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Research paper

Moringa oleifera based agroforestry system in carbon sequestration

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The agroforestry system represents a significant part of the environmental improvement in Niger. It contributes to food security and is a source of income for many households in this country. This study assessed the contribution of the agroforestry system based on *Moringa oleifera* Lam. to ecological resilience, particularly in terms of carbon sequestration in the urban commune of Tibiri-Gobir. There are many different cropping associations using moringa, depending on the farmer's objective. Thus, about ten moringa-based agroforestry practices have been identified in this area. In addition, this moringa-based agroforestry system contributes significantly to ecological resilience through carbon sequestration. Its growth capacity and root system now allow for the storage of a large amount of carbon in the soil and thus reduce the negative effects of climate change. In order to quantify the carbon sequestered by this system, the destructive method was applied to a sample of 30 moringa plants collected from 6 sites along the valley of Goulbi Maradi. Finally, local allometric models were developed to estimate the dry biomass of trees and their capacity to store carbon. Thus, a moringa-based agroforestry system can store up to 1.7tonne/ha of carbon in a monoculture and 0.54 tonne/ha in Mixed cropping.

Key words: *Moringa oleifera, climate change, agroforestry, carbon sequestration, allometric equation*

INTRODUCTION

Climate change has been a reality since the 1970s and its effects are visible on natural resources in developing countries in general and Sahelian countries in particular (GWP/AO, 2010). The effects of climate change are a combination of several factors. These include global warming, low rainfall, droughts and floods. All these factors result in the vulnerability of the world population. Like other African countries in general, and West Africa in particular, Niger, a Sahelian country with a land area of 1,267,000 km^2 is one of the most vulnerable countries to climate change. This high vulnerability is most often attributed to some of its physical (very significant contrast between humid and arid zones, interdependence with other countries regarding water resources) and socio-economic (extreme poverty, dependence of rural populations on rain-fed agriculture, very little exploited hydro-agricultural potential) characteristics that predispose it to be disproportionately affected by the negative effects of climate variations. Through its expected adverse effects on human health, food security, economic activity, water and other natural resources, as well as physical infrastructure, climate change is today considered one of the most serious threats to the sustainable development of the less developed countries and Niger in particular. According to the latest report of the Intergovernmental Panel on Climate Change (IPCC) in 2015, the observed climate change is indeed caused by human activities (Renaudeau, 2015). The concentration of CO_2 in the atmosphere has now exceeded 400ppm (parts per million), up from 350 ppm in 1985. If

agriculture contributes to the increase of the greenhouse effect, its specificity must however be recognized, on the one hand, agricultural emissions come from the natural process and are therefore more difficult to limit, on the other hand, agriculture as well as forests are the only activities able to store carbon sustainably and to produce substitutes to fossil materials and energies (Renaudeau, 2015). Faced with this situation, the farmers of the urban commune of Tibiri-Gobir did not remain indifferent. They have started to develop strategies of combining different systems namely: agropastoral system, agro sylvopastoral system and agroforestry system for several decades to increase the resilience of livelihoods in the face of threats and crises due to climate change. However, in this study we will focus on the agroforestry system based on *Moringa oleifera* to assess its contribution to ecological resilience through carbon sequestration in the urban commune of Tibiri-Gobir in Niger.
The moringa-based agroforestry system is the most widely practiced system in the valley of Goulbi Maradi , particularly in the urban commune of Tibiri-Gobir. The urban commune of Tibiri-Gobir is one of the major moringa producing areas in Niger. Moringa (*Moringa oleifera*) is a plant native to the Indian subcontinent. In Niger, it is cultivated for its leaves which are consumed in boiled form or as a fresh vegetable. It is produced under irrigation in market gardens sites in monoculture or in association with vegetable crops such as onion, lettuce, bell pepper, tomato or squash (Haougui et al., 2017). Moringa contributes to the improvement of the nutritional quality of the diet of Nigeriens (Koroney et al., 2019). Indeed, Moringa is rich in trace elements (mainly calcium, iron and vitamins) and proteins. Moringa is used as service wood. However, it finds its full use in agro forestry systems, but especially in human food and pharmacopoeia. The roots as well as the grains are highly sought after and used to purify the water. The leaves and young branches are also consumed by livestock. At the national level, moringa is the seventh most important vegetable crop with a cultivated area of 1425.45 ha (MAG, 2013). Annual production is estimated at 92 114,5 tons with an average yield of 23 t/ha (INS, 2015). The main production areas are located in the regions of Zinder, Maradi, and Dosso, but new production basins are developing in the regions of Tahoua, Niamey, and Agadez. Moringa production has increased steadily in recent years. Unfortunately, the socio-ecological contribution of this system to ecological resilience is not well known in this zone. Indeed, there is little data on the types of agroforestry systems in this area and their impact on carbon sequestration. In order to fill this gap of information, our study was focused on the evaluation of the contribution of the agroforestry system based on *Moringa oleifera* to ecological resilience through carbon sequestration in the urban commune of Tibiri-Gobir in Niger.

MATERIALS AND METHODS

Study area

The urban commune of Tibiri-Gobir is located between latitude 13º34'01'' North, and longitude 7º03'07'' East. It covers a land area of 1,200 km^2 and spreads from East to West over about 85 km which constitutes its South-Western base along the Nigerian border and from North to South over about 20 km along National Road N°1 (Figure 1).

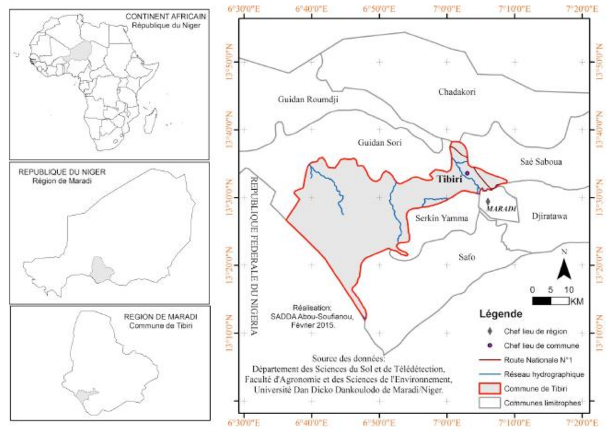

Figure 1. Presentation of the geographical situation of the commune of Tibiri-Gobir

It is bounded to the north by the rural communes of Chadakori and Guidan Sori, to the south by the rural communes of Sarkin-Yamma and Safo (Madarounfa department), to the east by the rural commune of Saé-Saboua and the town of Maradi and to the west, the Federal Republic of Nigeria. The population of the urban commune of Tibiri - Gobir is estimated at 136008 inhabitants (INS, 2014). The female component is 51% or 68701 women and men are 67307 or 49% of the workforce, with a density is 113 inhabitants per km². The urban commune of Tibiri-Gobir had 1903 households in 1988. This number increased to 2630 in 2001 and then to 10666 households in 2011 (INS, 2011), an average increase of 4381 every 10 years and 87 households per year.

Biological material

The main biological material is *M. oleifera*.

Other materials

The following material were used to conduct this stud:

- A 16 m tape measure for the measurement of diameters, heights, inter-bunch and inter-row distances of trees;
- A Global Positioning System (GPS) to geo-reference certain landmarks, such as the experimental field sites fields during the survey;
- A computer for data processing and analysis;
- A precision balance to measure fresh and dry biomass of trees;
- Plastic bags for samples packaging;
- An axe for making various cuts at the plant level;
- A shovel for holes diggings;
- A caliper for measuring the circumference at 20 cm from the ground;
- A Hoe for extracting roots;
- An oven for drying samples of stems and roots of the trees.

Sampling Methods

A sample of 15 fields chosen according to the location of the site along the valley of Goulbi-Maradi from Kawkay to Warao (Kawkay, Goumar, Sofan gari, Jargafa and Gamchet) was selected. At each site, 3 fields were measured. The choice of fields was random. In each field, 20 inter- seed pocket distances and 20 inter-row distances were measured to determine the seedling density of the field using the following formula :

$$D = 10{,}000 / IRD \times DIP$$

Where, D = seeding density (clusters/ha), IRD=inter row distance (in m) and ICD = inter cluster distance (in m).

Measurement of biomass

To conduct this study, the direct method was used. This method consists of cutting the trees according to different circumference classes (5 to 10 cm, 10 to 15 cm, 15 to 20 cm, 20 to 25 cm, 25 to 30 cm, 30 to 35 cm) in order to ensure the representativeness of the stand in the fields. A sample of 30 plants was selected for cutting. All of these plants were randomly selected. Each individual was measured for total height and girth at 20 cm from the ground. The plants were cut at the ground level and then dug up. Biomass was weighed separately as total fresh aerial biomass and total fresh root biomass. Note that aerial biomass was separated into stem and leaf biomass for each individual. From each plant, samples of the aerial and root biomass were taken and dried in the laboratory using an oven set at 100°C for 3 days to calculate the dry biomass.

Biomass Analysis

The conversion rate of fresh biomass to dry biomass was calculated using the following formula:

$$\text{Rate} = \frac{\textit{Sample dry biomass}}{\textit{Sample fresh biomass}}$$

This rate is used to calculate the dry biomass of each tree using the following formula:

For stem biomass:

Dried Stem Biomass = Fresh Stem Biomass x Rate

For leaf biomass:

Dried leave Biomass = Fresh leave Biomass x Rate

For total aerial biomass :

Total aerial biomass = Fresh Stem Biomass + Fresh leave Biomass

For root biomass:

Dried root Biomass = Fresh Root Biomass x Rate (roots)

The ratio of aerial biomass to root biomass was calculated using the following formula:

$$\text{Ratio} = \frac{\textit{Total aerial biomass}}{\textit{Dried root Biomass}}$$

Calculation of the amount of carbon sequestered

To determine the amount of carbon sequestered per tree, the default rate value given by the United Nations Framework Convention on Climate Change (UNFCCC) of 0.5 was used (UNFCCC, 2006). Thus the carbon sequestered by each moringa tree was calculated using the following formula:

Aerial carbon = Total aerial biomass x 0.5
Root carbon = Dried root Biomass x 0.5
Total carbon = Aerial carbon + Root carbon

To determine the amount of carbon sequestered per hectare, the density of moringa was used according to the type of crop:

In monoculture, the density formula used is as follows:

$$D = 10{,}000 / IRD \times ICD$$

In mixed culture, the density was determined using the following formula:

D = 10,000 / IRD x ICD
D = seeding density (clusters/ha)
IRD = inter row distance (in m)
ICD = inter cluster distance (in m).

Development of allometric equations

To develop the allometric equations, the following method was used:

Choice of regression

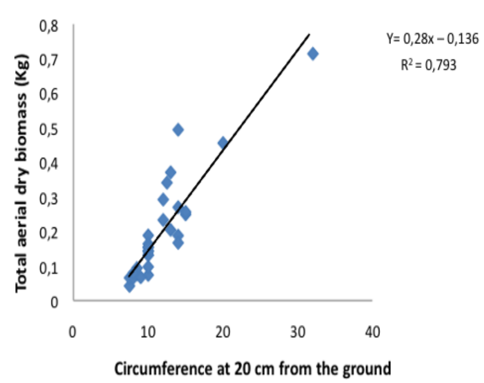

Figure 2. Total aerial biomass as a function of girth at 20 cm from the ground.

The choice of regression was based on the distribution of the scatterplot (Figure 2) and the relevance of the correlation between biomass (aerial and/or root) and dendrometric parameters (girth and/or height). Five regressions were tested: linear, logarithmic, exponential, power and polynomial (Table 1). Using this figure 2, a correlation coefficient R^2 was determined in order to have an equation that will allow to predict the dry biomass from the circumference at 20 cm of the ground. To do this, the following allometric relationships were tested:

Linear regression

$Y = ax + b$, $R^2 (y, x)$

Exponential regression

$Y = ae^{bx} \rightarrow lny = lnae^{bx} \rightarrow lny = lnc + x \rightarrow R^2 (lny, x)$

Power regression

$Y = ax^b \rightarrow lny = ln\ ax^b \rightarrow lny = lna + lnbx \rightarrow R^2 (lny, lnx)$

Logarithmic regression

$Y = alnx \rightarrow R^2 (y, lnx)$

Polynomial regression

$Y = ax^2 + bx + c \rightarrow R^2 (y, x^2)$

With y = biomass and x = dendrometric parameter (girth and/or height), a, b and c = coefficients of the regression.

Among all these regressions, the logarithmic regression presented the highest correlation coefficient with an $R^2 = 0.90$, as presented in Table 1. In this case, for the aerial biomass, this regression was used to establish the allometric equations for estimating the total dry biomass as a function of tree circumference.

Table 1. Correlation coefficients of the tested equations

Model	**Linear $R^2 (y, x)$**	**Exponential R^2 (lny, x)**	**Power R^2 (lny, lnx)**	**Polynomial R^2 (y, x^2)**	**Logarithmic R^2 (y, lnx)**
R^2	0.89	0.78	0.82	0.83	0.90

Once developed, this model was validated according to the homogeneity of its residuals i.e. errors or deviations from the mean. For the root biomass, the heterogeneity of variance of the residuals was observed. For this a logarithmic transformation was conducted to make the model more efficient (Mascaro et al., 2011).

RESULTS AND DISCUSSION

Different moringa-based agroforestry practices

In the Goulbi zone, nine moringa-based agroforestry practices were identified. According to the farmers surveyed, they combine other crops with moringa according to their needs. Therefore, the association depends on the farmers. Table 2 shows the percentages of each practice carried out or implemented by the farmers. Of all these practices, the practice of moringa associated with fruit trees and market gardening is the most dominant. In addition, farmers practice market gardening every year after the rainy season to continue irrigating the moringa. In fact, in order to have money at all times and to manage their farms, farmers combine moringa cultivation with fruit trees. This is an old system but it is still applied because of its profitability. In this system, the moringa does not benefit from special care. In addition, during the dry season, Tibiri-Gobir farmers grow vegetables in the moringa fields. This allows them to maintain the irrigation of the moringa but also to have another source of income to manage their farms. These different practices explain the difficulties in establishing a standard model for crop association in a moringa-based cropping system in this zone. Unlike the Djiratawa zone where only three practices have been identified including, moringa and cowpea/arachid; Moringa, Cassava and green anise; Moringa and banana with sometimes maize (Abdoulaye, 2013). However, in this same commune, some farmers avoid combining some species with moringa because they hinder its growth and/or quality through their shading or root systems. Thus, in 2010, Saint Sauveur and Mélanie Broin reported that intercrops that require a lot of nitrogen, such as maize and cassava, crops that require chemical treatments, and crops that grow too high and compete with moringa plants for light should be avoided in the moringa-based agroforestry system.

Moringa species cultivated and mode of production in the Goulbi-Maradi valley

Two moringa species are mainly cultivated in this zone. These are *M. oleifera* Lam. which is cultivated by 74% of the respondents and *M. stenopetala* cultivated only in the fields by 2% of the farmers. It should be noted that 24% of respondents cultivate both species simultaneously in their fields. In the different farms, we were also interested in the method of sowing which allowed us to distinguish essentially two types, namely, direct sowing by seeds practiced by 93% of the farmers and transplanting of seedlings produced in nurseries practiced by 7% of the farmers. Direct sowing of seeds consists of sowing 2 to 3 moringa seeds per stake in a hole about 5 cm deep. It is done at all times of the year, but is more common during the rainy season. The spacing depends on the system applied. For example, in monoculture the average spacing is 0.8m x 1m, and in association it is 1m x 2m.

Contribution of the system to carbon sequestration

The moringa-based agroforestry system contributes to the mitigation of greenhouse gas (GHG) emissions through the amount of carbon it sequesters through photosynthesis. The various measurements recorded in Table 3 allowed us to estimate the amount of carbon sequestered per moringa plant in the surveyed plots. Thus, we estimate that 0.141 kg of carbon is stored on average per moringa plant (Table 3).

Based on the biomass and the amount of carbon sequestered per moringa plant, we extrapolated the amount of carbon sequestered per hectare in a mixed and monoculture cropping system. Thus, at an average density of 12,066 plants/ha in monoculture, we calculated an average total biomass of 3.40 T/ha and a quantity of carbon sequestered of 1.7 tons per hectare. For the mixed cropping system, an average of 5,351 plants/ha was counted with an average total biomass of 1.08 T/ha and 0.54 T/hectare of carbon sequestered (Table 4). Finally, we calculated the amount of carbon sequestered for a moringa tree at the aerial and root system (Table 5). Through the carbon it sequesters, this system contributes significantly to the reduction of greenhouse gas emissions. Indeed, the results on the modeling of this agroforestry system based on moringa in this area, show that a moringa tree can have a quantity of 0.202505Kg of aerial biomass, 0.080025 Kg of root biomass and 0.28253 Kg of total dry biomass. A total biomass quantity of 3409;00698 Kg/ha or 3;4 t/ha in monoculture and 1511;81803kg/ha or 1;5t/ha in association. Then, the total amount of carbon per tree is equal to 0.14126 Kg; 1704.50349 kg/ha in monoculture and 755.8956 kg/ha in association. While the results of Adamou, 2012 shows that the root biomass of a tree is 2.5kg, the root biomass is 0.9kg and the total dry biomass is equal to 3.4kg. Multiplying the biomass by the carbon factor, the amount of carbon is estimated to be 1.7 kg/tree. The results of Dupriez and Leener, (1993) also estimated the number of trees on the Djiratawa farm to be

Table 2. Frequency of different agroforestry practices using Moringa

Agroforestry practices based on moringa	Percentage (%) of operators practicing
Moringa and cereal	7
Moringa + fruit tree	19
Moringa + market gardening	12
Moringa pure in hedge	2
Moringa + Henna	2
Moringa + Fruit tree + Henna + market gardening	12
Moringa + Fruit tree + market gardening	29
Moringa + Fruit tree + market gardening + Cereal	12
Moringa + Fruit tree + Cereal + market gardening + Cassava	5
Total	100

Table 3. Measurements taken to calculate the rate of carbon sequestered

Species	Number of plant	Circumference	Total height	Biomass per plant/kg	Carbon per plant/kg
M. oleifera	30	11.91	2.57	0.282	0.141

Table 4. Amount of biomass per hectare

Parts of the tree	Quantity of biomass in Kg/tree	Quantity of biomass Kg/ha in monoculture	Quantity of biomass Kg/ha in mixed culture
Aerial (leaves and stem)	0 .202505	2443.42533	1083.604255
Root	0.080025	965.58165	428.213775
Total	0,28253	3409.00698	1083.73803

Table 5. Amount of carbon sequestered per hectare

Parts of the tree	Quantity of carbon in Kg/tree	Quantity of carbon Kg/ha in monoculture	Quantity of carbon Kg/ha in mixed culture
Aerial (leaves and stem)	0.10125	1221.6825	541.78875
Root	0.0400125	482.790825	214.1068875
Total	0.14126	1704.50349	541.869015

Table 6. Statistical parameters of the selected logarithm model

Number of plant	A	B	R^2	Observed biomass	Predicted biomass	%Error	P. value
28	-852.262	433.93	0.93	193.4088126	193.408813	2.72	P <0.0001

R^2 : correlation coefficient; A and B are coefficients.

about 5000 trees/ha, or an estimated 8.5t/ha of carbon. All of these biomass and carbon values are higher than ours. This is simply due to the fact that the farms studied are not the same age. Another aspect not specified in the two studies is the nature of the farms, i.e. mixed or monoculture.

Allometric equations for estimating aerial biomass

The logarithm model was chosen for the estimation of the aerial biomass of moringa given its correlation coefficient which is equal to 0.93 and the error is 2.72% (Table 6). Twenty-eight samples were used to establish this model and the application of the model shows that there is no significant difference between the observed and predicted biomass. The probability p-value is equal to 0.0001, which means that there is a good correlation between the total dry biomass and the circumference at 20 cm of the ground and the model is very significant. These different parameters allowed us to obtain the following allometric equation, in order to predict the total dry biomass from the measurement of the circumference of the tree:

$$Y = -852.262 + 433.93 \ln x \quad (1)$$

After that, we evaluated the quality of the model using the homogeneity of variance test. Figure 3 shows the homogeneity of the residuals from the model and they cancel out around the value zero.

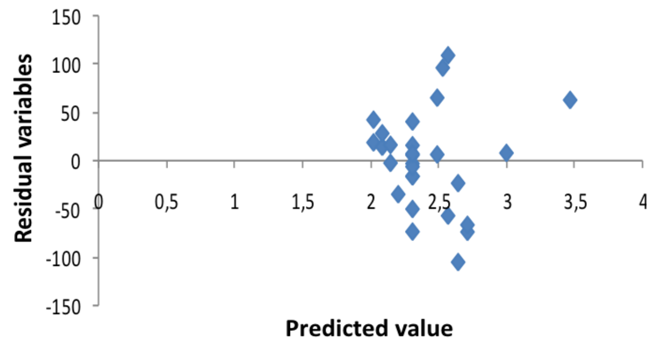

Figure 3. Plot of the variation of residuals as a function of the predicted value

Allometric equations for root biomass estimation

In order to determine the allometric equation for predicting dry root biomass from the circumference measurement, a logarithmic transformation was done to reduce the heterogeneity of the variance. This justifies the choice of the linear function. The correlation coefficient is equal to 0.54 and the error is 4.11% and as for the p-value is equal to 0.01

Table 7. Statistical parameters of the selected linear model

Number of plant	A	B	R^2	Observed biomass	Predicted biomass	%Error	P. value
30	1.679	1.004	0.54	4.11	4.11	2.61	0.01

Table 8. Statistical parameters of the selected model

Number of plant	A	B	R^2	Observed biomass	Predicted biomass	%Error	P. value
30	1.509	1.627	0.87	5.456011	5.45601117	0.440897	P<0.0001

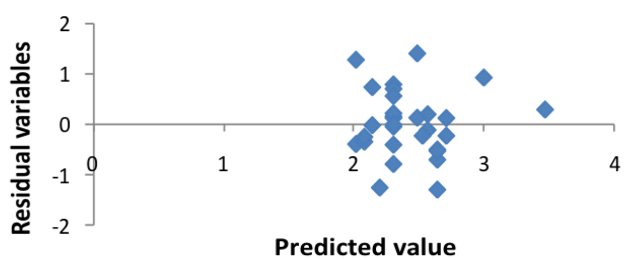

Figure 4. Plot of residual variation versus predicted value

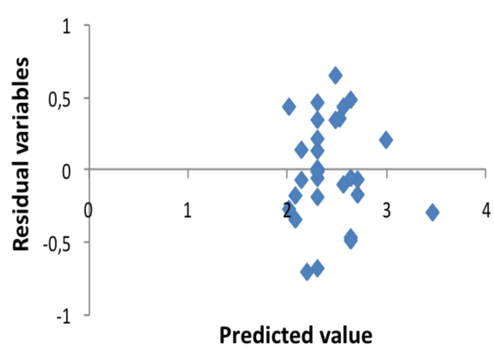

Figure 5. Plot of residuals versus predicted values

(Table 7). Thus, on the 30 samples tested, the observed biomasses and the predicted biomasses are almost identical, which justifies the quality of the model. These statistical parameters allowed us to obtain the following allometric equation:

$$\ln Y = 1.679 + 1.004 \ln x \quad (2)$$

The quality of the model was assessed using the homogeneity of variance test. Figure 4 shows the homogeneity of the residuals from the model which cancel out around the value zero.

Allometric equations for total biomass estimation

In order to justify the choice of the linear function for the determination of total biomass, the logarithmic transformation was established to decrease the heterogeneity of the variance. Thus, the deviation between the predicted biomass and the observed biomass gives an error of 4.11% and a correlation coefficient R^2 equal to 0.87 (Table 8). On the 30 samples used for the development of the present model there is no significant difference between the observed and the predicted biomass. The probability p-value is equal to $p<0.0001$. This means that there is a significant correlation between the total dry biomass and the circumference at 20 cm from the ground. These different parameters allowed us to obtain the following allometric equation to predict the total dry biomass from the measurement of the tree circumference.

$$\ln Y = 1.509 + 1.627 \ln x \quad (3)$$

The quality of the model was assessed using the homogeneity of variance test. Figure 5 shows the homogeneity of the residuals from the model, which cancel out around the value zero. The allometric equations obtained with circumference as a variable provide satisfactory estimates of tree dry biomass. These results are in line with those of Basuki and al., (2009) who report that dhp alone is a good predictor of biomass especially in terms of the multiple trade-offs between accuracy, cost and practicality of measurements. The correlations between girth and aerial, root and total biomass with respectively $R^2 = 0.93$; $R^2= 0.54$; $R^2= 0.87$ with the different probabilities being highly significant and the variance curves of the residuals being consistent. This demonstrates the quality of the models developed.

CONCLUSION

This study conducted in the urban commune of Tibiri-Gobir aims to determine the contribution of the agroforestry system based on *M. oleifera* in ecological resilience through carbon sequestration. Thus, we demonstrated that the moringa tree can store a significant amount of carbon through its different parts. Thus, our results show that in a monoculture, 1.7 tons of carbon are stored per hectare against 541 kg/ha in an mixed cropping system. The results of the biomass measurements also allowed us to develop allometric equations that can be applied throughout the Tibiri-Gobir area and elsewhere to determine the carbon stocks of moringa trees. To do this, it is sufficient to measure the circumference of a moringa tree and estimate its dry biomass without cutting the tree. In other words, the implementation of these models provides a tool for calculating biomass and predicting the amount of carbon sequestered quickly and reliably in such farms. Nevertheless, much remains to be done to to optimize this system. Further research should be conducted to determine the contribution of other system components in carbon sequestration. Also determine the quantity of carbon sequestered as a function of the age of the farms for the two major moringa production zones valley of Goulbi-Maradi and Niger River.

AUTHOR CONTRIBUTIONS

Koroney Abdoul-Salam supervised the fieldwork and wrote the article; Moussa Massaoudou and Tougiani Abass contributed to the elaboration of the allometric equations; Ibrahim Kasso Abdourahamane carried out the biomass analyses and Alzouma Mayaki Zoubérou supervised the project. All authors read and approved the final manuscript.

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COMPETING INTERESTS

The authors declare that they have no competing interest

ETHICS APPROVAL

Not applicable

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