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Impact of a Climate Smart Technology: Case of the Farmer Managed Natural Regeneration on Trees Biodiversity in Sudano-Sahelian Parklands of Kayes and Koulikoro, in Mali

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Abstract

In the Sahel, parklands are degraded due to climate change, human and animal pressure. The objective of this research was to assess the effect of Farmer Managed Natural Regeneration (FMNR) on trees biodiversity in Sudano-sahelian parklands of Kayes and Koulikoro, in Mali. Trees inventory was carried out in agricultural areas. The size of an inventory plot was 2500m². The inventory plots were 500 meters apart. The total area inventoried was 20 hectares. The woody flora of studied areas was made of 27 species of trees. Most represented families were Combretaceae (6 species); Mimosaceae (4 species) and Cesalpiniaceae (3 species). Families, species and genera of trees have varied according to the rural communities. In fact 8, 15, 12 and 11 species have been identified respectively in Tieneguebougou; Farako; Guemou and Bienkolobougou. The characteristic species has varied depending on studied areas with 2, 7, 3 and 3 species in respective localities. The index of regularity showed an identical high level of trees organization in Tieneguebougou, Guemou and Bienkolobougou. But, the index was low in Farako. A comparison of indexes values showed although the floristic composition was low in Tieneguebougou; Guemou and Bienkolobougou, their woody stand organization was further constant. The FMNR has increased the biodiversity of trees and consequently the volume of wood in agrarian areas. This biodiversity of trees contributes to carbon sequestration and strengthens the resilience of populations by providing them with goods (firewood, honey, etc.) and eco-systemic services. FMNR is a climate-smart technology, whose scaling up in Mali is essential.

Keywords: climate smart technology, FMNR, biodiversity of trees, Mali

1. Introduction

In the Sahelian regions with high population densities, disappeared vegetation is gradually replaced by agro-forestry systems such as in Zinder and Maradi, in Niger (Toudou and al. 2008), North of the Central Plateau of Burkina Faso (Ouedraogo and al. 2008); in the Gondo plain in Mali (Sahel-ECO. 2008). Comparison of aerial photos from 1975 with high resolution satellite images from 2005 for the same areas in Niger shows a sharp increase in woody trees densities in fields (15 to 20 times more woody trees in 2005 than in 1975). Regreening is estimated at least five million hectares with 200 million of woody trees (Reij and al. 2009). In Senegal, the PREVINOBA (Village Reforestation Project of the North-West of the Peanut Basin) thanks to the development of its research-action component in the department of Tivaouane, the density per hectare of 9 woody trees before the intervention of the project has increased to 27 woody trees due to the adoption of Farmer Managed Natural Regeneration (FMNR) by the populations (Diallo, 1992).

In Mali, some populations are threatened by the increasing degradation of natural resources, food insecurity (Djoudi and Brockhaus 2011; Bidou and al. 2019) and poverty aggravated by the effects of climate change (World Bank. 2020b). The resilience of Mali's ecological landscape to climatic fluctuations is weakened by the degradation of natural resources (trees, lands, etc.). Extensive agriculture due to population growth and modification of agricultural practices induced by agricultural development efforts, systematic removal of young trees from fields and climate change have also resulted in loss of vegetation cover and soil erosion (Bidou and al. 2019; USAID, 2018b ; Zamudio, 2016; Sanogo and al. 2017). Agroforestry practices, in particular Farmer Managed Natural Regeneration; can make an important contribution to the livelihoods and adaptive capacity of farmers to climate change (Djoudi and Brockhaus 2011; Bidou et al. 2019).

The Farmer Managed Natural Regeneration (FMNR) is an agroforestry technique that consists of protecting and managing the natural regrowth produced by the stumps of trees and shrubs in agricultural areas (Dia and Duponnois, 2010; Botoni and al. 2010). Regrowth management consists in eliminating the side branches to keep only a few main stems, which allows a better allocation of nutrients. The spared stems can thus continue their growth and have a good conformation and subsequently provide environmental goods and services: fodder, firewood, litter, habitat for wild animals and protection against wind and sun erosion.

In the regions of Kayes and Koulikoro (Mali), the adoption of Farmer Managed Natural Regeneration by farmers as part of Eco-agriculture Project implementation has contributed to the improvement of woody flora in agricultural areas. The objective of this research was to determine the effect of Farmer Managed Natural Regeneration on woody trees biodiversity in Sudano-sahelian parklands of Kayes and Koulikoro, in Mali.

2. Material and Methods

2.1 Description of Studied Areas

The experimentation was carried out in the regions of Kayes and Koulikoro, in Mali (figure 1). In each region; two villages have been chosen as Tieneguebougou and Farako (district of Kolokani, Koulikoro); Guemou and Bienkolobougou (district of Diema, Kayes).

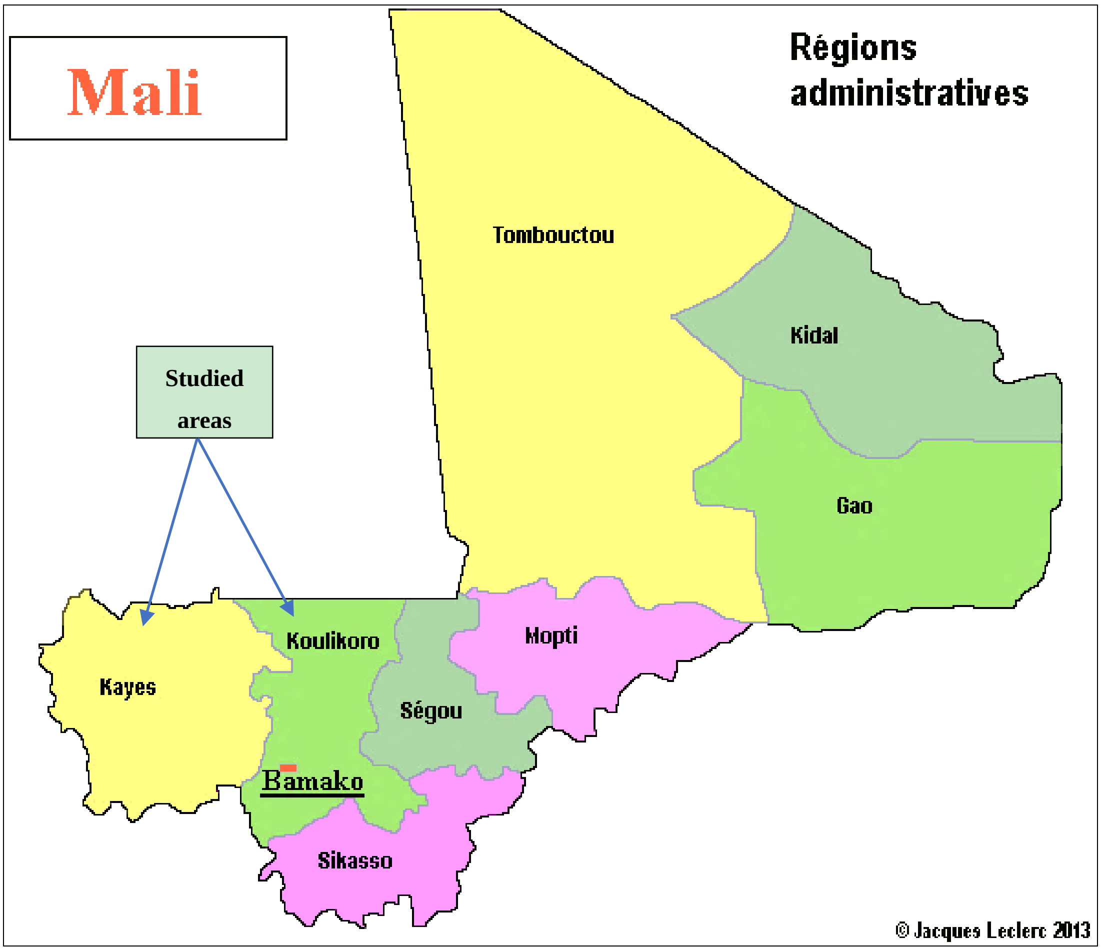

Figure 1: Location of studied areas (www.google.com ; January 17th, 2022)

The climate of the studied areas is Sudano-Sahelian with an alternation of two seasons: dry season and rainy season. The dry season is characterized by two periods, a cold period from November to February with an average minimum temperature of 21 °C and a hot period from March to May with an average maximum temperature of 32 °C. Rainfall varies between 500 and 600 mm year^{-1} (USAID and al. 2008; USAID and al. 2007; Dubut, 1999). The mean annual evapotranspiration ranges from 1800 mm in the north to 1700 mm in the south (USAID and al.

2008; USAID and al. 2007; Dubut; 1999). The years 1970 to 1980 were characterized by severe droughts in Mali. These long years of droughts have led to low agricultural production; desiccation of trees and famine in studied areas. The districts of Kolokani and Diema remain dependent on the effects of climate change which is perceptible by the irregularity of the rains between 1988 and 2015. Episodes of rainfall deficits were observed mainly in sequences of two consecutive years (1990 and 1991; 1995 and 1996; 2006 and 2007; 2010 and 2011; 2014 and 2015) and rarely in sequences of three consecutive years (2000; 2001 and 2003).

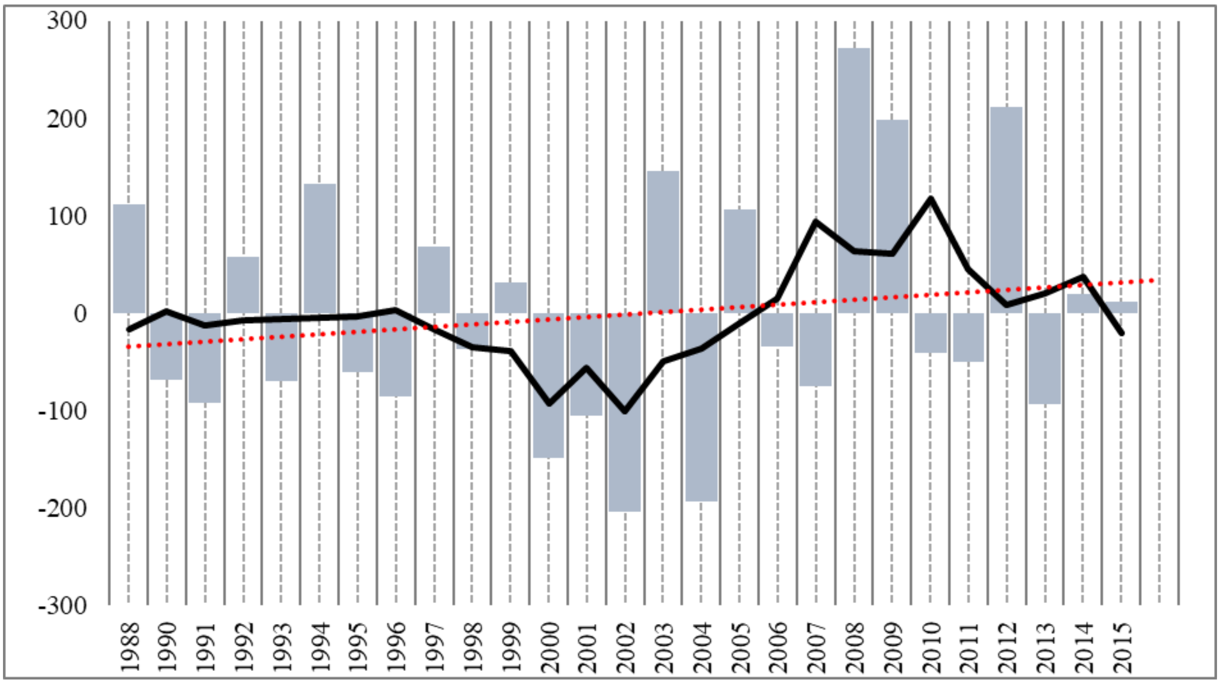

Figure 2. Anomaly of annual rainfall in Kolokani from 1988 to 2015 (Zerome, 2020)

2.2 Trees Inventory and Data Collection

The inventory of trees was carried out through transects following the longest direction of each village landscape in order to cover the maximum number of woody species. The demarcation of the inventory plots was made in the hut fields; the bush fields and in the fallow fields using a GPS (Geographic Positioning System), a rope and a tape measure. The principle consisted in each case of materializing the four vertices of each plot using the ribbon followed by geo-referencing of the perimeter and the trees inside with a Garmin-type GPS. This information provides the distribution of plots and trees in the agrarian space. Farmer Managed Natural Regeneration (FMNR) was practiced in these fields by the farmworkers. The scope of each inventory plot was 2500 m² (50m x 50m). The equidistance between the inventory plots was 500 meters. The total area inventoried was 20 hectares. About data collection, all species of trees present in the plots are systematically inventoried through measurements of the crown, the height, the stem circumference at 1.30 m from the ground; the determination of families, genera and species names using identification books.

Photo 1. Demarcation of inventory plots and identification of *Sclerocarya birrea* in Guemou (a) and *Combretum glutinosum* in Farako (b), in 2017

2.4 Data Analysis

The data collected were entered into Excel in order to elaborate the histograms. The diversity index was calculated using the Shannon Weaver formula (1949) and the Frontier and Viale regularity index (1991) or the Pielou fairness index (1966). The diversity index of Shannon and the index of regularity were calculated respectively using the following formulas.

Shannon index:

_s

$$H' = ((ni/Ni)*\log2\ (ni/Ni))$$

i=1

Index of regularity:

_ H H

$$e = \frac{H}{Hmax} = \frac{H}{\log2\ S}$$

Where ni: number of individuals of a given species, i ranging from 1 to S (total number of species).

N: total number of individuals.

3. Results

3.1 Floristic Composition

In Tieneguebougou and Farako (region of Koulikoro), Guemou and Bienkolobougou (region of Kayes), the flora of parklands in Farmer Managed Natural Regeneration (FMNR) system was made of 27 species of trees. The number of species has varied according to the rural communities. In fact, 8, 15, 12 and 11 species have been identified respectively in Tieneguebougou, Farako, Guemou and Bienkolobougou (Figure 3).

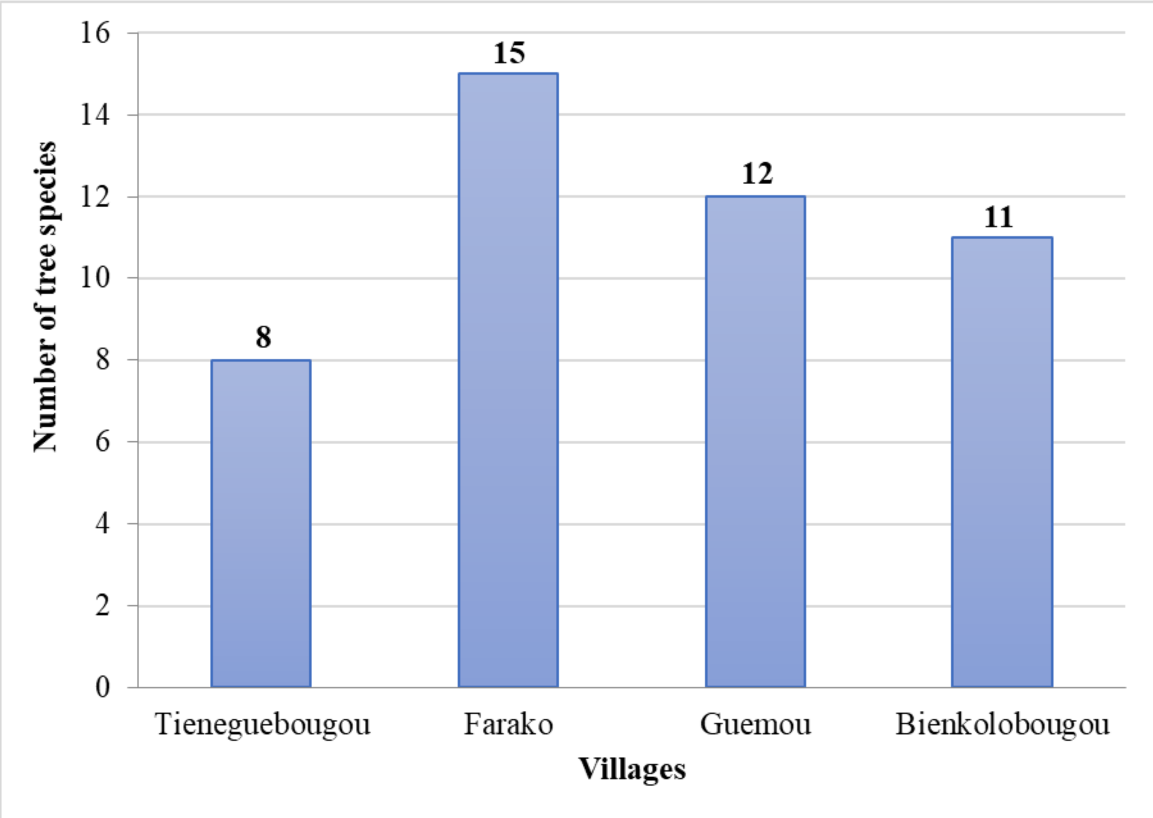

Figure 3. Number of tree species variation according to the villages' landscapes

In the studied areas, 27 species of trees belonging to 15 families and 25 genera have been inventoried (Table 1).

Table 1. Woody flora inventoried according to the rural communities

Families	Species	Rural communities			
		Tieneguebougou	**Farako**	**Guemou**	**Bignekolobougou**
Combretaceae	*Combretum collinum*	*			
	Combretum glutinosum	*	*	*	*
	Guiera senegalensis	*	*	*	*
	Anogeissus leiocarpus		*		
	Terminalia laxiflora		*		
	Terminalia macroptera				

Rubiaceae	*Gardenia erubescens*				*
Cesalpiniaceae	*Piliostigma reticulatum*	*	*	*	*
	Cassia sieberiana	*	*		
	Cordyla pinnata				*
Mimosaceae	*Acacia macrostachya*	*			
	Acacia albida				*
	Prosopis Africana		*		
	Acacia nilotica			*	*
Sapotaceae	*Vitellaria paradoxa*	*	*		
Meliaceae	*Azadirachta indica*		*	*	*
Bignoniaceae	*Stereospermum kunthianum*		*	*	
Rhamnaceae	*Ziziphus mauritiana*		*	*	*
Verbenaceae	*Vitex madiensis*		*		
Olacaceae	*Ximenia Americana*		*		
Anacardiaceae	*Sclerocarya birrea*		*	*	*
	Lannea acida		*		
Asclepiadaceae	*Calotropis procera*			*	
Logoniaceae	*Strychnos spinose*			*	
Capparaceae	*Boscia angustifolia*				
Bombaceae	*Bombax costatum*			*	*
Celastraceae	*Maytenus senegalensis*			*	
TOTAL		**8**	**15**	**12**	**11**

Legend: * indicates the presence of tree species in the villages' landscape.

The results of the inventory showed that the most represented families were: Combretaceae

(6 species), Mimosaceae (4 species), Caesalpiniaceae (3 species). In the experimentation locations, 3 species common to the four rural communities (Tieneguebougou, Farako, Guemou and Bignekolobougou) have been identified (11.11%). These were *Combretum glutinosum*, *Piliostigma reticulatum* and *Guiera senegalensis* (Table 1). The number of families has varied according to the villages' landscapes. There were 1, 2, 3 and 1 family respectively in Tieneguebougou, Farako, Guemou and Bignekolobougou. The number of genera also has varied according to the experimentation locations with respectively 1, 2, 2 and 1 genus.

3.2 Existing Status of the Woody Flora

The existing status of the woody flora is characterized throughout the indexes of diversity. The calculation of the diversity index according to the formula of Shannon Weaver (1949) and the regularity index of Frontier and Viale (1991) or the fairness index of Pielou (1966) showed that the index of diversity has varied according to rural communities. The diversity index of family was 1.17 in Tieneguebougou and Bignekolobougou, 0.87 in Farako and Guemou (Table 2). The diversity indexes in Farako and Guemou were identical and low. Tieneguebougou and Bignekolobougou produced the highest indexes. The regularity index of family has varied uniformly to diversity index of family in the four rural landscapes. The diversity index of gender has varied increasing by 0.05 for Tieneguebougou, 0.08 for Farako, 0.92 for Guemou and Bignekolobougou (Table 2). The regularity index of gender has followed the same trend as the diversity index of gender.

Table 2. Variation of flora parameters according to the rural landscapes

Parameters	**Values**			
	Tieneguebougou	**Farako**	**Guemou**	**Bignekolobougou**
Floristic richness	8	15	12	11
Index of family diversity	1.17	0.87	0.87	1.17
Index of family regularity	0.81	0.60	0.60	0.81
Index of gender diversity	0.05	0.08	0.92	0.92
Index of gender regularity	0.03	0.05	0.64	0.64
Index of Shannon	0.10	0.04	0.09	0.10
Index of regularity	0.06	0.02	0.06	0.06

4. Discussion

4.1 Floristic Composition

To improve trees biodiversity in the context of climate change, FMNR has been adopted as a climate-smart technology. The FMNR was conducted for 5 years (from 2016 to 2020) in the localities of Tieneguebougou, Farako (region of Kayes), Guemou and Bienkolobougou (region of Koulikoro). Before 2016, the number of tree species was low (3, 8, 4 and 3 species in the respective villages) due to climatic factors, human and animal pressure. The implementation of the FMNR has reversed this trend. The impacts of FMNR have resulted in an increase in the biodiversity of trees and the volume of wood in the agricultural areas of Tieneguebougou, Farako, Guemou and Bienkolobougou.

The flora of studied areas (Tieneguebougou, Farako, Guemou and Bienkolobougou) was characterized by the predominance of woody species belonging to the families of Combretaceae, Mimosaceae and Caesalpiniaceae. These results were consistent with those reported by Bakhoum in 2012. This author underlined the predominance of Combretaceae, Caesalpiniaceae and Mimosaceae in the groundnut basin (Senegal) whose ecological characteristics are similar to our studied areas.

The biodiversity of trees (botanic families, genera and species) had increased globally in the studied areas (Tieneguebougou, Farako, Guemou and Bienkolobougou) comparatively to the past ten decades. This increasing of trees species was due to World Vision Mali which had implemented in the studied areas a project of Farmer Managed Natural Regeneration (FMNR) named Eco-agriculture in Sahel. The farmers were trained on the techniques of FMNR and practiced it in agricultural areas. This FMNR practice consisted of preserving the main stems of plantlets; regularly pruning (cutting) of stumps and side branches; and making basins around these seedlings to promote the accumulation of rainwater. Added to this, was the protection of these trees against fraudulent cutting by offenders, bush fires, animal grazing and trampling. We noticed high diversity of trees (photo 2) in some agricultural areas (hut fields; bush fields and fallow fields) due to the good practice of FMNR.

Photo 2. High diversity of trees due to FMNR adoption in a bush field (Koulikoro, Mali), in 2017

It had been reported that fallowing bush fields promotes the natural regeneration of woody flora (Cisse, 1991a). According to Cisse (1991a, 1991b); the density of trees in Farmer Managed Natural Regeneration varies according to the species considered useful, the land use system (bush fields, hut fields), the technical route (manually cultivated fields, fields cultivated with a plow), the type of soil (sandy loam, sandy loam-clay and sandy-clay soil).

According to Larwanou and al (2006), the Farmer Managed Natural Regeneration ensures an improvement in biodiversity from local species adapted to the conditions of the environment and which tended to disappear due to the pressure of extraction exerted on them. This agroforestry technique both protects the environment while improving the living conditions of rural populations (Larwanou and al. 2006). The FMNR is low-cost technology in terms of monetary investment. In practice, each farmer can adapt it to his needs and situation. Studies have shown that properly cultivated crop fields with FMNR have more species than those irrationally cultivated (Ouedraogo and al. 2006).

The anthropization of agrarian spaces through the extensive agriculture was significant in Farako. This situation was due to population growth, the need for charcoal, non-timber products, service wood, firewood, fodder and arable land for cultivation causing the degradation of parklands trees. The timber products (charcoal, service wood, firewood and fodder) and non-timber ones (flowers, fruits, honey) were mainly sold in Kolokani and Didieni districts which are located at 15 km and 25 km respectively from Farako. The populations in Kolokani and Didieni are urbans and need more timber and non-timber products. This situation contributes regularly to low level of woody stand organization in Farako.

4.2 Existing Status of the Woody Flora

The woody stand in Farmer Managed Natural Regeneration in the studied areas was characterized throughout the index of diversity. Barbault (1992) reported that two woody stands can have a similar number of species and may have different structures. Two woody stands with a similar diversity index may have a different physiognomy. The index of regularity showed an identical high level of trees organization in Tieneguebougou; Guemou and Bienkolobougou. However, the index was low in Farako (Table 2). A comparison of indexes values proved while the floristic composition was low in Tieneguebougou, Guemou and Bienkolobougou, their woody stand organization was more constant. This means that the abundance of flora does not mandatory has a positive impact on the woody stand organization. The populations of Tieneguebougou, Guemou and Bienkolobougou practiced the Farmer Managed Natural Regeneration efficiently and respected regularly the local conventions on natural resources management. This is why the woody stand organization in these three rural communities was stable comparatively to the case of Farako.

Tieneguebougou and Bienkolobougou had the same index of Shannon (Table 2). In Farako and Guemou, the index of Shannon was 0.04 and 0.09 respectively. According to Akpo (1998), on the basis of Shannon index; regularity, richness and species diversity allow to make the classification of the woody stands.

The characteristic species has varied depending on studied areas with 2, 7, 3 and 3 characteristic species respectively in Tieneguebougou, Farako, Guemou and Bienkolobougou (Table 2). Tieneguebougou and Bienkolobougou had 1 characteristic family and 1 characteristic species. Farako and Guemou had 2 and 3 characteristics families respectively, but they had the same number of characteristic species (2 characteristic species per location). Farako was richer in characteristic species. This kind of situation is scare and presages the

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presence of a specific biotope. This result is consistent with those reported by Akpo (1998) and Ramade (2003). In the studied areas, rainfall data collected showed a regressive evolution with a strong inter-annual variability (Figure 2). The inter-annual variability of rainfall has been noted by many authors (Sarr, 2009; Toure, 2002; Batterbury and al. 2001; Hulme, 2001). In West Africa, the decline of rainfall was observed indicating the onset of drought since the 1970s (Ozer and al. 2010). This decrease in rainfall with dry periods has created many changes in different agro-climatic zones of West and East Africa (Diallo and al. 2001).

The local agreements for sustainable management of trees in agricultural areas were available in the studied areas but were respected differently by the rural communities of Tieneguebogou Farako, Guemou and Bienkolobougou. In fact, there was a low level of woody stand organization in Farako due to abuse of trees (photo 3).

Photo 3. *Combretum glutinosum* (a) and *Piliotigma reticulatum* (b) cutted down in agricultural area where FMNR was practiced; in 2017

The high carrying capacity of animals (photo 3) has contributed to overgrazing and to decline the level of wood stand organization in Farako. Moreover, there were natural factors such as the biology of trees, the type of soils and the climate change.

Photo 3. Watering session for animals in the dry season, in 2017

The results of this research are similar to those reported by many other authors. Some of these authors have shown the impact of drought on trees, human activities are probable to be factors of plant succession and environmental degradation (Dembele, 1996; Diallo and al. 2001). Kossi and al (2009), reported that climate aridity could cause the mortality of trees by reducing the availability of water and nutrients limiting the physiological functioning of trees. A reduction in defense systems of trees against disease attack could be driven by activation of physiological stress caused by the extension of periods of heat and dryness of environment (Wardell and al. 2003). Therefore, the species most sensitive to drought regress or disappear gradually. This situation confirms that the major climate constraint is not only low rainfall, but variability in the distribution that is a determining factor in the control of the Sahelian ecosystem, changing the flora and vegetation (Ozer and al. 2010; Hulme and al. 2001; Darkoh, 2003). These were species like *G. senegalensis*, *C. glutinosum*, *P. reticulatum*, *S. birrea* and *Z. mauritiana* that appeared more resistant to climate variability and were further represented in the inventoried plots (Table 1). The excessive cutting of trees has been highlighted as an important factor in the dynamics of woody regressive (Faye and al. 2008). In tropical Africa with increasing population, the fallow period is reduced or absent in places resulting in a degradation of vegetation (Kio, 1981).

The results of this research are also similar to those reported by Diallo and al. (2001), Dieye and al. (2008), Vincke and al. (2010), Akpo and Grouzis (1996b). According to those authors, in the majority of woody species that are undergoing a regression in semi-arid zone, the potential for regeneration exists, but environmental disturbances and certain factors inherent in species can compromise their reproductive patterns. Furthermore, animals' damages, mechanization, premature fruit picking, the decrease and variability of rainfall, pests (termites, grasshoppers) and the old age of trees are serious constraints to the regeneration of woody stand (Sene, 2000; Diouf, 2001). Yossi (1996), Cisse (1995), Alexandre (1989), Mitja (1993) reported that the strong anthropization of agroforestry parklands reduces the regeneration of woody trees and moreover their diversity.

According to Kio (1981) and Dembele (1996), despite the reservation of some useful trees in the fields, and the elimination of others by action of fire do not favor the recovery of the vegetation. Only the young trees are capable to regenerate quickly enough resulting in a change in vegetation structure and composition (Nasi, 1994; Fournier and al. 2001). This situation can be sustainable through the FMNR technology. In fact, this research has proved that the good practice of FMNR increases efficiently trees biodiversity and stabilizes the woody stand organization in parklands of rural communities. FMNR is a climate-smart technology. Its builds farmers' resilience through the provision of goods (fodder, firewood, etc.) and eco-systemic services (shade, micro-climate, carbon sequestration, etc.).

5. Conclusion

The FMNR has increased the number of tree species by 167%, 88%, 200% and 266% in the agricultural areas of Tieneguebougou, Farako, Guemou and Bienkolobougou. The FMNR has improved the volumes of wood by around 100, 99, 35 and 87 tons in the respective localities. However, the volumes of wood were low and have varied between 50 and 15 tons depending on the localities before the implementation of the FMNR project.

The scaling up of FMNR in Mali is essential, in order to reinforce populations' resilience facing to adverse effects of climate change.

Research must be continued in order to know the influence of *Sclerocarya birrea* and *Ziziphus mauritiana* on annual crops yields. This could help to appreciate their presence in agricultural areas.

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