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CARBON STOCKS OF TREES IN FARMER MANAGED NATURAL REGENERATION SYSTEM FACE TO CLIMATE CHANGE IN SAHELIAN ZONES OF TIENEGUEBOUGOU, FARAKO, GUEMOU AND BIENKOLOBOUGOU, IN MALI.

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ABSTRACT

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Climate change is global problem and presents enormous challenges for cereal production and food security in sub-Saharan Africa where 60% of the workforce are farmers. Climate change poses a great potential threat to the environment and sustainable development of the world. In Mali, poor populations are the most vulnerable because of their low adaptive capacities and their heavy dependence on climate-sensitive resources such as water resources, trees and agricultural production systems. However, Farmer Managed Natural Regeneration (FMNR) is a climate-smart technology that increases the density of trees populations in agroforestry parks in order to mitigate global warming throw carbon sequestration. The objective of this study was to assess the quantity of carbon sequestered by woody trees in FMNR system, face to climate change in Sahelian zones of Mali. To achieve this, forest inventory works were carried out in four village lands (Tieneguebougou, Farako, Guemou and Bienkolobougou) over a total area of 20 hectares. The inventory plots were implemented every 500 meters during transects in different management units, namely hut fields, bush fields and fallow fields. The size of an experimental plot was 10,000 m² (100 mx 100 m) in order to cover the most woody trees. The dendrometric measurements were related to the height of the woody trees, the diameter of the trunk at breast height at 1.30 m and the diameter of the crown (the length and width of the crown). The density of woody trees was 29 trees ha^{-1} in the village of Tieneguebougou, 91 trees ha^{-1} in Farako, 32 trees ha^{-1} in Guemou and 21 trees ha^{-1} in Bignekolobougou. The quantity of carbon balance varies depending on the study sites. There was 37.208 tons of carbon per hectare stored in the above and below biomass of woody trees in Farako, 6.139 tons of carbon per hectare in Guemou, 5.827 tons of carbon per hectare in Tieneguebougou and 2.531 tons of carbon per hectare in Bignekolobougou. The carbon stock variation depends on trees diameter, natural factors (woody trees biology, pluviometry, types of soil, etc.), climate change and anthropogenic pression.

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Keywords: Carbon stocks, Farmer Managed Natural Regeneration, Climate Change, Sahel, Mali.

INTRODUCTION

Climate change is global (IPCC, 2007) and bearings enormous challenges to cereal production and food security in sub-Saharan Africa where 60% of the working population are farmers (WDI, 2006). Scientific consensus indicates that global sea and land surface temperatures are warming under the influence of greenhouse gases, which is the main driver of climate change (IPCC, 2007; Hansen et al., 2007). Climate change postures a great potential threat to the world's environment and sustainable development. Poor populations are the most vulnerable because of their low adaptive capacities and their large dependence on climate-sensitive resources such as water resources, trees and agricultural production systems.

Despite their socioeconomic importance in Mali, woody trees remain vulnerable to climate change. Rainfall remains uncertain while the temperature will increase in the coming years (Sultan and Janicot, 2004; Oxfam, 2007). This situation could be detrimental to the growth and development of crops and woody trees (PANA, 2006). The effects of climate variability and change, namely rising temperatures, long periods of drought, the succession of floods to droughts and the uncertainty of rainfall, make agricultural and forestry activities difficult. However, woody trees in association with crops increase the quantities of carbon stock as well as those of organic residues and biodiversity in agrarian areas (Makumba et al., 2006 ; Traore, 2000).

Adequate management of shrubs in the northern Sudanian and Sahelian zones of West Africa enables farmers to improve soil fertility (Loupe, 1991; Pallo and Bationo, 1997) and to increase the duration of cultivation areas. Woody floras (trees, shrubs and shrubs) reduce global warming through carbon sequestration. In addition, trees protect the environment, improve soil structure and promote the infiltration of rainwater into the soil (CILLS, 2012; Chirwa et al.,

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2007; Kizito et al., 2005; IIRR and ACTT, 2005), increase the production of wood, fodder and non-timber forest products (Garrity, 2004; Pallo and Bationo, 2007). According to many authors, in the Sahel, vegetated anti-erosion structures (stone barriers, earthen bunds) show that shrub species such as *P. reticulatum*, *C. glutinosum*, etc., increase the lifespan of these anti-erosion structures. The biological activity and soil fertility of the surrounding environment are improved there, as well as the availability of wood and non-wood forest products (Pallo and Bationo, 2007; Bationo and Sankara, 2006). The objective of this study was to assess the carbon balance of woody plants in Farmer Managed Natural Regeneration in Sahelian conditions of Mali.

MATERIAL AND METHODS

Experimental sites

The experimentation was implemented in the localities of Tieneguebougou, Farako (district of Kolokani), Guemou and Bienkolobougou (district of Diema) in Mali. Figure 1 shows the location of the study sites. The geographical coordinates of these sites are as follows: Tieneguebougou -8.077450 West longitude and 13.573639 North latitude, Farako -8.006489 West longitude and 13.821139 North latitude, Guemou -9.312490 West longitude and 14.546290 North latitude and Bignekolobougou -9.375 North 9139 West longitude and 53.1904 latitude.

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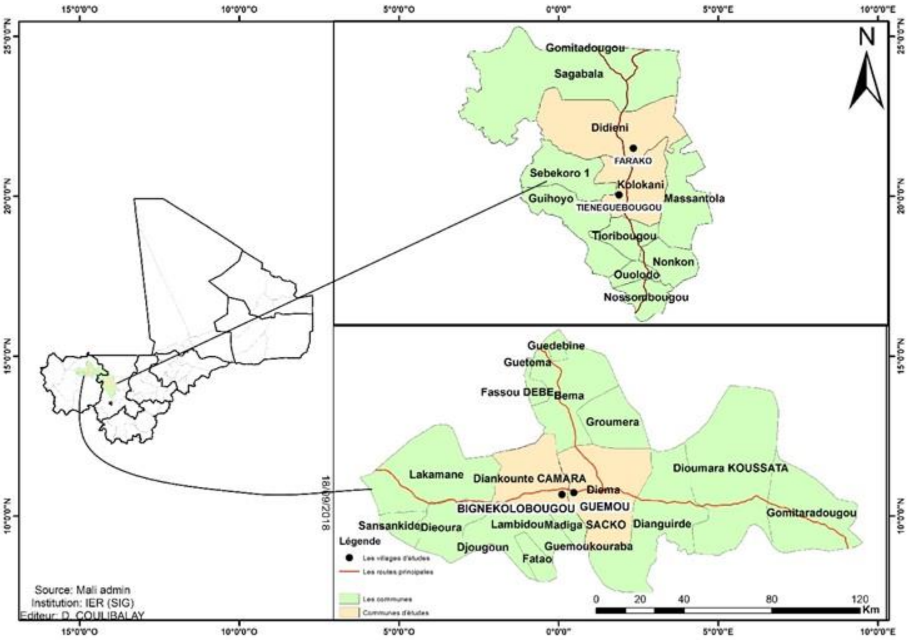

Figure 1: Location of study sites

Delimitation and mapping of inventory plots

Carrying out of these activities required the use of technical equipment, including a Garmin-type GPS for recording the geographical coordinates of the boundaries of the inventory plots and the trees they delimit. The delimitation of the inventory plots was made in the cultivation fields (hut fields and bush fields) and in fallows on a total surface of 20 hectares. The principle consisted in each case in materializing the four vertices of each plot using the ribbon and the rope followed by a geo-referencing of the perimeter and the ligneous trees inside with the GPS (photo 1-a) and a materialization in indelible ink of woody trees. This situation provides information on the distribution of plots and trees in agricultural areas. The maps of the inventory plots were produced using GIS (Geographic Information System) software.

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Photo 1: Rope demarcation and GPS mapping of an inventory plot in Tieneguebougou **(a)** and Bignekolobougou **(b)**

Forest inventory

Inventory work was carried out in four village areas (Tieneguebougou, Farako, Guemou and Bienkolobougou) over a total area of 20 hectares, either 5 hectares per village area. The route of the inventory transects crossed hut fields, bush fields and fallow lands. The inventory plots were implemented at an equidistance of 500 m. The area of a plot was 10,000m² (100m x 100m). A rod was used to measure the height of trees. The measurements of the diameter of the trunk at breast height at 1.30 m (photo 2) and the diameter of the crown (length and width of the crown) were made with a measuring tape. The measurement of these dendrometric parameters made possible to assess the quantities of carbon sequestered by the aerial (above) and root (below) biomasses of woody trees in Farmer Managed Natural Regeneration on the study sites.

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Photo 2: Measurement of the crown diameter of a *Combretum glutinosum* in Farmer Managed Natural Regeneration area in Guemou **(a)** and the height of a *Combretum glutinosum* in Bignekolobougou **(b)** in 2017

Data collected

The diameter of trees trunk at breast height (1.3 m), the height of trees and their crowns diameter were collected.

Data analysis

The data was entered into Excel and then analyzed with the statistical analysis software GenStat 12.1 using the analysis of variance method and the classification of means with the ppds test at the 5% threshold.

RESULTS

Famer Managed Natural Regeneration (FMNR)

At the end of our research work, the definition of Famer Managed Natural Regeneration (FMNR), the stages, the advantages and the actions favoring FMNR are as follows.

FMNR is an agroforestry technology consisting of identifying, preserving and managing the release of stumps and free standing trees from multipurpose woody trees (trees and shrubs) with

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a high capacity for natural regeneration in agrarian areas. FMNR is environmentally sustainable and economically viable.

The different steps of FMNR are as follows:

- ✓ the selection (identification and materialization) of the free feet and the rejections of stumps to be protected;
- ✓ the cutting of free feet and rejections of unselected stumps;
- ✓ the pruning every year of the free feet and the rejections of selected stumps.

The intelligent management of woody trees in FMNR provides goods (wood energy, service wood, lumber, fruits, fodder, pharmacopoeia, etc.) and ecosystem services (shade, improvement of soil fertility and conservation of humidity, creation of microclimate, increase in biodiversity, protection of ecosystems, etc.) for the well-being of populations in the context of climate change.

The contour tillage, grass strips and the micro-dose of organic and mineral fertilizers are climate-smart technologies that promote Farmer Managed Natural Regeneration. To these climate-resilient technologies, we can add the making of micro-bowls around woody plants to store rainwater; preserve them during field work (clearing crop fields, plowing with a plow, weeding with a daba, harvesting, etc.); protect them against bush fires, trampling and browsing by animals.

Mapping of inventory plots

Figures 2 and 3 represent the maps of the forest inventory plots. These maps show the distribution of woody trees in the agrarian areas of the study sites.

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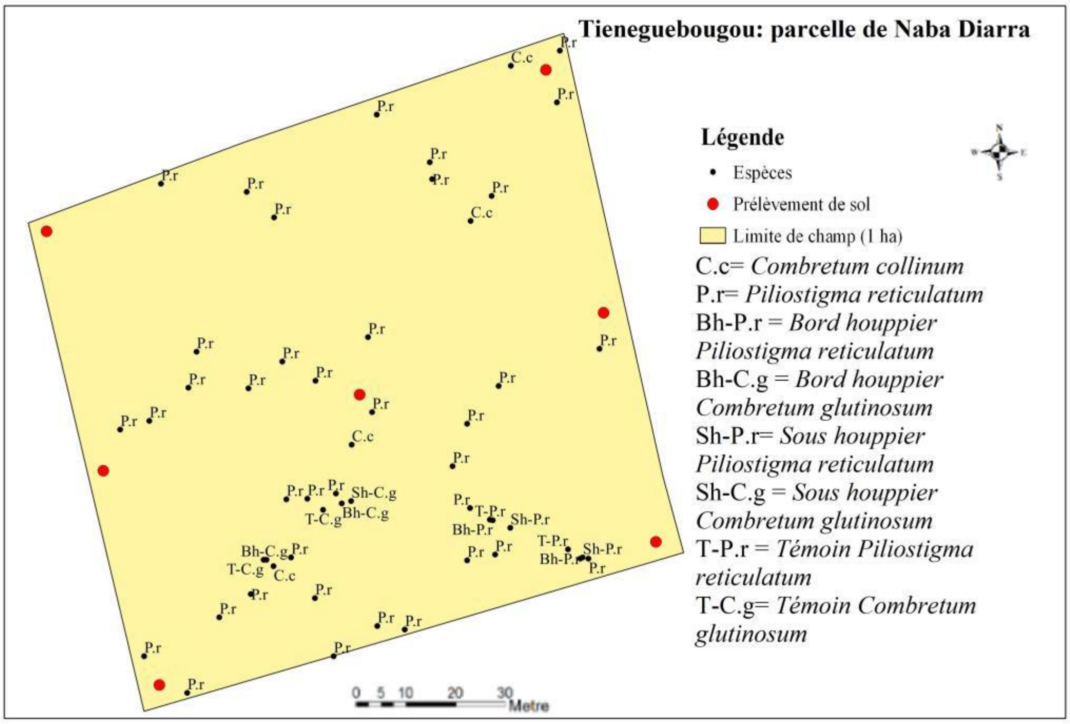

Figure 2: Map of a forest inventory plot in Tieneguebougou (Kolokani, Mali) in 2017

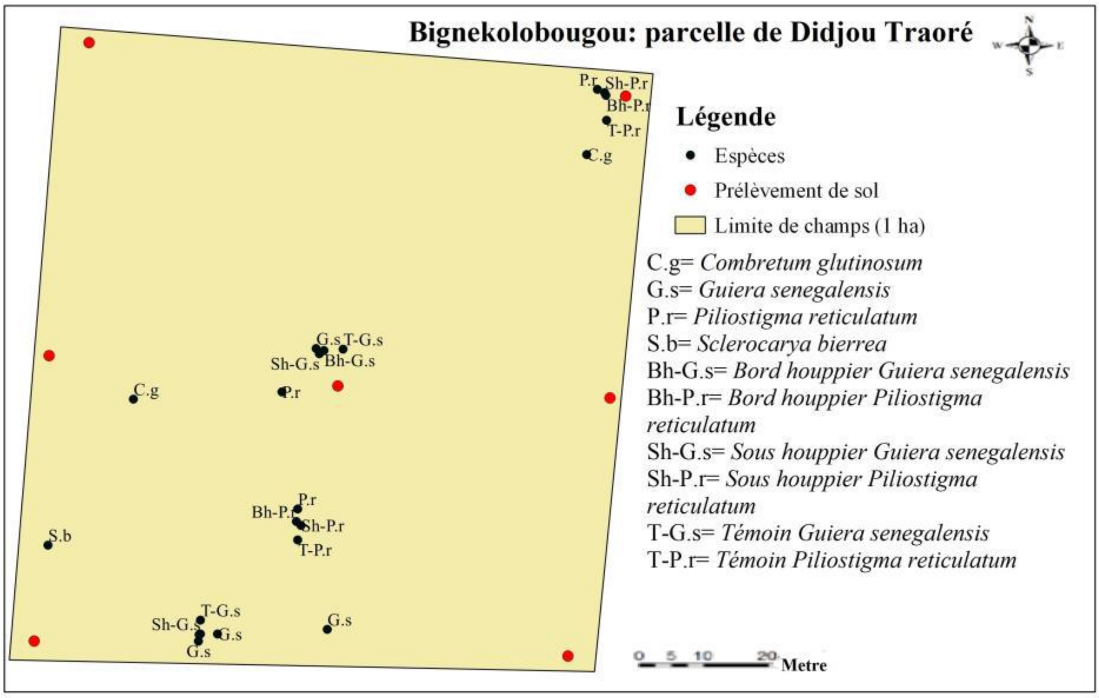

Figure 3: Map of a forest inventory plot in Bienkolobougou (Diema, Mali) in 2017

Density of woody trees in Farmer Managed Natural Regeneration

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The average tree density in all the study areas was 43 trees ha^{-1}. This density varied according to the study sites. It was 27 trees ha^{-1} in the Diema district and more than double (60 trees ha^{-1}) in the Kolokani area. It was 29 trees ha^{-1} in the village land of Tieneguebougou, 91 trees ha^{-1} in Farako, 32 trees ha^{-1} in Guemou and 21 trees ha^{-1} in Bignekolobougou. The woody population of FMNR plots was dominated mainly by *Combretum glutinosum*. Among 797 woody trees inventoried in the experimental plots, 471 were *C. glutinosum* with a density of 24 trees per hectare. *C. glutinosum* was followed by *Piliostigma reticulatum*, *Guiera senegalensis*, *Combretum collinum* and *Cassia sieberiana* with 231, 39, 33 and 23 individuals respectively.

Distribution of woody stems in circumference classes at 1.30 m

Figure 4 illustrates the variation in classes of circumference at 1.30 m of woody stems according to the FMNR plots in the village lands. It appears from the observation of this figure that the number of woody stems is higher in the village of Farako. Thus, whatever the village, it is in the class of circumference 2-15 cm that the maximum number of stems is encountered. As for the large diameters corresponding to classes 55 to 75 cm and more, they are poorly supplied in Guemou (figure 4).

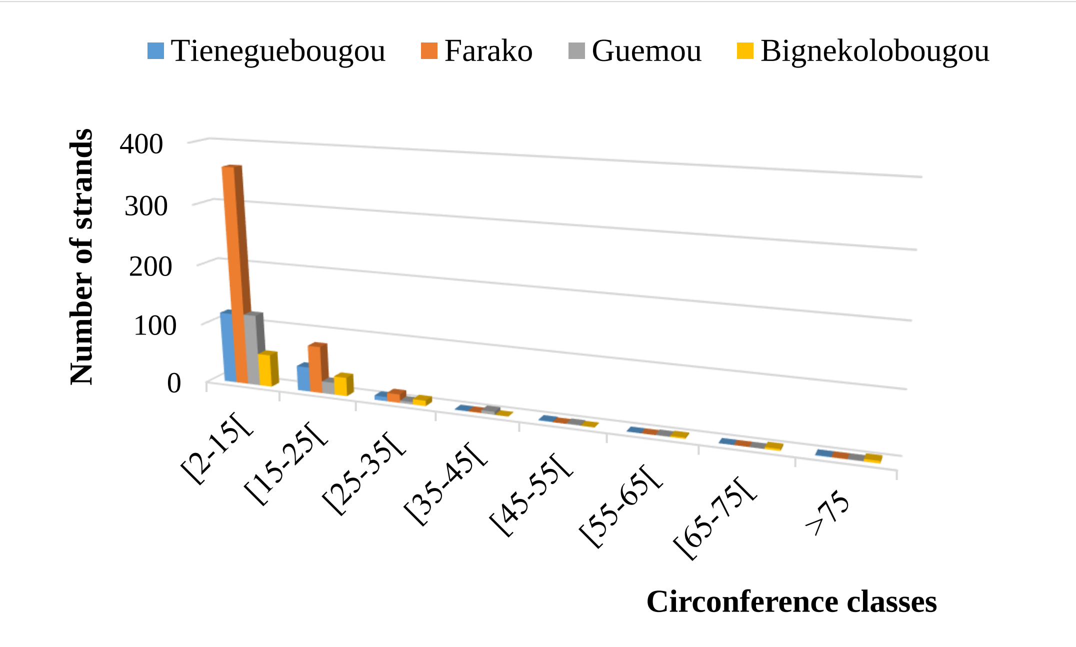

Figure 4: Distribution of trees stems in classes of circumference at 1.30 m per village

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Estimation of wood volumes produced by ligneous trees in Farmer Managed Natural Regeneration

After the forest inventory works in the management units (huts fields, bush fields and fallows), the volumes of wood were determined on the basis of the formula developed by Morel in 1987 presented as follows: $V = 10*G*P$

V = volume of wood in m^3; 10 = constant; G (basal area) = $C^2/4\pi$ with π = constant = 3.14 and C = circumference of the tree at 1.30m above the ground; P = average annual precipitation on the site or the nearest station expressed in mm.

The volumes of wood produced by ligneous plants in FMNR varied according to the villages. Indeed, the largest volumes of wood were produced in the villages of Tieneguebougou, Farako and Bienkolobougou (figure 5). The lowest volume of wood was detected in the village of Guemou.

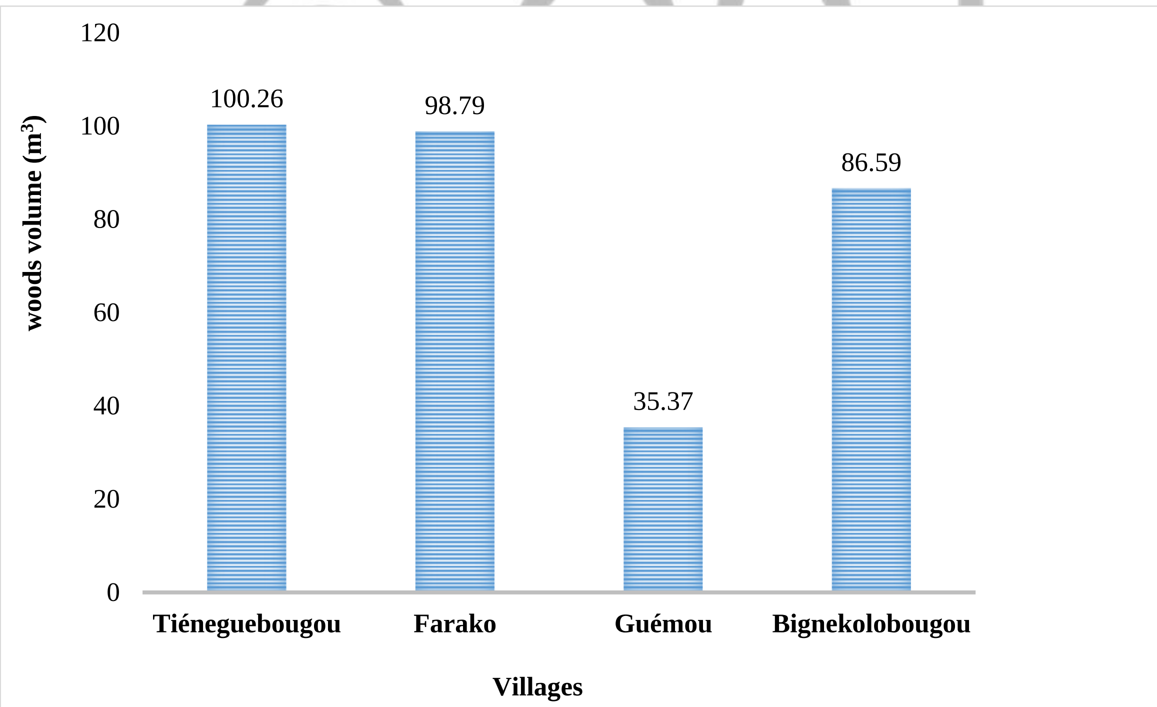

Figure 5: Volumes of wood produced by ligneous trees in FMNR according to villages lands

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Carbon stocks of woody trees in Farmer Managed Natural Regeneration

The forest inventory works had permitted to assess the quantity of carbon stored in the aboveground and belowground biomasses of woody trees in Farmer Managed Natural Regeneration (FMNR) system. The calculation of the carbon stock was carried out using the following formulas:

Estimation of the aboveground biomass of woody trees in Farmer Managed Natural Regeneration

The aboveground biomass of woody trees was estimated by using the allometric equation of Chave et al (2014).

$AGB = 0.0673 \times (HD2H)^{0.976}$

Where: AGB is the aboveground biomass of the tree (in ton)

D is the diameter of the tree (in cm)

H is the total height of the tree (in m)

U is the specific density of the tree in ($g.cm^{-3}$).

Estimation of the belowground biomass of woody trees in Farmer Managed Natural Regeneration

The estimation of the root biomass of standing woody trees complied with the guidelines established by the IPCC (2006). According to the latter, the equivalence in root biomass of standing woody trees was obtained by multiplying the value of the aboveground biomass (AGB) by a coefficient R whose value is estimated at 0.24.

$BGB = AGB \times R$

Where:

BGB is Belowground Biomass

AGB is Aboveground Biomass

And R the root/stem ratio.

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Evaluation of carbon stocks of woody trees in Farmer Managed Natural Regeneration

The carbon stocks were obtained by multiplying the sum of the biomasses (aboveground and belowground) by the CF ratio (carbon fraction) which is 0.47 (IPCC, 2006).

C = (AGB + BGB) × 0.47 with C the total carbon stock, AGB the aboveground biomass and BGB the belowground biomass.

The quantities of carbon sequestered by ligneous trees in Farmer Managed Natural Regeneration in the study sites are mentioned in Table 1. The high quantities of carbon stocks were obtained in the villages of Farako, Guemou and Tienegebougou. The lowest quantity was revealed in Bienkolobougou.

Table 1: Carbon stocks of woody trees in Farmer Managed Natural Regeneration in the study sites

Study sites	**Carbon stock ($tCha^{-1}$)**
Farako	37 208 a
Guemou	6 139 b
Tieneguebougou	5 827 c
Bignekolobougou	2 531 d
CV%	20
Ecart type	7 765
F Pr.	< 0,001
Signification	HS

Legend: $tCha^{-1}$ = ton of carbone per hectare, CV = coefficient of variation, FPr. = probability, HS = high signification

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DISCUSSION

The inventory study shows that the density of woody trees in Farmer Managed Natural Regeneration varies according to the localities. The highest densities and wood volumes (figure 5) of ligneous trees were obtained in the localities of Farako, Guemou and Tieneguebougou. The village of Bienkolobougou produced the lowest density of trees and the lowest volume of wood was discovered in Guemou. The situation could be explained by the diameter of trees. In fact, in Guemou there was more density of trees but their diameters were narrow than trees diameters (figure 4) in Bienkolobougou. The carbon stocks follow the same trends (Table 1). The results show that carbon stocks in trees biomass (aerial/aboveground and root/belowground) vary according to the diameter of the trees and the nature of the species. As such, Traore et al (2003) reported that the aerial parts of *Vitellaria paradoxa* sequester 24 tons of carbon against 8 tons for the root parts. Other no less important factors such as the nature of the soil, climate, rainfall and anthropo-zoogenic pressure can influence carbon stocks. Strong anthropo-zoogenic pressure (men and animals) was revealed by the rural communities of Guemou. This strong pressure results in the excessive cutting of wood and overgrazing (strong pressure from local animals and foreign animals on wood resources). The physicochemical characterization of the soils in the study sites presented a sandy-loamy to sandy-loamy texture (Zerome et al., 2019a). These results corroborate those of Kooke et al (2019). Kooke et al (2019) reported that carbon stocks vary according to several conditions including climate change, the biology of woody species, natural factors (soil, climate such as temperature, rainfall, etc.), anthropogenic factors (human pressure to satisfy the needs for fodder, pharmacopoeia, agriculture, wood, etc.). Strong pressure on wood resources reduces carbon sequestration. According to the same source, there is a strongly negative and significant correlation between temperature and carbon stock. High temperatures contribute to low carbon sequestration and vice versa. In Mali, there will be rainfall variability (Tekete and Siwakumar, 1995; Sultan and

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Janicot, 2004) and a rise in temperature of 1 to 2.75ºC more by 2030 (Oxfam, 2007), which could lead to a decrease progressive agricultural production (Konate, 1984; PANA, 2006). Added to this, are violent winds, soil degradation, the disappearance of plant and animal species, the silting up of rivers (Niger River), the reduction in surface and ground water recharge, the reduction in fishery resources (Adeel et al., 2005). The climate scenarios following the MAGGICC (Model for the Assessment of Climate Change induced by the Greenhouse Effect) and SCHENGEN (PNUD et al., 2014; CNRST, 2003; Butt et al., 2005) models report an increase in the average temperature of 30.5°C during the period 1961-1990, to 32.5°C in 2050, and 34.5°C in 2100 and a decrease in precipitation of 10 to 15% (including a shift current isohyets towards the south of Mali). This is in addition to an increase in the frequency of extreme meteorological phenomena (high heat, violent winds, etc.) with real impacts on the living conditions of populations, in terms of access to health, drinking water, and meeting food security needs. This situation could affect the potential of carbon sequestration of woody trees in Mali in general and in the study sites in particular because the strong heat accelerate the decomposition of organic matter and the release of carbon.

Other authors reported that the long duration of cultivation (prolonged monoculture) has a negative effect on the regeneration and richness of the woody population, and therefore on carbon sequestration (Yossi, 1996; Cisse, 1995; Alexandre 1989; Mitja 1993). On the other hand, the good practice of Farmer Managed Natural Regeneration of woody trees promotes carbon sequestration in agrarian areas. Indeed, the high carbon stocks in the localities of Farako, Guemou and Bienkolobougou can be explained by the large-scale adoption of Farmer Managed Natural Regeneration (FMNR) by farmers in their crop fields thanks to the support of the Project Eco-agriculture in the Sahel from World Vision (Zerome et al., 2019b). This scaling up of the FMNR is supported by local agreements for the management of woody resources guaranteeing its sustainability. The contour tillage, grass strips and the micro-dose of organic

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and mineral fertilizers are climate-smart technologies that promote Farmer Managed Natural Regeneration. These technologies conserve soil moisture and promote not only the growth of woody trees in FMNR but also the germination of seed stocks of woody trees in the soil (Zerome et al. 2021). The construction of micro-pits around the feet of woody trees to conserve rainwater, their preservation during field works (clearing of crop fields, plowing with a plow, weeding, harvesting, etc.), their protection against bush fires, grazing and trampling of animals are actions that contribute to the promotion of FMNR.

Farmer Managed Natural Regeneration is a climate-smart technology which provides efficiently woods for populations needs (firewood, service wood, fruits, fodder, etc.) and sequesters carbon for alleviating the global warming.

CONCLUSION

The density of woody trees in Farmer Managed Natural Regeneration (FMNR) and the volumes of wood vary according to the study sites. Carbon stocks follow the same trends. The variation in carbon stocks was linked to the diameter of woody trees, natural factors, climate change and anthropo-zoogenic pressure.

Farmer Managed Natural Regeneration is a low-cost climate-smart technology that could be replicated anywhere in the Sahel and other zones with similar ecologies for mitigating the adverse effects of climate change such as the global warming through carbon sequestration.

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