

Carbon Sequestration of Tree Species in Different Vegetation Formations of the Sudan Ecological Zone of Mali

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SUMMARY:

This study is a contribution to estimating the carbon sequestration capacity of tree species in different vegetation formation of the Sudan ecological zone of Mali. It was conducted in the Dioïla area of the region of Koulikoro. Both primary and secondary data were used for this study. Hence, Primary data has been generated from the use of forest inventory questionnaire sheets and phyto-ecological questionnaire sheet while the secondary data has been generated from the Technical Service of Water and Forests of Mali. The stratified two-stage sampling method was used to collect data. Tree measurements (dendrometrical inventory) and phyto-ecological measurement were performed in the four vegetation formations encountered in the study area. Different analysis software's were used for data analysis (SAS, R 3.2.2 software). The amount of carbon sequestered varies according to the vegetation formations area. The agro forestry parks/fallow is the formation that has the largest amount of carbon (12,091,159.49 tons). Carbon sequestration capacity of the four vegetation formations was estimated at 159.75 metric tons of carbon. The carbon sequestration capacity is higher in woody savanna and arborous savanna than in other vegetation formations (agro forestry / fallow parks and shrubby savannah). The tree species carbon sequestration is different from one vegetation formations to another. The species *Vitellaria paradoxa* has the higher carbon sequestration capacity in vegetation formations of Park agro forestry/Fallow (11.087t.C.ha⁻¹) and of arborous savannah (9.5t.C.ha⁻¹). While in the vegetation formation of the shrubby savannah *Daniellia oliveri* has the higher carbon sequestration capacity with a quantity of 4.04t.C.ha⁻¹. The amount of carbon sequestered is correlated to trees circumference and tree species number per family. It would be interesting to conduct a long-term experiment to study and a better understanding of the carbon sequestration capacity of tree species of Sudan ecological zone of Mali.

Key word: Carbon, Sequestration, Tree Species, Sudan zone, Mali.

I. INTRODUCTION

Biological resources, including vegetation, occupy a very important place in people's lives and survival. In Africa, peoples get most of their subsistence needs (food, energy, medicines...) from these resources. In Mali about 90% of peoples' needs are met by vegetation exploitation (Konaté et al., 2001). This exploitation affects the production and productivity of the different formations and therefore their carbon stock tanks. Forests, which are important reservoirs of carbon, by their biomass, are continuously burnt. The repeated burning and anthropogenic disturbances can cause vegetation to lose a significant portion of the carbon stored for centuries (Laporte, 2010).

The ecosystem of Mali, a Sahelian country, is rich

and hold varied tree species, which are heritage to preserve. These ecosystems are subject to significant deterioration, due to combined effects of climatic and anthropogenic disturbances (Meateu, 2000). Most of the ecosystems are fragile and soils are generally poor. Also, the natural vegetation production is low and gradually decreases because of human exploitation. So, carbon sequestration is an important way to attenuate the effects of climate change on plant production and productivity (ILWAC, 2013).

The vegetation of the Sudan zone is mainly savannah ecosystems: grassland, shrubby land, savannah, woodland, gallery forest, open forest. The grassland cover is dominated by annual and perennial grasses (PIRT, 1986). The structure and composition of the vegetation present is thus mainly dictated by plant accessibility to water resources. The presence of

different trees species is therefore governed by the capacity of the soil to preserve a sufficient level of water (Le Houerou, 1984). However, this water dependent organization is altered by human activities that exert substantial and constant pressure on the vegetation formation (Depierre and Gillet, 1971; Delwaulle, 1977; Hiernaux et al., 1999).

In the Sudanian zone in Mali, we identified four vegetation formations where the potential product is reducing under human pressure as in farming and fuel-wood attraction (Dube and pickup, 2001; Sekhwela, 2003; Dembélé et al., 2005). These activities affect carbon sequestration potential of the formations. Also, this scenario has often been investigated in the context of fuel-wood energy policy of Mali (Amélie, 2006; Leys, 2011; Borough, 1998). The carbon sequestration of different formations has been widely studied (Gray, 2015; Tung, 2010; ILWAC, 2013). Carbon sequestration by trees species has been less frequently addressed (Amélie, 2006; Akbari, 2001).

This paper, focus on the carbon sequestration by the different formations and in each formation by tree species. The vegetation formations types in the Koulikoro region (Dioïla circle), in the southern part of the Soudan ecological zone of Mali, were the subject of tree species inventoried.

This study sought to advance knowledge on the carbon sequestration in the vegetation formations of Sudan ecological zone in Mali. The main aim of this study was to help in improving knowledge about the amount of carbon sequestered by tree species of vegetation formations in the Sudan ecological zones of Mali.

II. MATERIAL AND METHOD

Research design for this work on the carbon sequestration capacity of tree species in different vegetation formations of Sudan ecological zone in Mali, was basically a field based on field survey in which several data equipment such as: GPS, tailor tape, pole of six meters, data sheets etc. were deployed for data acquisition handling and management.

2.1. Study area

Mali is a landlocked country in West Africa, located between 10 ° and 25 ° North latitude and between 4 ° East and 12 ° West, with an area of 1,241,238 km² (fig1). The prevailing wind is the North-East trade wind. A part the republic of Niger, Mali is the largest state in West Africa. It extends for considerable distances 1500 km from north to south and 1,800 km from east to west (Ballo, 2005). Two-thirds of its area (about 61%) is occupied by the dry areas (MEATEU,

2000), where most of the territory is desert. On the rest of the country, almost 30% is affected by desertification.

The Sahelian nature of Mali justifies its present in the Inter-State Committee for the Fight against Drought in the Sahel (ICFDS) by (Dembélé et al., 2004). The comprehensive inventory conducted as part of the establishment of the general situation of biodiversity in Mali (2000). There are essentially five major ecosystems types that are: Sahara; Sahel; Central Niger Delta; Sudanian Zone; North-Guinean Zone. These zones, including those Mandingo Plateau, the Upper Bani Niger, Central Niger Delta, Gourma and the Adrar of Ifoghas, (Meateu, 2000). They are of great interest because of the potential of biological importance they harbor.

This study was carried out in the Sudan zone specifically within the Dioïla Circle in Koulikoro region at the extreme south of the Sudan zone of Mali (fig1). This choice is not only because of its strategic position in the Sudan Zone in Mali. But also, of the importance of its vegetation and multiple anthropogenic disturbances. It is located in the Southeast part of Koulikoro region with an area of 12,794 km², an estimated population of 387,565 and a density of 30.58 in habitants / km². The dominant ethnic groups are the Bambara, the Somono, Bozo, Fulani and Marka (USAID, 2012).

The climate is hot and humid Sudanian type, with high average annual rainfall which can reach up to 800 mm / year. The average annual temperature is 26.9 ° C with a maximum of 31.9°C at March-April. Soils are mainly five types: gravelly, sandy loam, clay loam, sandy and clay in the depression areas. Abundant vegetation is mainly savannah ecosystems (grassland, shrubby land, savannah, woodland, gallery forest, open forest). Agriculture is the main activity of populations in this area, with major crop types being: sorghum, cotton, maize and rice (Figure 1).

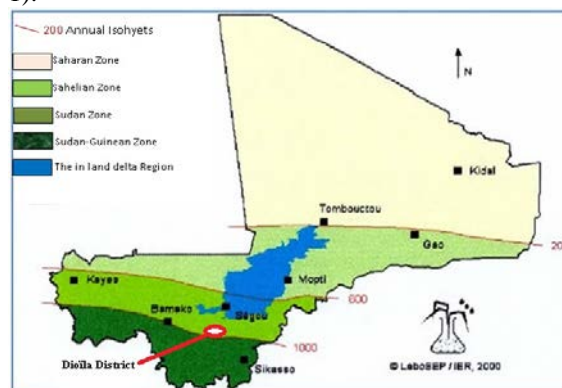


Figure 1 : Map of Eco-climatic zones of Mali (IER, 2000).

2.2. Field Survey

The quantitative data related to the diversity, diameter of breast height, height, and composition of

different tree species in the different vegetation has been used. Two sources of data namely primary and secondary have been used. Primary data has been generated from the use of forest inventory questionnaire sheets and phyto-ecological questionnaire sheet while, the secondary data have been generated from the Service of Water and Forests in Mali. Also, from any others information sources related on the different vegetation in the Sudan zone in Mali.

2.2.1. Sampling frame

For data collection, a stratified two-stage samplings method was adopted due to the availability of time and resources. However, it has been identified that the different types of vegetation had already been carved out from the vegetation formation on vegetation map of OCS 2013. We extracted the area of interest from this map to identify the different vegetation formation.

This map was produced as a way to minimize the variability of variables as much as possible to estimate stem density per hectare and to measure the volume of timber. Each different type of vegetation is represented as a group of strata. In entire six (6) vegetation formations were noted. According to the reality in the study zone, the study area was limited to four (4) vegetation formations with 1602 strata on an area of 1,247,917 hectares (Figure 2).

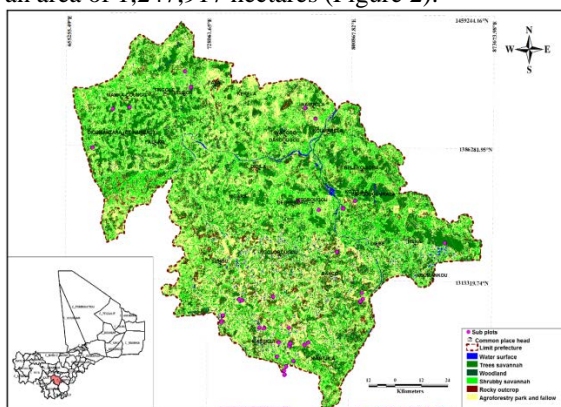


Figure 2 : Map showing the different plots in red.

2.2.2. Survey technique

The circular plots and subplots were chosen according to the ecological conditions in the study area and the type of inventory. The diameter of the plot was set at 250 meters and that of subplots at 50 meters with a radius of 25 meters. The area of the subplots is 0.19625 ha corresponding to 1962.5 m² well, above the minimum of the area 1000m² (Sylla, 1987). Each plot consists of five subplots with an area of 0.98125 ± 1 hectare (fig3).

On the demarcation of the major round of sub plot for inventory the center was located by using GPS (fig2). The field assistant was placed in the center and another took one end of the cord whose length was adjusted to the radius of the plot or subplot. The other

field assistant took the other end of the cord and went round making out a line round the boundaries of the plot or subplot. Once the plots and subplots were made, data collection was performed (figure 3).

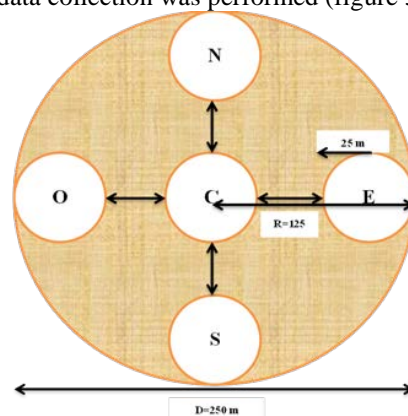


Figure 3 : Forms and dimensions of sampling plot.

NB: N=North; E= East; S= South; O= West; R=Layer; D= Diameter.

2.2.3. Data collection technique

To measure the various trees parameters, two methods of data collection were used; the Phyto ecological inventory and forest inventory/dendrometry.

(i) Phyto-ecological inventories

The method of phyto-ecological inventories was adopted to determine the composition and diversity of vegetation formation in the area. This inventory reflects the woody stratum and that of herbaceous plant were identified in each inventory plot. Indeed, on the survey of each plot to investigate census was made to cover all the surface of the each plot. Different plots tree species were systematically identified and counted while taking into account the environment of the communities living species (health status of species, logging, climate, soil, etc...).

(ii) The forest inventory or dendrometric inventory

For the evaluation of woody plant biomass, dendrometric inventory in each inventory plot for each plant formation was undertaken.

In each unit plot inventoried, each stem having a basal circumference greater than or equal to 10 cm, the circumference at the base (C0, 0), the circumference to height (C1, 30) and the total height (H); were measured. Choosing this basal circumference greater than or equal to 10 cm, were explained by the fact that the rods having this size and larger are used as wood fuel. In contrast, all stems having a basal circumference of less than 10 cm were rejected. These measurements have been made using the tailor's tapes and forestry calipers.

(iii) Height measurement

The height measurement was done using a graduated pole of 6 meters for each individual tree. Individual's species that exceed 6 meters heights have been estimated electronically with the measuring apparatus Suunto.

2.2.4. Calculation of tree species carbon sequestration

Tree species carbon sequestration was calculated in two stages:

(i) Calculation of tree species biomass

✓ Calculation of aboveground biomass

According to the inventory, the volume of wood or aboveground biomass of each species was determined based on the formula developed by Morel (1987) in Mali with Excel software.

- $V=10 \times G \times P$
- V: volume of Woody in m^3
- 10: constant
- G: Basal area in m^2 ;
- P: average annual precipitation on the site or the nearest station in (cm).

✓ Calculation of underground biomass

Ground biomass of each species was calculated using the estimating guide to the amount of sequestration in Mali, The underground biomass of trees is the volume or weight of the root system. In Mali it has been estimated at **50%** of the total volume of wood on feet ILWAC project (2013). Thus, it will be used this formula:

$$C_{(root)} = \left[(V \times 1/2) \times 0.27 \right]$$

(ii) Estimation of tree species carbon sequestration

- ✓ To change the volume of timber to the quantities of carbon sequestered by different trees species, the following equation was used with Excel software:

1 m^3 of woody exploited=1 ton $CO_2=0.27$ tons of carbon

(iii) Determination of tree species carbon sequestration

To determine tree species carbon sequestration for each vegetation formation, we did the ratio between the individual tree species carbon sequestered and the subplot number of this vegetation formation.

2.3. Determination of the amount of carbon sequestered by vegetation formations

To determine the amount of carbon sequestered by each vegetation formation of the study area, we did the sum of the quantity of carbon sequestered by each tree species in this vegetation formation.

2.4. Data analysis

The different amounts of carbon sequestered by tree species and vegetation formations were calculated

using the R software. Also, the Dynamic cross table was established using the Excel software.

To evaluate the correlation between some parameters of trees species and the amount of carbon sequestered, it has performed a Pearson correlation test with the package "SPSS" and "SAS" software. These tests have been conducted at the level of the general population of our study environment. Also for homogenization of data, we used logarithm function ($\log(x+1)$).

III. RESULTS

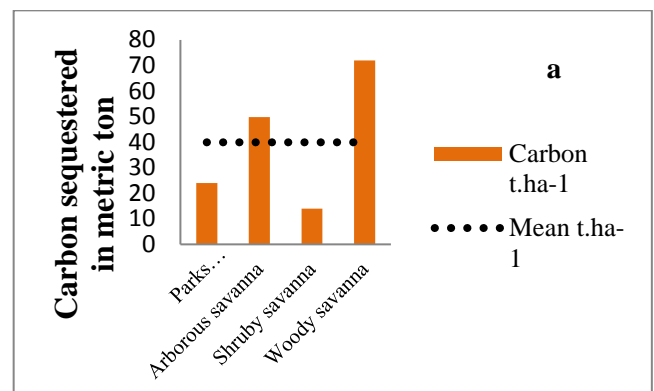
The results of this study are related to the amount of carbon sequestered in different vegetation formations via their trees species. Four vegetation formations were identified in the study area for inventory: Park Agro forestry/Fallow, woody savannah, Shrubby savannah and Arborous savannah.

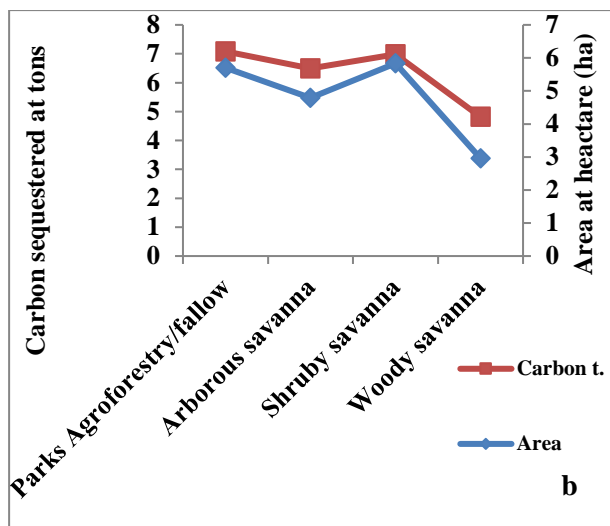
3.1. Quantity of carbon sequestered by Vegetation Formations

3.1.1. The amount of carbon sequestered by vegetation formations

Figure 4 presents the total amount of carbon sequestered by each formation (a) and the carbon sequestration capacity of each formation (b) in the study area. This is showed that the carbon sequestration capacity and the amount of carbon vary depending on the formation.

In average, the carbon sequestration capacity of the study area was estimated at 159.75 metric tons of carbon. But, the carbon sequestration capacity varies depending on the vegetation formations types and the different tree species of formation (fig 4.a). The vegetation formations that are the largest amount of carbon by area are not fiercely the formation that has the higher carbon sequestration capacity. In term of carbon sequestered per hectare, the woody savanna has the largest carbon sequestration capacity ($71.95t.ha^{-1}$). It is followed by the arborous savanna having a capacity of $49.86 t.ha^{-1}$ and agro forestry parks/fallow for up to $23, 98t.ha^{-1}$. The vegetation formations that have the lowest carbon sequestration capacity per hectare are shrubby savannah with a capacity of $13.97t.ha^{-1}$.





NB: for homogenization of data, we used logarithm function ($\log(x+1)$).

Figure 4: Amount of carbon sequestered of different vegetation formations (a), and Carbon sequestration capacity of different vegetation formations (b) in the study area.

The amount of carbon sequestered varies according to the area. The more is vegetation formations area the amount of carbon sequestered is important (fig 4.b). Thus, in terms of total amount of carbon sequestered in the study area, the agro forestry parks/fallow is the formation that has the largest amount of carbon (12,091,159.49 tons). It is followed by shrubby savannah (9,513,606.304 tons) and arborous savannah (3,079,764.902 tons). The amount of carbon stored is low in the woody savannah vegetation (65,470.17819 tons).

3.1.2. Contribution of the four vegetation formations in Carbon Sequestration.

The figure 5 shows the contribution of different vegetation formation types in the amount of carbon stored in the area. The amount of carbon available in the study area is estimated to be 24750000.88 tons. It appeared that the contribution of different vegetation types is in relation to the all amount of carbon stored that all tree species has sequestered in the area. In this line, in the Sudan ecological zone of Mali, the vegetation formation of parks agro forestry/fallow contributes more to the carbon sequestration up to 49%. The shrubby savannah is the second vegetation formation to sequester more carbon with 38% followed by arborous savanna (13%). The lowest is the being woody savanna (0.3%).

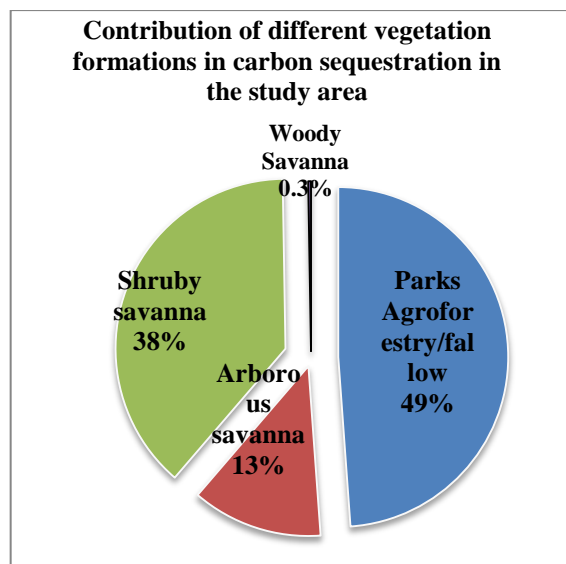


Figure 5: Contribution of different vegetation formations to the carbon sequestration in the studied study area.

3.1.1. The best three of tree species in carbon sequestration in the studied area

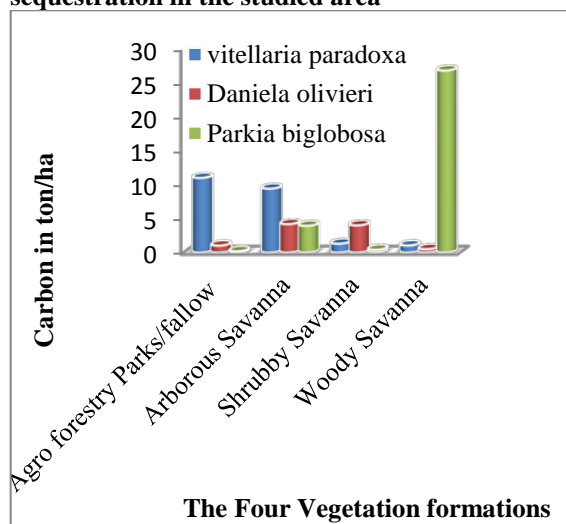


Figure 6: The best three of tree species in carbon sequestration of fours vegetation formations.

It reveals that in the figure 6 that the quantity of carbon sequestered by tree species varies from one vegetation formations to others. Globally, the tree species *Parkia biglobosa* has the largest capacity in carbon sequestration per hectare (26.8t.C.ha⁻¹) in woody savanna. But, it is not the tree species that has the higher carbon sequestration capacity in all the vegetation formations in the Sudan ecological zone of Mali.

Specifically; *Vitellaria paradoxa* is the most dominant sequestration tree in the vegetation formations of Park agro forestry/Fallow (11.087t.C.ha⁻¹) and it is followed by arborous

savanna (9.5t.C.ha⁻¹) while in the vegetation formation of the shrubby savanna *Daniellia oliveri* is the most dominant (4.04t.C.ha⁻¹).

3.2. Correlation between tree parameters and the amount of carbon sequestered

The tree parameters include the circumference, floristic richness, tree species diversity and size. These are correlated with total carbon sequestered so as understand which tree parameter is more significance.

3.2.1. Relationship between the amount of carbon sequestered and the circumference of tree species

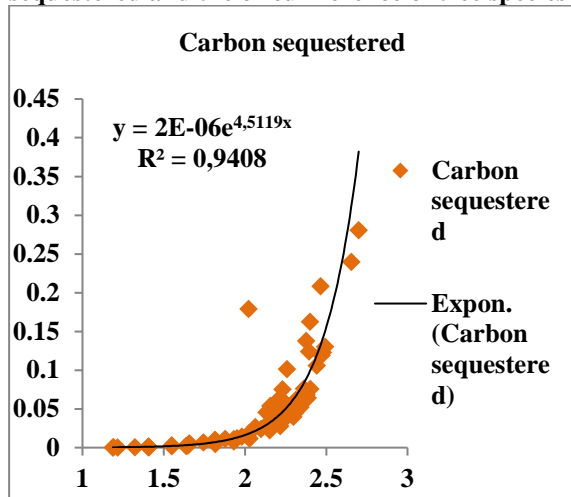


Figure 7: Correlation between trees circumference and the amount of carbon sequestered.

The figure 7 presents the correlation between trees species circumference and the amount of carbon sequestered in the study area. The analysis of the figure 7 reveals that there is a positive and exponential correlation between the amount of carbon sequestered by tree species and the circumference class of this tree species. Thus, it shows that when the tree species circumference is greater the amount of carbon sequestered is important.

3.2.2. The relationship between floristic richness per family and the amount of carbon sequestered

Floristic richness is the amount of tree vegetation species in the study area.

There is positive and binomial correlation between the number of tree species per family and the amount of carbon sequestered in the study area. Indeed, it appears from the analysis that the amount of carbon sequestered varies with the number of tree species per family (figure 8). The statistical correlation analysis between the number of the tree species per family and the amount of carbon sequestered gives a high significant correlation. The correlation coefficient (r) shows a positive sign. This explains that the more tree

species in a family, the more carbon is sequestered.

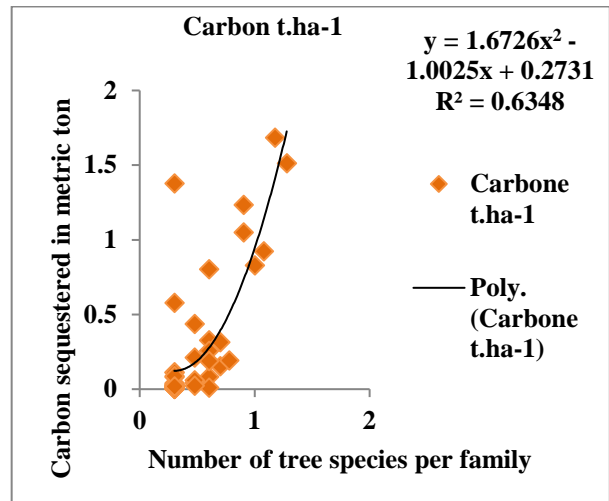


Figure 8: Correlation between the number of tree species per family and the amount of carbon sequestered in the study area.

IV.DISCUSSION

The amount of carbon sequestered varies with tree species and the types of vegetation formations. Similar observations were made by Amélie, (2006) and Gray, (2015). Besides the area, this amount of carbon sequestered is also depending on the tree species, similar result was reported by (Borough, 1998; Leys, 2011).

In this study area *Parkiabiglobosa* is the specie that has the largest (26.8t.C.ha¹) capacity in sequestration of carbon per hectare in the woody savanna, Ranjan et al, (2016), found that the individual tree of *Tectona grandis* one species that has great quantity of carbon sequestered (6859.92 pounds of carbon) in Vinoba at Bhave University Campus, Hazaribag. Specifically the species *Vitellaria paradoxa* is most dominant in vegetation formations of agro forestry Parks / Fallow (11.087t.C.ha⁻¹) and of arborous savanna (9.5t.C.ha⁻¹). The dominance of *Parkia biglobosa* and *Vitellaria paradoxa* in these savannas could be explained by the fact that they are spared not often exploited because of their socio-economic importance and also their total protection in forest legislation according to the country law. The similar result was observed by SANOGO, (2016) about *Vitellaria paradoxa* species (writ the result of this similar study). The tree *Daniellaoliveri* is the best species in carbon sequestration in the shrubby savanna that can be explained by its rapid growth, but it is not much used by loggers in study area due to the lower quality of its wood. Comparatively at the results of Akbari (2001), who studied the annual sequestration capacity of 12 species and reported that varieties of *hybrid poplar* (Deltoid) sequester more

carbon annually, and at maturity is 14.9 kg/year against the second, *blue spruce*, with 6.7 kg / year and 29.6kg / year at maturity and against the *white pine*, the second with 15.2 kg / year.

The amount of carbon sequestered per hectare is higher (71.95t.C.ha⁻¹) in the vegetation formations of woody savanna and of arborous savanna (49.86t.C.ha⁻¹) than in parks agro forestry/fallow vegetation formation (23.98t.C.ha⁻¹) and shrubby savanna (13.97t.C.ha⁻¹). This could be explained by the fact that the first two vegetation formations are less subject to human disturbance and have various species of large trees (Dembélé et al., 2005). Then the park agro forestry and shrubby savannah are under farming and fuel-wood logging, which has long been identified as the cause of reducing vegetation formations potential as observed in other African semi-arid area (Dube and pickup, 2001; Sekhwela, 2003; Dembélé et al., 2005). It can be due to the forest management, climate change mitigation activities, and life cycle assessments in this area (e.g. Hennigar et al., 2008; Smyth et al., 2014; Lamers et al., 2014). Aside, woody savanna has the best amount of carbon sequestered per hectare (71.95t.ha⁻¹) in the study area, this amount is less than the one found by Claire, 2013 who, after the evaluation and comparison of carbon stocks in agro forestry systems in Cameroon Cocoa Centre; a Case of the district of Bokitio says that the fallow has a capacity of sequestration average of 58 tons per hectare. Tung (2010), while estimating the amount of carbon stored by a regrowth forest in Gabon Republic, reported that the amount of carbon sequestered by young fallow is about 118 tons of carbon per hectare, which is much higher than the amount of carbon sequestered per hectare of parks agro forestry / fallow vegetation formation in this study area which is located in semi-arid and not in humid area like Gabon and Cameroon Republic.

The rate of carbon sequestration by vegetation formation and trees species depends at many factors and parameters. Age and stage of growth of tree, growth parameter and density of wood are some important parameters among them (Ranjan et al, 2016; Eneji et al., 2014).

The amount of carbon sequestered per hectare depends largely on the circumference of a species, the number of species per family in the studied area. The bigger the tree species, the amount of carbon sequestered or stored is important and more the tree species growth its carbon stored increase also (Boulmane et al., 2014); Eneji et al., 2014). Similar result was found by Leys et al. (2011) who noted that the amount of carbon stored depends on the species, growth condition in the environment, age of tree and density of surrounding trees. There is positive and binomial correlation between the number of tree species per family and the amount of carbon sequestered. The linear correlation was observed by

Adam et al. (2011). The amount of carbon sequestered varies according to the trees species number per family (Hu et al. 2015).

V. CONCLUSION

The results of this work provide a real knowledge about the carbon sequestration capacity of tree species of different vegetation formation in the Sudan ecological zone of Mali. It also enables to understand the relationship between certain parameters of the vegetation and the amount of carbon sequestered. It appears from the results that Sudan ecological areas of Mali have big potentiality in carbon sequestration of about 159.75 metric tons of carbon through their tree species, and the carbon sequestration capacity. It also reveals that the variation of the amount of carbon depends on the vegetation formation. It shows that the quantity of carbon sequestered is correlated to certain parameters of trees species namely Circumference and the tree species number per family. In the light of the conclusions, it should be recommended to supply a greater accuracy in assessing the amount of carbon sequestered by tree species in the savannas of Mali; it would be desirable to develop a formula more adapted to the species and the ecological zone and to also consider roots and branches of the tree species.

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