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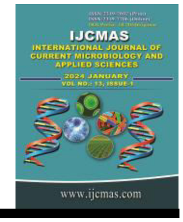

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Short-Term Evolution of Provision and Regulation Ecosystem Services in the Early Stage of Farmer Managed Natural Regeneration-Based System in Niger

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A B S T R A C T

Thousands of hectares have been treated with Farmer Managed Natural Regeneration (FMNR) over many decades to reverse the adverse effects of land degradation. Many studies have attempted to evaluate the effect of this Soil Land Management (SLM) practice a posteriori. The aim of this study is to assess the evolution of Ecosystem Services (ES) in the first stage of FMNR based agroforestry system in Niger. We, therefore, monitored the evolution of Ecosystem services in sixty farmers (30 practicing FMNR and 30 without practicing FMNR) over three years (2017, 2018 and 2019). The year 2017 was considered as the reference year. Provisioning ecosystem services (agricultural production, fire, wood, service wood) and regulating services (Carbone sequestration) where quantified each year from the same farmers and in the same fields. All crop yields were quantified by biophysical measurements using a plot yield (10m x 10m) included in a larger plot (50m x 50m) for dendrometry measurements. Carbone sequestration was measured by soil carbon analysis and allometric equation for vegetation Carbone. The evolution of financial benefit is measured using Cost Benefit Analysis (CBA). The results showed that the increase in yields in FMNR fields compared to non-FMNR fields was not regular for all crops. Furthermore, the FMNR system improves the regulatory service, and hence, it stores a higher amount of organic carbon (605.5 mg / kg) than the systems without FMNR (432.5 mg / kg). The results of the CBA showed that the incremental cost is negative in 2017 but positive in 2018 and 2019. Therefore, the FMNR practice makes farmers wealthier. Soil Land Management Practices are financially profitable when all ecosystem services are quantified and valued.

Introduction

Land degradation is a global phenomenon influenced by natural and socio-economic factors (Gichuki *et al.,* 2019). It is defined as the "decrease or disappearance of the biological or economic productivity of the land" (Dudley and Alexander, 2017).

The costs of land degradation due to human actions affect everyone in one way or another (Gichuki *et al.,* 2019). Land degradation through human activities also has a negative impact on the well-being of the rural population (Boureima, 2009). It leads to a massive extension of cultivated land to the detriment of fallow land, protected areas, forests, and a profound transformation of the land use system (Mahamane, 2001). It also leads to a reduction in soil carbon content, poor water storage, a reduction in biodiversity, a disappearance of ecosystem services and consequently, a reduction in food production (Dudley and Alexander, 2017; Gilbey *et al.,* 2019). It also causes a recurrent decline in fodder production, scarcity of non-timber forest products (NTFP), and wood in agrarian systems in the Sahel (Larwanou *et al.,* 2006).

The global economic loss resulting from the loss of ecosystem services due to land degradation and desertification has been estimated between USD 6.3 and 10.6 billion, or between USD 870 and 1,450 per person per year (ELD, 2015).

To address this situation, several initiatives are being undertaken at the regional and sub-regional levels aimed at counterbalancing land degradation through sustainable soil management and restoration (ELD, 2015).

In this context, the concept of land degradation neutrality (LDN) has emerged and disseminated on a regional scale by scientific communities (Gichuki *et al.,* 2019). This neutrality refers to "a state in which the quantity and quality of necessary land resources remain stable or increase over temporal and spatial scales.

At the sub-regional level, sustainable land management (SLM) initiatives are being implemented, such as Farmer Managed Natural Regeneration (FMNR) associated with anti-erosion measures, to reclaim unproductive land, enhance soil fertility, and increase crop yields (Bokoye, 2008). In other areas, various cropping systems involve practices like agricultural half-moons with millet, Zaï with millet, and dune fixation with FMNR (ELD, 2015). The results of these practices have led to an improvement in the monetary income of farmers and have promoted responsible land use by gradually enhancing soil fertility and increasing crop yields (Douramane *et al.,* 2019).

In certain areas of the Maradi region, for example, the adoption of FMNR has significantly reduced the reliance of high-dose crop protection products, and the use of chemical fertilizers has also decreased compared to situations without of FMNR practices. Additionally, several other ecosystem services derived from FMNR have shown improvement in the reclaimed areas (Jangorzo *et al.,* 2019).

This technology, being simple and mastered by farmers in their crop systems, is widely adopted. It has enabled the management of soil fertility and the intensification of cultivated crop production (Botoni *et al.,* 2005). Previous studies have demonstrated that the practice of FMNR and other SLM practices, adapted to their contexts, reduces land degradation and helps maintain livelihoods over time (Robert, 2002; Botoni *et al.,* 2010; Dia and Dia, 2012; SEI, 2014; Abdou *et al.,* 2014; Diedhirou, 2018; Jangorzo *et al.,* 2019; Serge Félix *et al.,* 2020). They have also preserved ecosystems and the livelihoods of communities, thus increasing ecosystem services for the benefit of land users (Abdou *et al.,* 2014; Douramane *et al.,* 2019; Seghieri and Harmand, 2019; Serge Félix *et al.,* 2019).

The diversity of ecosystem services provided by agroforestry systems underscores the importance of conserving young plant populations that regenerate naturally, considering the goods and services they offer to humans. Monitoring the dynamics of these ecosystems will help us understand the variations in the services they provide to humanity. Most studies that assess the impact of this practice on ecosystem services provision overlook the starting point of the practice. The evaluation is, therefore, conducted a priori. The objective of this study is to assess the dynamics of ecosystem services in the first stage of the evolution of FMNR-based agrosystems.

Materials and Methods

Study site

This study was conducted over three years (2017, 2018 and 2019) in the village of Mallam Kaka, situated in the rural commune of Sabon Machi (Dakoro department). It is located approximately 6Km from the commune of

Sabon Machi, 55km from Dakoro and 46km from the town of Maradi. The village of Malan Kaka is located at 13,995277778° East latitude and 7,2091666667° North longitude. Malan Kaka is located in the most populated part of the Maradi region (Dakoro department) but with the lowest density (24 inhabitants/km²). As of 2012, the population of the village was 847 inhabitants, primarily composed of farmers (INS, 2012). The climatic characteristics of this village are marked by an average rainfall of 437.9 mm. The temperature exhibits minimum values ranging between 15 and 20°C during the cold dry season and maximum values reaching 39 to 42°C during the dry season. The vegetation is predominantly shrub savannah. The main economic activities in this village include agriculture, livestock, and trade. The pedoclimatic and socio-environmental conditions of this village are almost similar to those of the Maradi region.

Socioeconomic sampling: choosing farmers to participate in the study

A complete list of farmers who were targeted to receive technical support on the practice of FMNR was established. To determine the number of farmers considered in the present study, hence used the random sampling method. A total of 60 farmers were individually surveyed, including 30 practicing FMNR and 30 not practicing, allowing for a comparison between the two situations.

Data collection

Three data collection methods were used: i) a focus group followed by ii) an individual survey and iii) biophysical measurements for all the 60 farmers. The biophysical measurements included crop yield, soil carbon, and dendrometry parameters for trees.

Measurements of crop yield

After identifying the target farmers, nine yield plots (10m x 10m) were randomly distributed in each field over the three years. At harvest, the weights of both grain and fodder from the cultivated crops were measured.

Soil sampling

Soil samples were collected at a depth of 20 cm from each plot using an auger. In each 100m^2 plot we collected five (05) elementary samples (four samples on the diagonals and one sample at their intersection), which were then mixed to create one composite sample per plot. Subsequently, the nine samples were combined to form one composite sample per field. In total, sixty (60) composite samples were collected and analyzed.

Measuring dendrometry parameters

Three plots of 50m x 50m (2500 m2) were implemented in each and same field along the three years. In each plot, the density and number of trees are measured. The parameters measured on trees are the diameter at the height of 1.3 m, the size and diameter of the crown, and the height. Additionally, the shoots and the number of their stems were counted and recorded.

These measured parameters were used to estimate the carbon stored by vegetation in each field. The total carbon captured by vegetation is the sum of carbon stored in aboveground biomass and below ground biomass. The value of carbon stored in above ground biomass is estimated by allometric equation and tested by Mbow (Mbow, 2009) and reported by Kuyah and in REED+ (Kuyah *et al.,* 2012; REED+, 2017), which appears to well-suited for agroforestry system in tropical regions. This equation, with a prediction probability of 95% and a bias of -0.8, was employed to estimate the quantity of aboveground tree biomass.

The equation is written as follows:

$$Y_{tree} = 0.229xH^{2.237}$$

Where: Y_{tree} is the biomass contained in a tree; H is the diameter at height 1.3 m from the ground.

Root biomass is estimated at 50% of standing trees and shrubs (Mille and Loupe, 2015), using another allometric equation established in Kenya by Kuyah *et al* (2012). This equation overestimates the tree biomass by 14%. The equation is written as follows:

$$Y_{ground} = 0.49xZx0.923$$

Where: Y_{ground} is the root biomass (below ground); Z is the aerial biomass (above ground).

Total biomass is the sum of aboveground biomass and below ground biomass. Vegetation carbon is calculated by multiplying the total biomass by the carbon fraction, which is (0.5) (Ouedraogo *et al.,* 2020). To correct overestimation errors resulting from the equation, 14% is subtracted from the plant carbon.

Collection of socio-economic data through surveys

Socio-economic data were collected using SurveyXact implemented on tablets. The data are relate to the agricultural carried out, and the ecosystem services provided practices of the producers (surface area exploited, type of crop rotation), the costs of the different cultural operations through the adoption of FMNR.

Soil analysis

Soil pH (1:2.5) and soil carbon (analyzed using the method developed by Vaneck *et al* (2018) were analyzed.

Data analysis

The collected data were cleaned, and descriptive analysis were carried out to understand the general trend in the evolution of certain ecosystem services. Subsequently, the average of all services was determined and compared according to year and practice. Analysis of variances and statistical test (T-test) for independent samples, with a margin error (0.05), was done to examine the effect of the year.

For the economic analysis, the various costs of all cultivation operations and other outputs (investment made), as well as the products of all services and other inputs were calculated. The net benefits of each situation were determined, as well as the Incremental Cost.

Results and Discussion

Evolution of provisioning services at business as usual

The evolution of ecosystem services supplied in farms where FMNR is not practiced indicates that only cowpea grain yield, firewood, and service wood demonstrate a significant increase over time. Indeed, a gradual evolution of cowpea grain yield is observed from 2017 to 2019 (Figure 1). Specifically, there is a gradual improvement in cowpea grain yield observed from 2017 to 2019 (Figure 1). This suggests that even without practicing FMNR, ecosystem services can still increase based on environmental conditions. The statistical test results show that cowpea grain yield is significantly higher in 2019 than in 2017 (T-test, p=0.031).

The highest cowpea grain yield is approximately 2000 kg/ha, produced in 2018 and 2019, while the lowest is approximately 800 kg/ha, produced in 2017. The quantity of firewood supplied in 2019 is higher than that of 2017 and 2018 (Figure 2). On average, the quantity of energy wood supplied per year and per farmer is around 100 bundles.

The general trend of variation in the quantity of firewood supplied during these years indicates an increase in the production of energy wood in both the fields of producers practicing FMNR and those who do not. This trend is consistent with the quantity of service wood produced in 2017, which is lower than that in 2018 and 2019 (Figure 2b).

Evolution of ecosystem services in FMNR

The evolution of provisioning services in FMNR fields from 2017 to 2019 shows a significant increase in millet grain yield, cowpea grain yield, the quantity of firewood, and service wood. However, the general trend in the variation of millet grain yield (Figure 3) exhibits a significant difference between 2017, 2018, and 2019 (ANOVA, p=0.045).

The millet grain yield in 2019 is significantly higher than that in 2018 and 2017. The cowpea grain yield in 2017 is around 300 kg/ha, while that in 2018 is around 2000 kg/ha, and it decreased in 2019 to around 400 kg/ha (Figure 4). The cowpea grain yields in 2018 is significantly higher than those in 2017 and 2019 (ANOVA, p=0.029).

This shows that the evolution of cowpea grain yield is not only dependent on the practice but also on the year. As the production system depends on the rainy season and attacks by biopests, these factors could affect the yield more than the SLUM practiced in the field. The quantity of firewood and service wood supplied by the FMNR-based ecosystem in 2017 is lower than that in 2017 and 2018 (Figure 5). The different is statistically significant (ANOVA, p= 0.026; p= 0.05 respectively). The results suggest that something may have happened in 2018 that induced the decrease in wood supply. This could be explained by the temporality in action concerning the wood collect in a FMNR field. However, firewood and, particularly service wood is not collected each year.

In 2017 and 2019, the volume of service wood taken each year and per farmer is around 500 stakes, while in 2018, the volume is low and is around 200 stakes.

Does the FMNR practice increase provision ecosystem services?

We compared rh ecosystem services provided in FMNR fields to those without FMNR year by year. In 2017, the results showed that the quality of millet grain, sorghum grain, and sorghum stalks in FMNR fields is significantly higher than that without FMNR (Figure 6).

The other services show a trend of increase, but he difference is not significant. This means that farmers who practice the FMNR significantly increase the grain yield of principal cereals (millet and sorghum) compared to those who do not practice in the same period of time. In 2018, we also observe a similar evolution. However, the grain yield of millet, cowpea, and sorghum, as well as the stalks yield of sorghum, are significantly different depending on whether FMNR is practiced of not (Figure 7).

The practice of FMNR significantly increases the yield of major crops in family farming, and this has a positive impact on the income of households. The same trend is observed in 2019 as in 2017, where the grain yield of millet and sorghum, as well as the stalks yield of sorghum, are significantly different according to the practice (T-test, $p<0.0001$; $p=0.000$; $p=0.01$, respectively). Farmers who practice FMNR significantly increase the yield of most cultivated crops. The other components show slight increases for farmers who practice FMNR, but the difference is not significant.

Evolution of regulatory service

Soil carbon is a true indicator of soil fertility. Therefore, the value of the soil carbon content obtained in 2018 (350 mg/Kg of soil) in the fields with FMNR is slightly higher than that obtained in 2019 in the same fields (Figure 8). On the other hand, the value of the soil carbon content obtained in fields without FMNR in 2019 (300 mg/kg) is higher than that obtained in 2018 (250 mg/Kg). These results show how this practice allows the restitution of organic matter in the soil. The general trend of the variation in soil carbon in these two systems between the two successive years shows that the evolution of the soil carbon is more significant in the fields under FMNR. In 2019, the soil carbon increased simultaneously with a small difference between fields under FMNR and fields without FMNR. The maximum potential for additional carbon storage in agricultural soils could be of the order of 1 to 3 million tons per year (Jérôme, 2014).

Results of vegetation carbon quantification show that the quantity of vegetation carbon captured by trees in 2018 (15t/ha) is greater than that captured in 2019 (10t/ha). The general trend in the evolution of vegetation carbon shows that the difference is more marked between years than between the practice.

Cost benefice analysis

The results show that, under the business as usual scenario, the incremental cost is negative (Table 1), indicating that, at the beginning of the FMNR practice, farmers, based on their initial investments, are losing money. However, it's better for them to invest their money elsewhere than in FMNR. But from 2018 the incremental cost becomes positive, which means that it increased significantly with an average annual income gain of 307,105 FCFA.

In 2019, the incremental cost decreased to 163,939 FCFA. This change in the status of the incremental cost shows that from the second year of the practice of FMNR, it is profitable for the producers who practice it.

This indicates that the longer the practice lasts, the more producers earn a significant monetary income. Additionally, apart from the installation of the FMNR, some producers use other sources of spending money such as purchase of organic manure, mineral fertilizers, phytosanitary treatment, and others, which are the subject of significant investments.

Evolution of production in 2017, 2018 and 2019 among producers who do not practice FMNR

The results of studying the evolution of services over time show that in the system without FMNR, the returns on speculation have increased. This increase in yields of the three main crops observed over two years in the fields of producers not practicing FMNR could be explained by the agroecological advantages of crop association, especially the association of legumes with cereals, where interspecific competition is reduced. Associated species can manage their quantitative and qualitative needs for nutrients, water, and sunlight differently. According to the idea of Boureima (2009), the first advantage of crop association is the increase in the overall yield of associated crops. Indeed, the result of the study by Abass (2020) carried out in Dosso and in the Maradi region showed that among the yields of the crops studied, the highest are observed in the association of cowpea with millet (29.44 kg/ha) and sorghum (29 kg/ha).

In the agroforestry system, several speculations are associated with very heterogeneous species densities per hectare. As for the densities of trees and shrubs of different species, they are too diversified in producers' fields where previous cultivations are not taken into account. Therefore, several factors not taken into account would explain this drop in peanut yield: for example, a bad combination of the components of the association, a bad cultural precedent, and/or a very high density of associated speculations.

Our study shows that nine types of associations are found in producers' fields, among which three types of associations are composed of legumes such as peanut, cowpea, sorrel, and sesame. An antagonistic effect of the previous crop was demonstrated by Viaux (1999) on the cultivation of peanuts where the previous crop, soybean, gave a yield of 0.46 kg/ha. As for the drop in cowpea yields and the quantity of energy wood noted in 2018, it could be explained by i) human and animal overexploitation of cowpea tops; ii) abusive, clandestine, or fraudulent cutting of trees and shrubs by women, children, and the threat of animals."

Evolution of production among producers practicing FMNR

Summary of table 2 shows that all yields of cultivated crops fell from 2017 to 2018 in the FMNR system, with the exception of millet, cowpea, and cowpea tops. However, we know that the agroforestry system based on FMNR is a basin with good productive potential for all the main crops encountered in the area. The average density of trees and shrubs in producers' fields in the area is 47 plants/ha in fields without FMNR compared to 77 plants/ha in fields with FMNR. Thus, the area is spotted with numerous stumps of regenerating doum palm (*Hyphaene thebaica*). This difference in positive and negative evolution of yields observed between the different productions could be partly explained by the interspecific competition between trees and crops for the use of the limiting resources available (water, light, temperature, and mineral elements), and intraspecific competition between associated cultures. A similar situation was demonstrated by Abdou *et al* (2014), where the effect of shading can constantly reduce the number of fertile tillers and then the yield of grain sorghum.

According to Serge *et al* (1995), the genotype of the plant is not the only one responsible for the production of a cultivated variety. The observed reductions in yields could be explained by the cumulative rainfall deficit recorded in 2018 in the study area.

The annual cumulative rainfall was 487.1 mm in 37 days (zone facilitator source). On the other hand, the increase in yields of all crops observed apart from cowpea in 2019 could be explained by the complementary contribution of the practice of FMNR, through its mechanism for maintaining soil fertility.

SEI (2014) showed that depending on tree density, an increase in millet grain yields ranging from 32 to 165 kg/ha for an FMNR of less than 3 years, from 59 to 221.5 kg/ha for an FMNR of 3 to 6 years, and of the order of 120 to 209.5 kg/ha for an FMNR of 6 years or more was observed in the department of Aguié. Larwanou *et al* (2012) showed that the use of trees in fields contributes to improving soil fertility and agricultural production in general. However Abdou *et al* (2014) showed that the tree promotes the regulation of pH, the accumulation of organic carbon (C), nitrogen (N), cation exchange capacity (CEC), assimilable phosphorus (P), and the sum of exchangeable bases (S) through the recycling of its external organs (falling leaves, fruits, and branches) and underground roots.

Evolution of carbon sequestration in systems with and without FMNR

Organic carbon (C) stored in the soil represents the largest reservoir interacting with the atmosphere (Robert, 2002; Roland, 2018). This study showed that the concentration of soil carbon in fields with FMNR is greater than in fields without FMNR for all years of our study, with the difference being more visible in 2018.

Table.1 Results of financial analysis in three consecutive years in Malan Kaka

Without FMNR			
	2017	2018	2019
Cost (CFA)	155 405	350 813	155 405
Product (CFA)	783 881	783 881	413 779
Benefit (CFA)	628 476	433 068	258 374
With FMNR			
Cost (CFA)	350 813	131 050	118 926
Product (CFA)	90 115	871 223	541 239
Benefit (CFA)	-260 698	740 173	422 313
Incremental cost (CFA)	-889 174	307 105	163 939

Figure.1 Evolution of ecosystem cowpea grain yield depending on time in farms where FMNR is not practiced

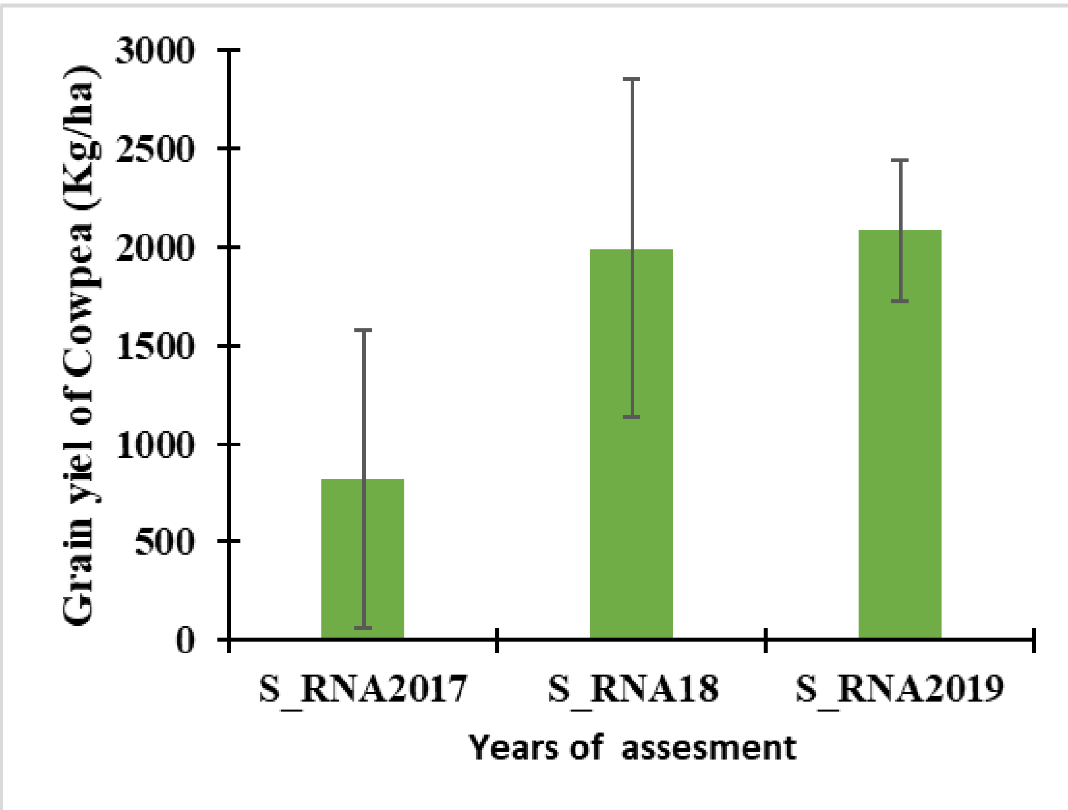


Figure.2 Evolution of fire wood (a) and service wood (b) quantity depending on time in farms where FMNR is not practiced

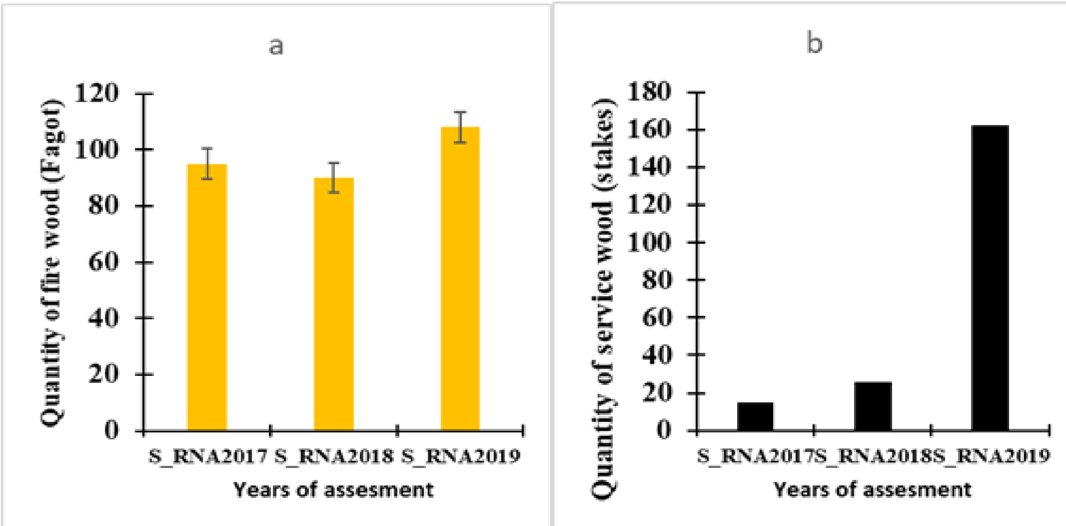


Figure.3 Evolution of millet grain yield depending on time in farms where FMNR is practiced

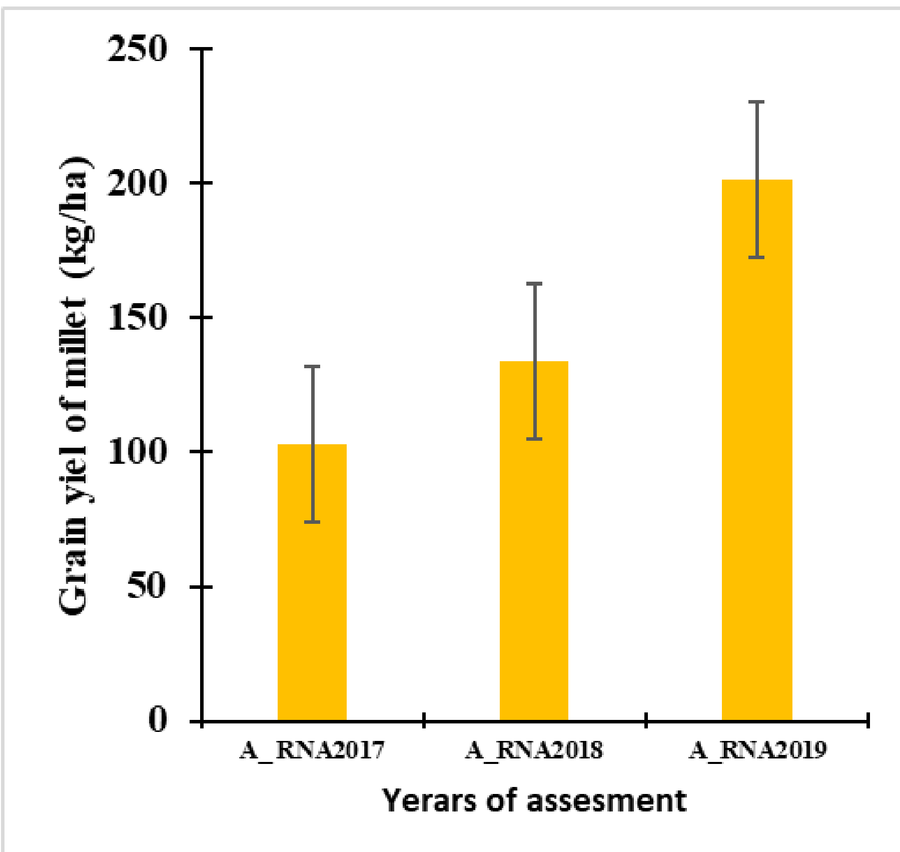


Figure.4 Evolution of cowpea grain yield depending on time in farms where FMNR is practiced

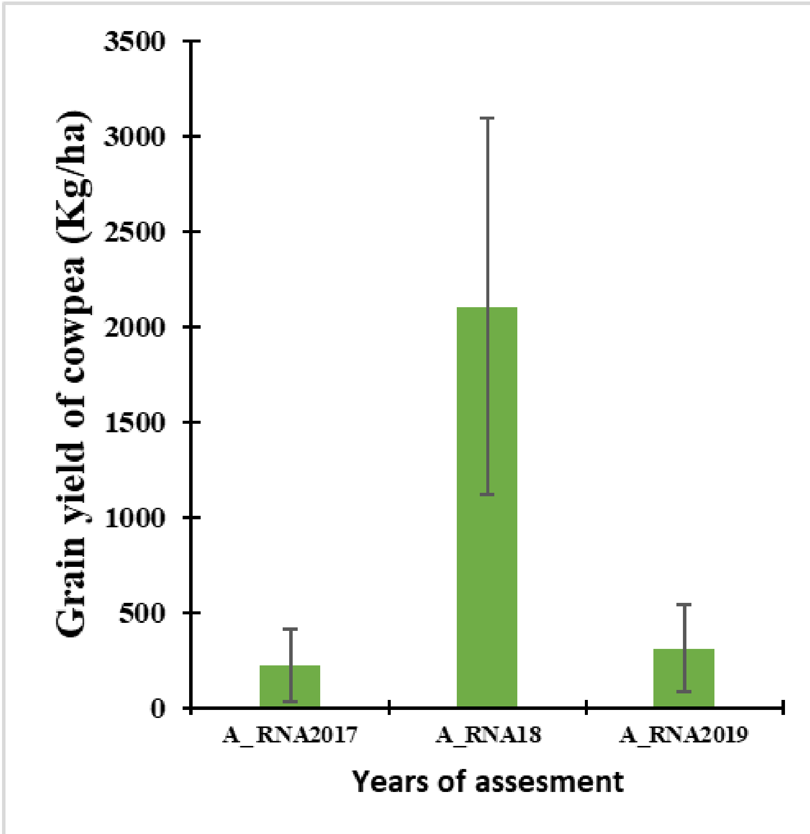


Figure.5 Evolution of fire wood (a) and service wood (b) quantity depending on time in farms where FMNR is practiced.

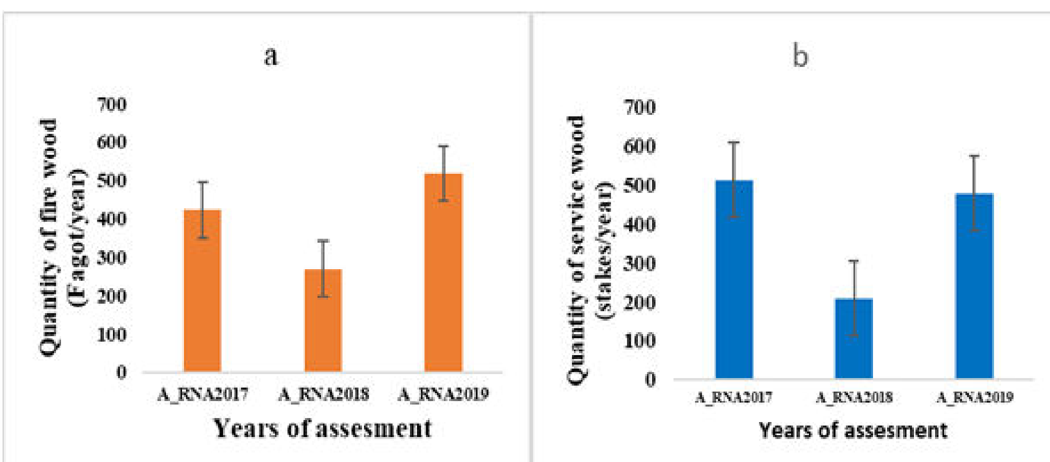
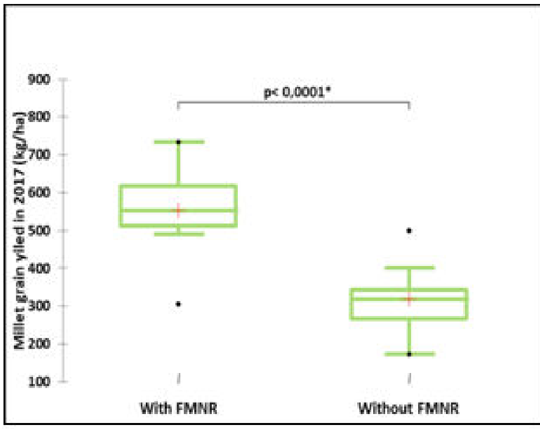
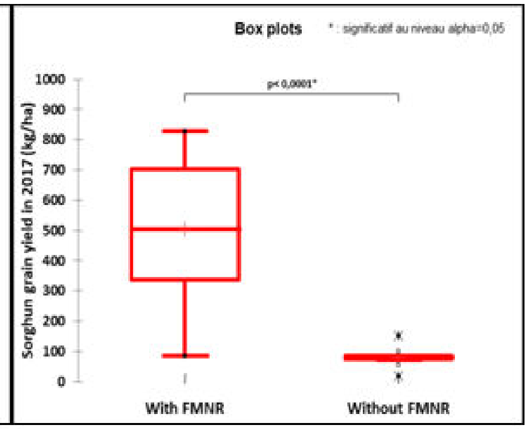


Figure.6 Evolution of millet grain yield (a), sorghum grain yield (b) and sorghum stalks yield in 2017 depending on the practice.

a



b



c

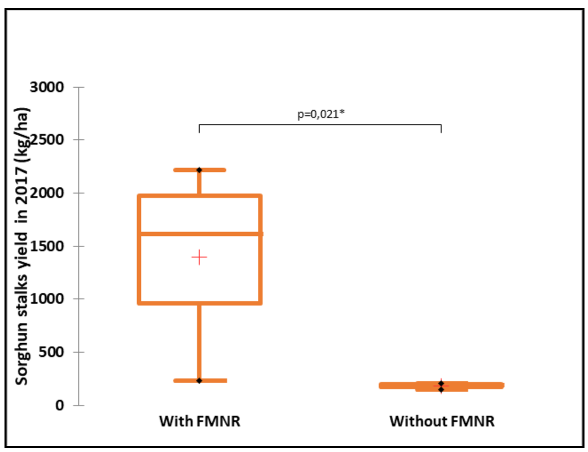


Figure.7 Evolution of millet grain yield (a), sorghum grain yield (b) cowpea grain yield (c) and sorghum stalks (d) yield in 2018 depending on the practice.

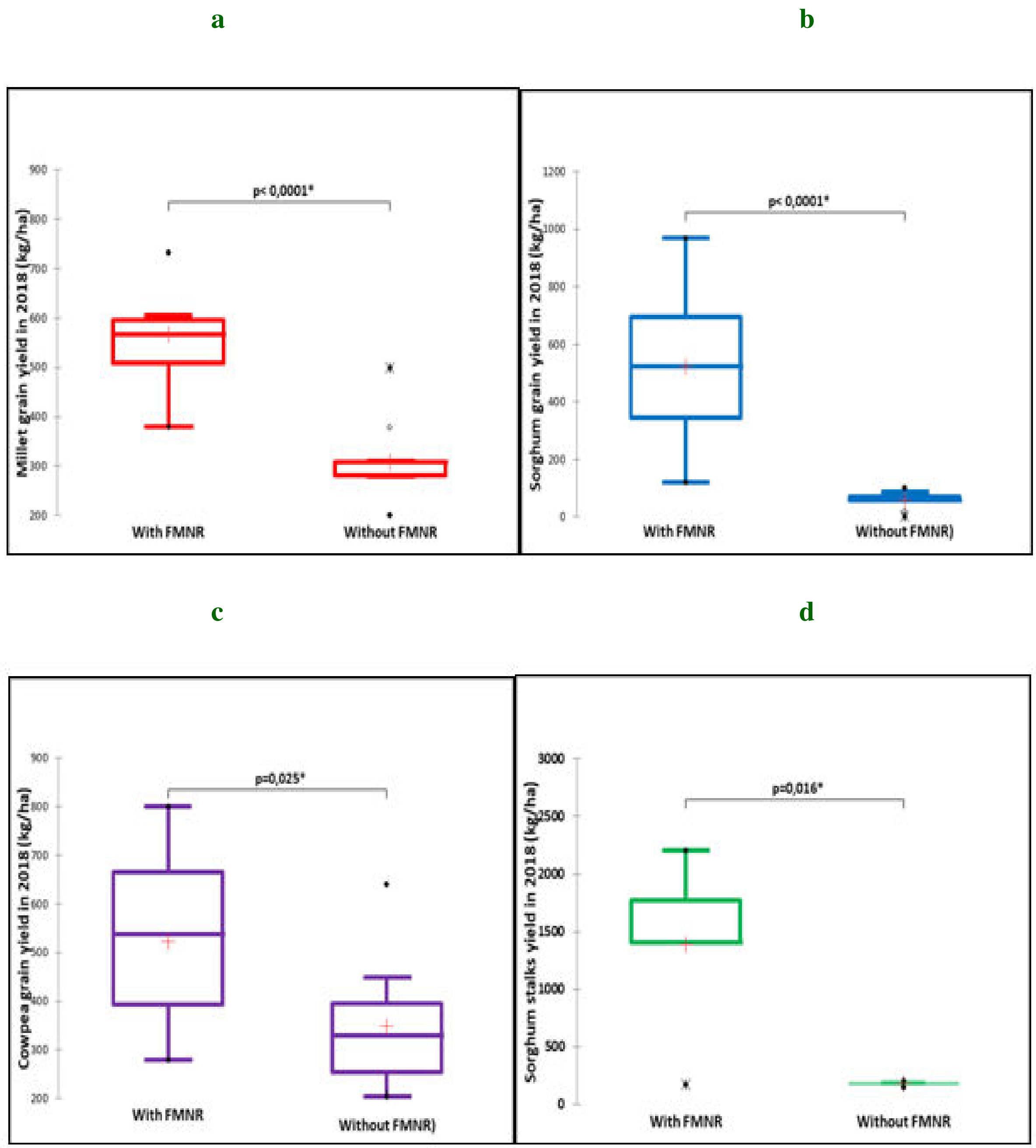
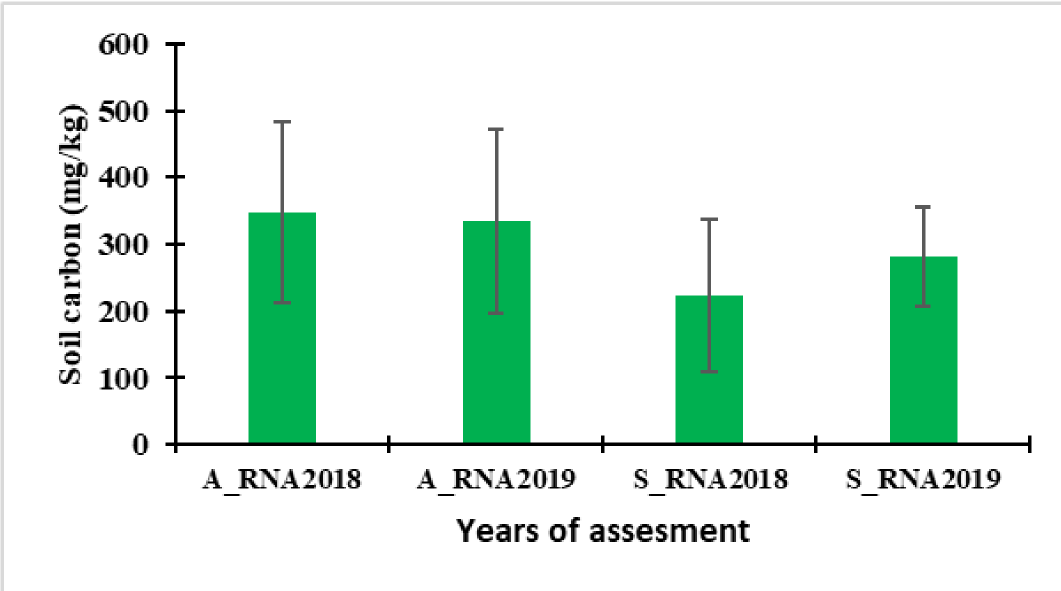


Figure.8 Evolution of soil carbon in fields with and without FMNR during the years 2018 and 2019.



The increase in carbon content can be explained by the mechanism of recycling of soil organic matter following the decomposition and mineralization of tree and shrub litter from this ecosystem. The organic matter rate in fields with FMNR amounts to 605.5 mg/kg of soil, while in fields without FMNR, this rate is around 432.5 mg/kg of soil. This can be explained by a gradual recovery in soil fertility following the recycling of organic matter. These results differ from an organic matter rate of 0.54% obtained in open fields and 0.66% around *Faidherbia albida* found by Zakari (2015) in Araourayé in the rural commune of Sherkin Haoussa (department of Mayahi). This result shows that the cultural practice of soil fertility management based on FMNR plays a vital role in the renewal of mineral elements taken during the exploitation of land resources.

Zakari *et al* (2016) showed that the yields of the main crops are better in fields with woody plants. For example, the presence of trees makes it possible to obtain grain millet yields varying from 100 kg/ha to 370 kg/ha, while grain millet yields in control fields are around 50 to 100 kg/ha.

The result of this study highlighted the multiple environmental benefits that FMNR plays in an agroforestry system. In fields without FMNR, the carbon value of vegetation is close to 10 tC/ha. Carbon sequestration by vegetation explains that FMNR contributes to the reconstitution of plant populations and the reduction of significant quantities of atmospheric carbon dioxide (CO_2) (Robert, 2002). According to ILWAC (2013), all plants, including trees and other forest plants, use photosynthesis to absorb CO_2 and transform it into different organic compounds that make up plant material like wood, bark, or leaves. This, therefore, contributes to the reduction of CO_2 in the atmosphere. Because, according to Abasse *et al.,* (2017), the carbon concentration of vegetation is positively correlated with the growth parameters of different plant species. FMNR plays multiple environmental roles through the regeneration of trees and shrubs and wood production. Thus, through the development of root systems fixing the soil and significant soil coverage, it contributes to ensuring the storage and/or sequestration of carbon, improving the physical, chemical, and even biological fertility of the soil.

This point of view is confirmed by Botoni *et al* (2010), who assert that one of the environmental benefits of FMNR is the contribution to carbon sequestration. Thus, Abasse *et al* (2017) showed that depending on the annual rainfall and the plant species that dominate the ecosystem, sequestered plant carbon is more important in the agroforestry system than in wood production areas.

The result of this study showed that the practice of FMNR in an agroforestry system increased the stock of soil carbon and the quantity of carbon sequestered by vegetation. So, this improved the physico-chemical structure of the soil through the progressive accumulation of organic matter in the soil and its resistance to erosion. However, soil fertility and crop yields remain too unstable.

Evolution of monetary income

The economic evaluation part of this study highlighted the realities of the practice of FMNR in an agroforestry system. We found a negative additional net benefit in the reference situation, explaining why the practice of FMNR was not economically profitable when first implemented. This loss incurred by producers practicing FMNR could be explained by the installation costs used by certain producers, which far exceed the products obtained.

The average annual cost spent by all the producers concerned in this village for the implementation of the FMNR amounts to 350,813 FCFA. If the year is not good in terms of rainfall and other natural calamities, it is very likely that yields have fallen, leading to a drop in monetary income for producers practicing FMNR. Botoni *et al* (2010) showed that the costs of installing the FMNR in the 3M strip in Zinder only concern the costs of clearing, the costs of locating and maintaining young shoots, as well as the costs of the conduct of the FMNR. In total, the amount spent for a producer is around 22,000 FCFA. In this case, the practice is economically profitable.

On the other hand, the additional net profit is positive from 2018 to 2019, showing that the FMNR improves the economy of producers in rural areas. This is explained by the sale of various products resulting directly or indirectly from the practice of FMNR. This result shows that producers who practice FMNR benefit economically from FMNR.

However, the average annual monetary income earned is very unstable from one year to the next. This result is confirmed by Sitou *et al* (2018) in their study on the evaluation of the contribution of FMNR in the economy of vulnerable households in Dan saga department of Aguié.

It demonstrated that the sale of products from the RNA generates an annual income of 19,793,291 FCFA, or 199,932 ± 33,624 FCFA per household, significantly increasing the level of household food coverage. Therefore, the FMNR, through its ecological, agronomic, economic, and societal roles, contributes to improving the living conditions of the populations in the area.

In conclusion, this study aimed to assess the dynamics of ecosystem services over a three-year period in the early stages of a Farmer-Managed Natural Regeneration (FMNR) based agro-system. The quantity of various ecosystem services in such a system increased over the years, irrespective of FMNR practice. Traditionally, farmers refrain from completely clearing trees on their farms, preserving some for firewood, service wood, and for the regulation and cultural ecosystem services they provide. Distinguishing fields where FMNR is practiced solely based on tree presence is challenging, but discernment can be achieved through tree density and structural analysis.

Moreover, certain ecosystem services, especially provisioning services, exhibited higher quantities in FMNR fields compared to business-as-usual practices. The valuation of these ecosystem services demonstrated that FMNR practices enhance farmers' income compared to those not engaged in the practice. This study underscores the imperative for long-term monitoring of agroforestry systems to comprehensively understand their dynamics and the evolving ecosystem services crucial to humanity.

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Author Contribution

Nouhou Salifou Jangorzo: Investigation, formal analysis, writing—original draft. Abou-SoufianouSadda: Validation, methodology, writing—reviewing. Sami Mari Ousmane:—Formal analysis, writing—review and editing. Hassane Bil-Assanou Issoufou: Investigation, writing—reviewing.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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