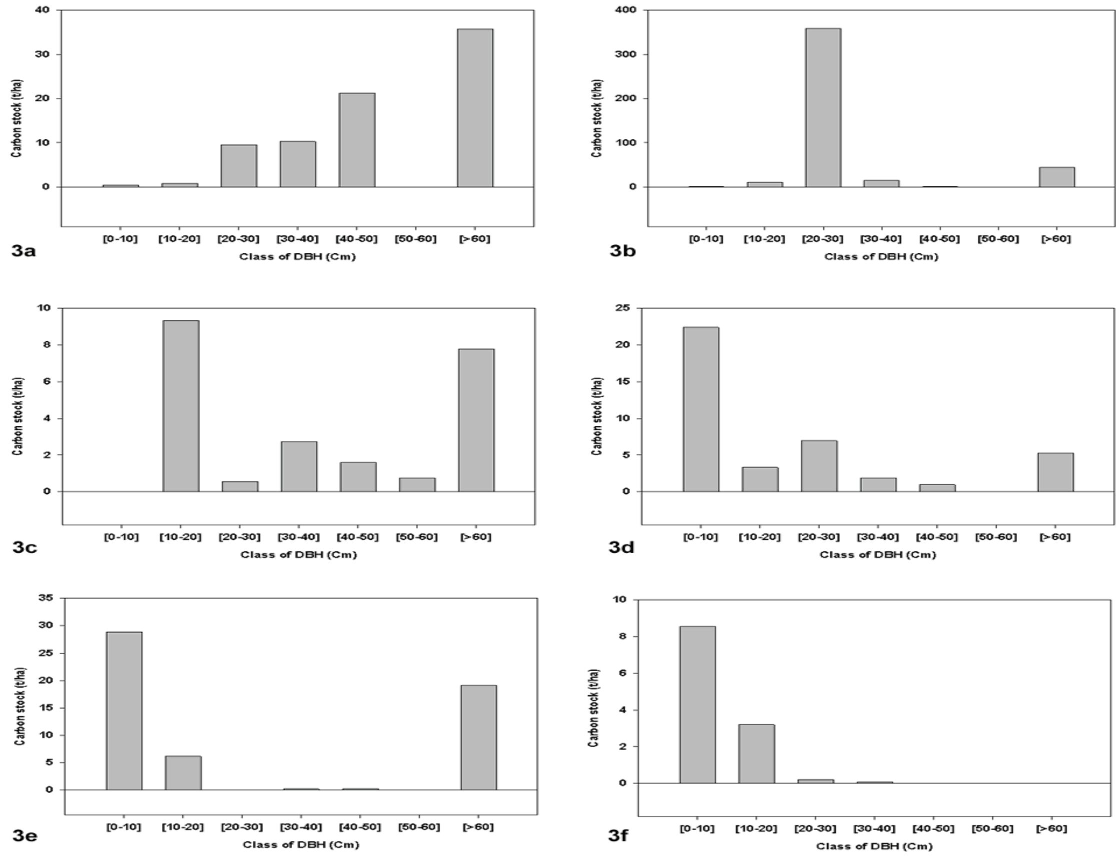

Figure 3: Carbon stock density per diameter class (3a: whole surveyed landscape, 3b: A. digitata parkland, 3c: P. biglobosa parkland, 3d: S. setigera parkland, 3e: V. paradoxa parkland, 3f: fallows zones).

The 147.7 t ha^{-1} estimated as the overall contribution in carbon biomass among agroforestry systems in the study areas was based only on tree physical measurements. The involvement of these agroforestry systems in total biomass carbon sinking could be more important if all the components of the parkland were taken into account. Based on previous results, a given parkland made of crops and trees could produce the amount of biomass carbon which ranges from 16.5 to 18 t $ha^{-1}yr^{-1}$ (IFDC-SWE, 2012). That can confirm the place and high functionality of agroforestry parkland in basic carbon cycle, in the context of areas very sensitive to climate change as Sudanian and Sahel zone. By contributing to mobilizing this modest amount of biomass carbon in this Sudanian area of Togo, the parkland with the perpetual traditional management system is involved in maintaining several ecological and environmental services.

In *V. Paradoxa* parkland 1.93 t ha^{-1} of biomass carbon for 6 trees/ha was measured; this value is four times inferior to that obtained (7.5 t ha^{-1}) in northern Cameroon (Peltier *et al.*, 2007). Comparing the average carbon stock of the major parkland in the study area, only *A. digitata* parkland (16.9 tha^{-1}) has an amount of carbon stock higher than the value estimated in smallholder agroforestry systems of sub-Saharan Africa (3.92 tha^{-1}). Parkland almost contributes to increase and enhance soil cover, structure and productivity. Gnankambary *et al.*, (2008) showed that litter generated from the leaves of two species has high decomposition rates. Regarding the result of this study; parkland with high specific richness may be more helpful to ensure ecosystems service such soil fertility and soil carbon stock quick improvement than agroforestry systems with few perennial species.

A strong relationship between tree's diameter, height, density and above ground biomass can be observed. The similar finding was found out in several previous research on above-below biomass estimation (Juwarkar *et al.*, 2011; Zeng *et al.*, 2010). In the five parklands of this study, high carbon stock is accumulated in dbh class ranging from [0-10] to [30-40]. The *S. setigera, V. paradoxa* and young parkland showed high proportion of individuals with class diameter ranging from 0 to 10 cm; their contribution in total carbon stock could be more efficient in the ecosystem in the future if some measures of conservation and sustainable management were employed. Although *A. digitata* and *P. biglobosa* parkland seem old compared to other parkland, the significant proportion of individual with high diameter classes could still improve their total carbon stock production by reducing pressure on seedlings and regeneration process in these parklands. Some authors found that old parkland may have an overall positive effect on associated crops while younger trees do not (Bayala *et al.,* 2011).

Agroforestry practices have a long history in Sudanian and Sudan-Sahelian transition zone. In most of climatic and environmental sensitive zones of Togo, traditional agrosystems are integrated patterns of landscape and mostly represent woody areas after open forest (Luedeling *et al.*, 2011; Wala *et al.*, 2005). Comparatively, the global average of carbon storage in parklands of Sudanian zones (Togo) would be relatively lower than other wooded natural vegetation. Key research on agrosystems contributions in ecosystem function confirm that they can have indirect effects on carbon sequestration as it helps decrease pressure on natural forests that are the largest sinks of terrestrial carbon. Agrosystems can also conserve soils and thus enhance carbon storage in trees and soils (Luedeling *et al.*, 2011; Murthy *et al.*, 2013).

CONCLUSION

The results from this study showed that agroforestry system in northern Togo has substantial carbon stock capacity. These capacities can be improved if both traditional and modern practices can be employed in the framework of sustainable management of parklands. Agroforestry practices could be an open door to promote the development of peasants' activities and remain a simple way to improve their income by receiving funds for carbon sequestration. The biomass carbon stock evaluation obtained in this study can encourage administrators to analyse global carbon credit inside parklands. It can be helpful to improve the agroforestry resources in Togo and in countries with the same environmental conditions in the framework of clean development mechanism (CDM).

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