EQA - International Journal of Environmental Quality
ISSN 2281-4485 - Vol. 48 (2022): 1-9
Journal homepage: https://eqa.unibo.it/

published by

Carbon auditing in tree-soil nexus: a sustainable approach towards CO_2 sequestration and environmental transformation

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Article info
Received 14/11/2021; received in revised form 7/03/2022; accepted 10/04/2022.
DOI: 10.6092/issn.2281-4485/13838

Abstract
Anomalies in climatic behavior is threatening various aspects of life including environmental degradation, food insecurity, and widespread of diseases. The continual build-up of atmospheric carbon dioxide (CO_2) and other malpractices are among the factors responsible for ecosystem degradation. Field experimentation was conducted, where stratified random sampling was employed to delineate point were *Phoenix dactylifera* and *Mangifera indica* was sampled. Experimental point was replicated twice where moist soil was examined for its organic matter and organic carbon content, before and after the experiment. The textural class of the area using USDA textural model after laboratory analysis indicated soils of University of Abuja, Federal Capital Territory of Nigeria ranging from loam to sandy-loam soils. Laboratory fractionalization indicated that the soils of the area has coarse sand value (1.8 g kg^{-1}), fine sand content ranging from (4.5 – 5.2 g kg^{-1}), silt content at (4.5 – 5.2g kg^{-1}) and clay content at (72 g kg^{-1}). Estimation analysis revealed that the organic matter and organic carbon content of the area is low to moderately low. Results of the study revealed that *Phoenix dactylifera* and *Mangifera indica* was able to sequester carbon in the form of CO_2 which was audited in the form of soil organic carbon (SOC). The study thereby encourages the cultivation of *Phoenix dactylifera* and *Mangifera indica* which is not onlyeconomic trees that produce food or fuelwood, but as a climate change tool that could be used to regulate climate change in the form of CO_2 sequestration.

Keywords
climate; manipulation; sustainable environment; Man; CO_2; SDG

Introduction

The continual suffering of humans, animal and the environment due to the variation in the earth climatic system is a far cry to sustainable development. Climate Change (CC) has been recognized as one of the major threats to food security, environmental sustainability including human-health development in the twenty-first century (Christensen *et al*., 2007; Seager *et al*., 2007; Adiaha *et al*., 2020). The Intergovernmental Panel on Climate Change (IPCC) concludes that climate has changed over the past century, in which human activities have had an influence on these changes, and that climate is expected to continue to change in the future (IPCC, 2007). Even under conservation scenarios, future climate change is likely to include further increase in global mean temperature (above 2°C - 4°C) with significant drying in some regions (Christensen *et al*., 2007; Seager *et al*., 2007), as well as increase in

DOI: 10.6092/issn.2281-4485/13838

frequency and severity of extreme droughts, hot extremes, and heat waves (IPCC, 2007, Steri *et al*., 2008).
Several reports have stated integrated approaches including agroforestry, terrestrial carbon monitoring and auditing as a strategy in tackling carbon emission in the form of carbon dioxide (CO_2) sequestration, as these could act as an approach to convert the problematic CO_2 that heat-up the earth for plant utilization, and for soil beneficial utilization (Adiaha *et al*., 2020; FAO-UN, 2006; UNFCCC, 2000).
In line with the Sustainable Development Goal (SDG -13) which targets climate action aligns with the target of this study. This goal (SDG-13) as applied in this research targets the decline in Carbon dioxide (CO_2) in the Earth using economic trees as a clean mechanism to sequester CO_2 and buildup soil organic carbon and organic matter. Numerous scientific reports including the research of Allen et al. (2016) has reported green and near-green technologies been able to be applied in achieving the target of SDG, 13. The sustainable modification of ecosystem through terrestrial carbon auditing in tree-ecosystem nexus as a focus of this study aligns with SDG-15 of the United Nations (UN) which targets the protection, restoration and promotion of sustainable use of terrestrial ecosystem. Positive outcome has been reported from many scientific literatures including the work of FAO-UN (2017) on the manipulations of green-tools for sustainability and modification of the ecosystem.
The uses of trees as a tool for climate monitoring and regulation has been stressed in the work of UNFCCC (2000). Economic trees have been stressed to have significance to humans as a source of food, building materials, including been utilized for paper production (FAO-UN, 2015), and also as a green-approach to cut-down the impact of climate change in-terms of sequestration of atmospheric CO_2 (UNFCCC, 2000), where different tree species has been reported having abilities to trap and store certain amount of atmospheric carbon in the form of CO_2 in their biomass and in the soil. This view was also amplified in the work of Adiaha *et al*. (2020) where the researcher reported different tree species been able to trap, store and carbon-related with the soil in the form of soil organic carbon. Similar view as expressed in the work of Adiaha *et al*. (2020) was reported in the work of Seager *et al*. (2007) where the Scientists stated green-technology as a strategy for reducing the temperature of the heating globe.
Many diagnostic criteria and soil classifications are based on the color of horizons. For this purpose, soil scientists often use the Munsell color system, identifying soil color by visually comparing albums of color chips with the color of the soil sample. The precursor to these albums, The Munsell Atlas of Color, was published over 100 years ago in 1915. These albums, commonly called Munsell color charts, have not changed significantly since the 1940s (Simonson, 1993). Building upon this technology, several advance in soil science and engineering has been recorded. For instance the findings of Kirillova *et al*., (2018) has indicated that the Munsell Atlas of Color (Munsell Colour chart) could be used to estimate the amount of organic matter present in soil. This view was practically explained and presented in the work of FAO-UN (2006) where the report indicated that at a specific soil textural class, the Munsell Colour chart can present the amount of organic matter present in soil (Table 1).
As a targeted strategy to contribute to the ongoing scientific approaches in combating the impact of climate change, this study seeks to present the interaction between man and carbon in terms of using economic trees as a tool for CO_2 sequestration. Building upon this expectation, the following objective arises:
- present the influence of Date palm (*Phoenix dactylifera)* tree in CO_2 sequestration in terms of influence in soil organic carbon;
- present the influence of Mango (*Mangifera indica*) tree in CO_2 sequestration in terms of influence in soil organic carbon.

Materials and Methods

Geography and Climate of the Study Area

Gwagwalada is a suburb of the Federal Capital Territory (FCT), Nigeria. It is situated along Abuja-Lokoja road at about 55 kilometers away from FCT main town and centrally located between latitudes 8˚55' N – 9˚ 00'N and longitudes 7^O^ 00' E - 7^O^ 04' E (Ishaya, 2013). With a population of about 157,770 at the 2006 census (FCDA, 2016). The region covers a total landmass of about 65 km^2 out of the 8,000 km^2 of the total FCT landmass and located at the center of very fertile area with abundance of grasses (Ishaya, 2013).

DOI: 10.6092/issn.2281-4485/13838

Table 1. *Estimation of organic matter content based on Munsell Soil Color*

Munsell Soil Color		Moist soil			Dry soil		
		S	LS, SL, L	SiL, Si, SiCL, CL, SCL, SC, SiC, C	S	LS, SL, L	SiL, Si, SiCL, CL, SCL, SC, SiC, C
	value	(%)					
Light gray	7				< 0.3	< 0.5	< 0.6
Light gray	6.5				0.3–0.6	0.5–0.8	0.6–1.2
Gray	6				0.6–1	0.8–1.2	1.2–2
Gray	5.5			< 0.3	1–1.5	1.2–2	2–3
Gray	5	< 0.3	< 0.4	0.3–0.6	1.5–2	2–4	3–4
Dark gray	4.5	0.3–0.6	0.4–0.6	0.6–0.9	2–3	4–6	4–6
Dark gray	4	0.6–0.9	0.6–1	0.9–1.5	3–5	6–9	6–9
Black gray	3.5	0.9–1.5	1–2	1.5–3	5–8	9–15	9–15
Black gray	3	1.5–3	2–4	3–5	8–12	> 15	> 15
Black	2.5	3–6	> 4	> 5	> 12		
Black	2	> 6					

Source: FAO-UN (2006)

The area is bordered by Kuje area council to the East, Abaji area council to the West, Kwali area council to the south and Abuja Municipal Area Council to the Northeast and to the North by Suleja Local Government Area of Niger State (Balogun, 2001). The area records about 60% of rainfalls during the months of July to September, during which flood occur within the area lying around the floodplain of River Usuma (Adakayi, 2000; Balogun, 2001). The highest rainfall is recorded in the month of August with rainfall amount of about 1400mm, while the least amount of rainfall is recorded in December, which records an average amount of 1mm. With an average of 258mm, with the most precipitation occurring in September. The variation in precipitation between the driest and wettest months is about 257mm annually (Balogun, 2001). The temperature of Gwagwalada is generally high during the day and falls sharply at night. Changes in temperature of about 17^{O}C have been recorded between the highest and lowest temperature in a single day (Balogun, 2001). During the rainy season, the maximum temperature is lower due to dense cloud cover; Diurnal annual range is also much lower sometimes not more than 7^{O}C in July and August (Balogun, 2001). The mean maximum monthly temperature ranges between 28^{O}C– 30^{O}C and the mean minimum monthly temperature ranges between 25^{O}C– 27^{O}C (Balogun, 2001).

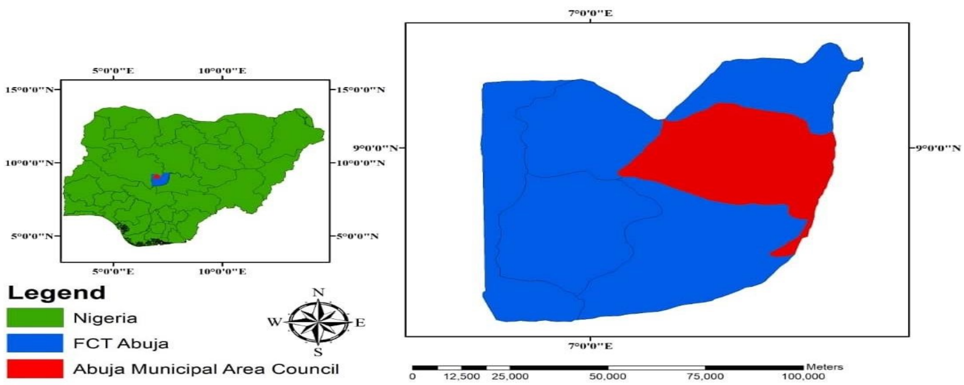

Plate 1. Study area location, Nigeria, West Africa. Source: Oku et. al. (2020)

DOI: 10.6092/issn.2281-4485/13838

Experimental Design

The experiment took an empirical survey method, where sites of study was replicated twice:

Site A: Tree species 1 (*Phoenix dactylifera*)
Tree species 2 (*Mangifera indica*)

Site B: Tree species 1 (*Phoenix dactylifera*)
Tree species 2 (*Mangifera indica*)

The study sites was delineated though reconnaissance surveys.

Sampling Techniques

The experiment adopted a stratified random sampling method, where areas sampled where surveyed following a common element of interested.

Soil sampling: Two sets of soil sampling was done: on-field sampling at 0-30 cm using a soil core was done, and was used to estimate the amount of organic matter in the moist soil. While the second sampling was taken to the laboratory for physical analysis

Laboratory analysis

Soil textural determination, and Analytical procedures:

I. *Air drying of soil samples*: The soil samples collected were air-dried at room temperature.

II. *Laboratory grinding*: The soil sample was grind using the laboratory pistol and muter

III. *Sieving*: Sieving of the grinded soil particles was done using a 2 mm sieve. The sieved particles were labeled accordingly to the various sites investigated to avoid error

IV. *Parameter determination*: The sand, coarse sand, fine sand, silt and clay content in the soil particles was determine following the Bouycucos (1935) analytical procedure for hydrometer method.

V. Soil textural class was determine using the USDA textural class system.

CO_2 Sequestration Potential Determination, and Soil Fertility Assessment

Organic Matter determination: Soil organic matter contents were determine following the procedures of the Munsell Colour Chart at moist soil condition-

Organic Carbon Determination: The organic carbon content of the soil was estimated from the quantity of organic matter present in the soil. This procedure was done following the equation as presented by van Bemmelen, which presented a value of 0.58, as a standard for converting SOM to SOC, thus:

$$Organic\ Carbon\ (OC)\% = Organic\ Matter\ (OM)\% \times 0.58 \qquad [1]$$

Data analysis and Statistical Application

Field data was analyzed following the Sorensen's Species Similarity Index:

Sorensen's Species Similarity Index. Sorensen's Species Similarity Index was obtained using the procedure by Sørenson (1948) as modified by Nath *et al*. (2005) for estimating Sorensen's Species Similarity Index between two locations was calculated, thus:

$$Sorensen's\ Species\ Similarity\ Index\ (SI) = \left(\frac{2C}{a+b}\right) \times 100 \qquad [2]$$

where: C = number of species in site a and b; a+b = number of species at site 1 and 2 respectively. Assumption: At Sorensen's Species Similarity Index of: 1000 (10%) = Very high, 200 – 400 (2-4%) = Moderate, 600 - > 600 (6% – > 6%) = High

Correlation Statistics. The Pearson Product Moment Correlation (PPMC) Analysis was used to draw up relationship and evaluate the performance of each Site (A and B) in terms of change in Soil Organic Carbon (SOC), where Coefficient of Determination (R^2) was utilized to present the percentage change in the amount of CO_2 the different tree species were able to sequester at each site.

$$r = \frac{n\,(\varepsilon XY) - (\varepsilon X)(\varepsilon Y)}{\sqrt{[n\,(\varepsilon X^2) - (\varepsilon X)^2][n\,(\varepsilon Y^2) - (\varepsilon Y)^2]}} \qquad [3]$$

Where: r = Pearson's correlation coefficient; n = number of paired scores;
X = score of the first variable; Y = score of the second variable; XY = the product of the two paired scores

DOI: 10.6092/issn.2281-4485/13838

Results and Discussion

Sorensen's Species Similarity Index

Applying the Equation of Sørenson (1948) as modified by Nath *et al*. (2005), then:

$$(SI) = \left(\frac{2C}{a + b}\right) \times 100 \qquad [4]$$

$$SI = \left(\frac{2 \times 4}{2 + 2}\right) \times 100 = 200\sim 2\% \qquad [5]$$

The result of the outcome of the Sorensen's Species Similarity Index indicated that the Similarity Index (*SI*) of the performance of the tree species that exist between the two locations is (200 or 2%), which was ranked with a standardized value presented by Nath *et al*. (2005) to be moderate, indicating a view that the two tree species in the area acted similarly in their ability to sequester and look-up atmospheric carbon dioxide (CO_2). Building upon this ability, it could be stated that the trees species used statistically responded positively in their ability to act as a sink for the pile-up atmospheric CO_2. This view expressed through the ability of the tree species used to sequester CO_2 confirms the work of UNFCCC (2000); IPCC (2000) including Adiaha *et al*. (2020), which stated tress as a clean mechanism for atmospheric CO_2 sequestration, while acting as a green approach for environmental sustainability.

Soil Physical Properties Behavior Relating to Soil Organic Matter and Soil Organic Carbon Determination

Behavior of Soil Physical State at Site A. Soil physical analysis at the start of the CO_2 sequestration monitoring (Table 2) indicated that the soils at the points where the two tree species were are Loam for (point at location of Species 1) and Sandy-loam for (point at location of Species 2). With coarse sand content of (1.8 g kg^{-1}), Fine sand content of (4.5 g kg^{-1}), Silt content in the 50 g soil sample was obtained at (424 g kg^{-1}), while the sand content was observed at (497.7 g kg^{-1}). At the point where Mango tree was a soil physical property of sand was obtained at (650.4 g kg^{-1}), coarse sand content of (12.1 g kg^{-1}) was obtained. The fine sand content at point of specie 2 was (21.5 g kg^{-1}), while the silt and clay content of the 50g soil sample was observed at (274 g kg^{-1} and 42 g kg^{-1} respectively). This range of value obtained for the soils of this location confirms the work of FAO-UN (2006) including the work of Oku et al (2015) that that stated textural class of soil of the tropics been a factor to soil fertility due to their easy degradation because of it textural class that often contain high content of sand among other factors.

Table 2. *Site A Soil Physical Properties at start of CO_2 sequestration monitoring*

Species (Spp)	Sand	Coarse sand	Fine sand	Silt	Clay	USDA Textural Class
	(g kg^{-1})					
Date plam (Spp 1)	497.7	1.8	4.5	424	72	Loam
Mango (Spp 2)	650.4	12.1	21.5	274	42	Sandy-loam

Site A Soil Physical Properties after 5 months of CO_2 sequestration monitoring (Table 3) indicated a view that the soil textural class did not change, rather a slide reduction was observed in Sand content at point of specie A where (497 g kg^{-1}) was obtained. An increase in the fine sand content was observed for fine sand, which was obtained at a value of (5.2 g kg^{-1}) which stands over the value of (4.5 g kg^{-1}) obtained at the beginning of the experiment. At point of Specie B (Mango), a reduction was obtained for the sand content at a value of (650.1 g kg^{-1}). An increase was observed for the content of fine sand (21.8 g kg^{-1}) and (27.5 g kg^{-1}) for silt content respectively. Although there was an increase in some of the textural parameters, but the textural class of the soil did not change, this unchanged soil textural status confirms the work of FAO (2006) that indicted that soil textural change is a very slow or may not change. The work of Oku *et al* (2005) also validate this finding, where the researchers indicated that soil textural change may seem impossible or extremely slow, especially in problematic soils.

DOI: 10.6092/issn.2281-4485/13838

Table 3. *Site A Soil Physical Properties after 5 months of CO_2 sequestration monitoring*

Species (Spp)	Sand	Coarse sand	Fine sand	Silt	Clay	USDA Textural Class
	(g kg^{-1})					
Date plam (Spp 1)	497.0	1.8	5.2	424	72	Loam
Mango (Spp 2)	650.1	12.1	21.8	275	41	Sandy-loam

Behavior of Soil Physical State at Site B. The physical status of the soils at Site B (Table 4) indicated that the soil has sand content of (598.5 g kg^{-1}), coarse content of (7.9 g kg^{-1}), fine sand content of (17.6 g kg^{-1}), silt content of (334 g kg^{-1}) and clay particle observed at (42 g kg^{-1}), the range of values observed in this soil indicated that the soil is a Sandy-loam soil. The same textural class was observed for the soil found at point of specie 2, although, a little variation was observed at this point, where it was found that the sand particle valued at (578.5 g kg^{-1}), coarse sand particle was obtained at (8.8 g kg^{-1}), fine sand content was found to be (16.7 g kg^{-1}), while silt and clay content was obtained at (324 g kg^{-1} and 72 g kg^{-1} respectively).

Table 4. *Site B Soil physical properties at start of CO_2 sequestration monitoring*

Species (Spp)	Sand	Coarse sand	Fine sand	Silt	Clay	USDA Textural Class
	(g kg^{-1})					
Date plam (Spp 1)	598.5	7.9	17.6	334	42	Sandy-loam
Mango (Spp 2)	578.5	8.8	16.7	324	72	Sandy-loam

Site B Soil Physical Properties after 5 months of CO_2 sequestration monitoring (Table 5) revealed that the soil still maintain the textural class of sandy-loam soils after five (5) months of study, this reveal that fact that soil do not easily change its texture, this view is in-line with the assertion of Adiaha (2016) who confirms no-change in soil textural class after physical and chemical soil manipulation with mineral fertilizer. Although there was no change in the soil textural class, slide decrease was found in the sand content at the point of Species 1 recorded at (595.5 g kg^{-1}), while a little increase in coarse sand content was observed at a value of (10.9 g kg^{-1}). At point of Specie 2 a reduction to the tune of (576.5 g kg^{-1}) was observed. An increase at a value of (10.8 g kg^{-1}) was observed for coarse sand. An increase to (18.7 g kg^{-1}) was observed for fine sand content, while a reduction in the silt content was noticed at a value of (322 g kg^{-1}). This increase and decrease in the different soil fragment indicated that a variation occurred in the different soil ped over the period of five (5) months. This view agrees with the work of FAO (2006) who reported variation in the system over a period of time due to interaction of soil with the ecosystem including the atmosphere.

Table 5. *Site B Soil physical properties after 5 months of CO_2 sequestration monitoring*

Species (Spp)	Sand	Coarse sand	Fine sand	Silt	Clay	USDA Textural Class
	(g kg^{-1})					
Date plam (Spp 1)	595.5	10.9	17.6	334	42	Sandy-loam
Mango (Spp 2)	576.5	10.8	18.7	322	72	Sandy-loam

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Table 6. *CO_2 Sequestration Ability of Phoenix dactylifera and Mangifera indica for Modification of the Earth Climatic System, and for Soil Fertility Improvement*

Differences that Occur in the amount of CO2 trapped into the soil				
	START		END	
	Location		Location	
	SITE A	SITE B	SITE A	SITE B
Tree Spp	OM (%)	OC (%)	OM (%)	OC (%)
Date Palm Tree (Spp 1)	3	1.74	4	2.32
Mango Tree (Spp 2)	4	2.32	3	1.74

OM=Organic matter, OC=Organic carbon

Table 7

Change that occur in the amount of CO_2 trapped into the soil

Change that occurred in the amount of CO2 trapped into the soil	
Change in trapped CO_2 (%)	Change in trapped CO_2 (%)
SITE A	SITE B
OM 2-OM1	OC2-OC1
1	0.58
1	0.58

OM=Organic matter, OC=Organic carbon

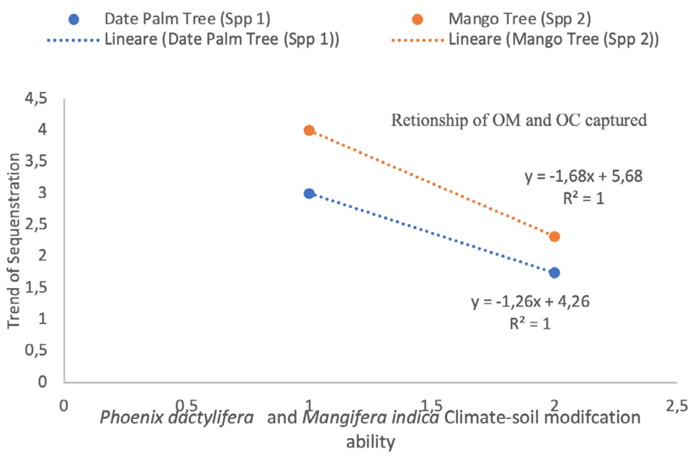

Figure 1. *Climate manipulation Ability of Economic Trees in terms of Soil fertility development at Site A.*

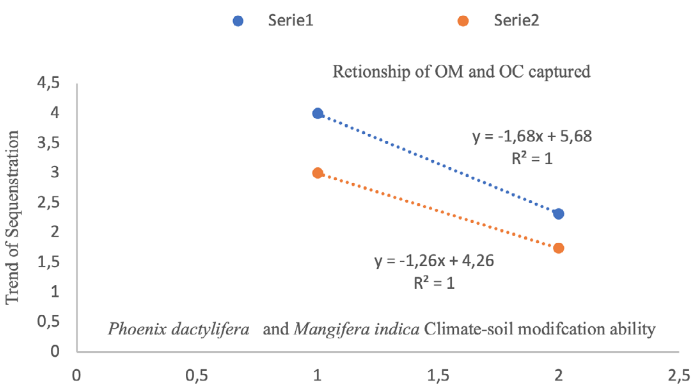

Figure 2: *Climate manipulation Ability of Economic Trees in terms of Soil fertility development at Site B.*

DOI: 10.6092/issn.2281-4485/13838

CO_2 Sequestration Ability of *Phoenix dactylifera* and *Mangifera indica* for Modification of the Earth Climatic System, and for Soil Fertility Improvement

Applying Equation 1, as described by van Bemmelen, soil organic matter (SOM) at Site A was found to be 3% and soil Organic Carbon (SOC) was found to be 1.74% indicating a view that the soil contains relatively low to minimal quantity of soil organic matter and organic carbon. At Site B, it was observed that the soil contains 4%OM and 2.3 organic carbon. There was an increase in the amount of soil organic matter to the tune of (SOM% = 4) at Site A at the end of five (5) months of carbon sequestration and auditing. An increase in Organic carbon was also observed at a value of (SOM% = 2.32). This finding presents a view that Date palm (*Phoenix dactylifera*) tree is able to act like a clean strategy or mechanism that could be harnessed for modification of the atmospheric CO_2 and for regulation soil fertility. This finding agrees with the research findings presented by UNFCCC (2000) which stated trees as been statistically fix and economically stable in acting like a green-approach for climate regulation and CO_2 sequestration. The findings of Adiaha *et al*. (2020) also reported similar outcome presented in this result, where their indicated various tree species been able to capture and lock atmospheric CO_2 into tree biomass and the soil system.

Auditing of CO_2 sequestered as a result of Change that occurred in the amount of CO_2 trapped into the soil

Building upon the behavior of the soils at Site A and Site B, it was observed that there was a change at (1%) in organic matter content, and a (0.58%) change in the amount of organic carbon in the form CO_2 that the tree-soil system was able to trap, thereby indicating that *Phoenix dactylifera* is practically fit for capturing CO_2 and for climate regulation. It was observed that *Mangifera indica* also captured (1%) organic matter and (0.58%) organic carbon, indicating a view that Mango tree is also fit for climate regulation in terms of carbon capturing, and storage into the soil-atmospheric system. The increase that occurred in the carbon trapped indicated that the two economic trees acted productively and positively in climate-soil regulation. Findings of this study agree with the research of Adiaha *et al*. (2020) that stated trees including economic trees as a clean mechanism for atmospheric CO_2 sequestration. The work of IPCC (2000); UNFCCC (2000) is also in-line with the findings of this research, where their repot indicated both economic trees and all green-plant as a sink for CO2 concentration in the atmosphere.

Relationship of Organic Matter and Organic carbon in Climate Regulation

Result indicated a perfect correlation between organic matter and organic, with a coefficient of Determination at ($R^2 = 1$) for Site A and Site B respectively. Percentage analysis indicated that 100% interaction existed in the climate-soil interaction. The view of this finding supports the research of UNFCCC (2000) that indicated that strong correlation exist between tree species and the climate, presenting a view that trees are targeted tool for moderating atmospheric temperature, and as a tool for CO_2 sink.

Conclusions

The study indicated that *Phoenix dactyli*fera and *Mangifera indica* can productively capture atmospheric CO_2 and store as soil organic carbon and soil organic matter. The modification ability of the economic tree species indicated that the trees has most of the required ability to be included as a clean development mechanism tree for combating local variation in the climate as climate change. Five (5) months period has been found to be productive in atmospheric CO_2 sequestration ability of *Phoenix dactyli*fera and *Mangifera indica* in regards to soil fertility improvement for agricultural, soil and environmental sustainability.

Competing Interest Statement

The authors declare that there are no competing interests

Author's Contribution

M. S. Adiaha, V. O. Chude , G.I.C. Nwaka and E. E. Oku designed, conducted experiment, analyzed data and wrote paper.

Acknowledgment

We thank the Nigeria Institute of Soil for providing internet facility to enhance the literature search, manuscript type-setting and for providing enabling environment for data analysis and interpretation.

DOI: 10.6092/issn.2281-4485/13838

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