Medicon Agriculture & Environmental Sciences
Volume 4 Issue 6 June 2023
Article Type: Research Article
ISSN: 2972-2691

Effects of Tree Planting on Soil Organic Carbon and Nitrogen Content in Nigerian Agroforestry Systems

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Received: June 21, 2023; **Published:** June 30, 2023

DOI: 10.55162/MCAES.04.120

Abstract

Agroforestry systems have the potential to increase carbon and nitrogen content of the soil. The increase of these elements promises agroforestry to be a useful practice for mitigating climate change, through an increased sequestration of carbon, and improving the food security of the area it is implemented. This is particularly important for Nigeria as it is a country identified as vulnerable to climate change. However, there is a lack of data to support the theory that agroforestry systems increase carbon and nitrogen content over time. In this study it was explored how tree planting in Nigerian oil palm agroforestry systems can influence the carbon and nitrogen content of the soil as the age of the agroforestry increases. At oil palm plantations aged 4, 27, 58 and 60 a total of 40 samples were taken from 2 depths (0-15cm and 15-30cm) and were shipped to Newcastle University for elemental analysis. The results showed that there was a significant difference between the carbon and nitrogen content of the soil and the age of the plantation for both depths (ANOVA, $p<0.001$). However, it was found that the youngest plantation had the greatest percentage of carbon and nitrogen measured in the soil with an average carbon content of 2.66% and an average nitrogen content of 0.212%. The results found were unexpected as the carbon and nitrogen content decreased as the age of the plantation increased, which could be due to the different crops grown and land management of the individual plantations. Overall, future research should focus on studying a greater number of agroforestry systems with a greater variety of ages to determine where the carbon and nitrogen content peaks. Additionally, the same study should be carried out in a set number of years to compare the results overtime, thus eliminating the factors of crop grown and land management practices.

Keywords: Agroforestry; plantation; climate change; food security

Introduction

Agroforestry is a land management practice in which trees are planted around or among crops and pastureland. This practice has several benefits which include increasing food security, improving biodiversity and improving resilience to uncertain climate (Tschora and Cherubini, 2020). It has also shown promise in other studies to enhance system nutrient accumulation, specifically carbon and nitrogen (Isaac et al, 2004). The increase in soil carbon is important to maintain soil structure, provide substrates and energy to support microbial activity, increase plant productivity (due to improved soil water retention and nutrient storage) and create a more physically cohesive soil to resist soil losses by wind or water erosion. Perhaps more importantly increasing carbon storage in soil could contribute to the mitigation of climate change (Milne et al, 2015). In most environments nitrogen is limiting plant growth and therefore it is critical to increase stocks of the nutrient in the soil to help with crop growth, metabolism, and creation of chlorophyll (Scharf, 2020).

These benefits are increasingly important to Nigeria- a country identified as vulnerable to climate change. This means agricultural activities in the area are highly susceptible to floods, severe windstorms, and excessive rise in temperature (Anyoha et al, 2018), ultimately leading to the poor food security for Nigeria. As a large percentage of the Nigerian population are dependent on locally grown crops and food harvested from the immediate environment (Bationo et al, 2007) there is a great demand for improved food security, biodiversity protection and climate change mitigation. Overall, agroforestry could aid in achieving the global sustainable development goals of zero hunger, climate action and life on earth.

It has been shown that agroforestry systems can increase nitrogen storage by 13% when compared to crop monocultures (Muchane et al, 2020). Additionally, one study has estimated that the implementation of large-scale agroforestry across seven countries in West Africa could sequester up to 135 Mt CO_2/year over two decades. This is equivalent to 166% of the carbon emissions caused by fossil fuels and deforestation in this region (Tschora and Cherubini, 2020). However, there is some controversy surrounding the theory that tree planting increases soil carbon stocks with one study finding that there was no net gain in ecosystem carbon stocks as a result of tree planting (Friggens et al, 2020). Another study conducted by Ribeiro de Carvalho et al concluded that a strong spatial variability in soil carbon stocks could not be detected, however this may be due to the young age of the plantations investigated (de Carvalho et al, 2014). Overall, there is a lack of research on the long-term system level sustainability of nutrient cycle and storage because of tree planting (Isaac et al, 2004).

Other factors that have been shown to affect the carbon and nitrogen content of the soil are the pH level and the soil texture (percentage of sand, silt, and clay). Gruba and Socha (2019), found that the fine-fraction (silt and clay) content of the soil positively affected carbon stocks. Additionally, one study concluded that changes in pH can affect soil microbial activity and the rate of soil carbon and nitrogen cycling (Kemmitt et al, 2006). Therefore, it is important to investigate the impact both pH and soil texture have on the carbon and nitrogen content of the soil to determine if they are as great of a contributing factor as plantation age.

Aims and Objectives

The overall aim of this project is to explore how tree planting in agro-forestry systems in Nigeria influence soil carbon. There is wider view towards understanding the relative contribution of soils to net ecosystem carbon storage.

Specific Objectives of the study:

- To analyse the soil Organic Carbon and Nitrogen content in relation with soil depth.
- To the analyse statistical difference between the age of plantation and the soil carbon content.
- To discuss the potential of tree planting to increase carbon storage in mitigating climate change.

Study Location

The samples were taken from oil palm plantations located in Acharu, Dekina, Kogi, Nigeria (Figure 1), a breakdown of each site is given in table 1. In this agroforestry system cassava, cowpea, sorghum, and vegetables (spinach, tomatoes, and peppers) are integrated among the oil palm agroforestry systems. Pisoplinthic Plinthosols is the dominant soil in this area, it occurs in moist tropical regions in low-lying positions where iron from soil and adjacent uplands is accumulating (Jones et al, 2013). The average sand, silt, and clay percentage of soil in the area is 59, 16 and 20%, respectively. It is estimated that the soil contains 19.1 g/kg carbon and 1.2 g/kg nitrogen, and the average pH is 5.8 (iSDA, 2022). In November, when the samples were taken, the average temperature is 26.6°c compared to the yearly average of 26.9°c and the mean precipitate rate in November is 13.82mm and the mean annual precipitate rate is 1165mm (World Bank Group, 2021).

Figure 1: A map of Acharu with each of the sample sites labeled, highlighting the exact location (GoogleEarth, 2021).

Site	***Latitude***	***Longitude***	***Elevation (m)***	***Age***	***Soil Type***	***Crops***
1	7.49982934	7.28867268	353.0	27	Sandy Clay Loam	Cassava, Cowpea
2	7.50263789	7.29596452	364.0	58	Sandy Clay Loam	Cassava, Cowpea, Sorghum
3	7.50570188	7.29631257	374.0	60	Sandy Clay Loam	Cassava, Cowpea
4	7.52446677	7.30802503	397.0	4	Sandy Clay Loam	Spinach, Tomato, Pepper, Cowpea

Table 1: Shows the latitude, longitude, elevation, plantation age, soil type and the crops grown at each individual site where soil samples were taken.

Methodology

Field Sampling & Laboratory Analysis

A random sampling technique was used to collect soil samples from each of the plantations in Acharu, in which samples were taken at randomly generated coordinates to avoid bias. The oil palm plantations selected were of various ages: 4, 27, 58 and 60 years old and samples were taken at 2 depths: 0-15 cm and 15-30 cm. Overall, 40 samples were collected with 5 samples at each depth for each plantation age. Samples were taken with the aid of a soil urger and before being shipped to Newcastle Upon Tyne they were air dried for 48 hours and sealed into airtight containers.

In the Inorganic Geochemistry-Laboratory of Newcastle university, samples of 0.1g (+/- 10%) for each of the plantations and both depths (40 samples total) were weighed out into foil cups and sealed ready for analysis. To analyze for the carbon and nitrogen content of the soil multiple samples were placed into an elemental analyzer (*LECO CHN628*) where the software calculates the amount of resultant gases as a percentage of the initial sample weight and ultimately gives the results for the percent carbon and nitrogen content. However, the samples analyzed at this weight did not produce usable values, as many of the values for nitrogen were negative and there were large differences between the replicates. Therefore, a further 0.3g (+/- 10%) of sample was weighed out into foil cups and sealed for re-analysis as outlined above.

When measuring the pH only 12 of the samples were measured- 3 samples from each plantation for the 0-15cm depth. Of these samples, 2.5g of soil was measured out and placed into a test tube before adding 6.25ml of distilled water. The test tubes were shaken for 10 minutes and then left to rest for a further 10 minutes. A pH meter was used to measure how acidic or alkaline each of the soil samples were and the results were recorded.

To measure the soil texture 3 samples from each plantation for the 0-15cm depth were used, clear glass jars were filled to a 1/3 with the soil and the remaining space filled with distilled water and roughly 2g of sodium hexametaphosphate (Calgon). The jars were then shaken vigorously for 3 minutes until a uniform slurry was formed and set aside on a level surface for 48 hours. After this time, the sand silt and clay separated into each layer and then measured using a ruler and used to calculate the percentage of each for the overall soil sample.

Results and Discussion

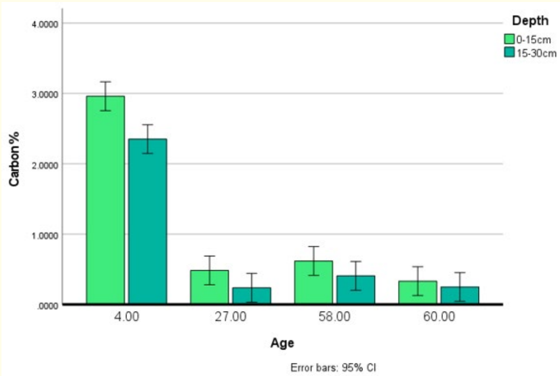

Figure 2: Average carbon percentage of soil samples (±CL) for each plantation age (n=4) and depth of sample (n=2).

At both depths there is a greater percentage of carbon in the soil samples taken at the plantation of 4 years old than the other ages of plantation. For the depth 0-15cm at the plantation aged 4 the carbon content was 2.47%, 2.34% and 2.63% greater than in the plantations aged 27, 58 and 60, respectively. For the depth 15-30cm at the plantation aged 4 the carbon content of the soil was 0.61% lower than at the 0-15cm depth for the same plantation- this decrease between the depths continued for all plantations. However, the decrease between the carbon content and the plantation age is not completely linear as the carbon content at age 27 is 0.13% and 0.17% lower than at age 58 for depths 0-15cm and 15-30cm respectively. Overall, there was a statistically significant difference between the carbon percentage in the soil and the age of the plantation (ANOVA, $p<0.001$), and between the carbon percentage in the soil and the depth at which the sample was taken (ANOVA, $p<0.001$). The interaction between the age of the plantation and the depth of the sample taken was significant at the $p<0.1$ level but not at the $p<0.05$ level (ANOVA, $p=0.075$) (Figure 2).

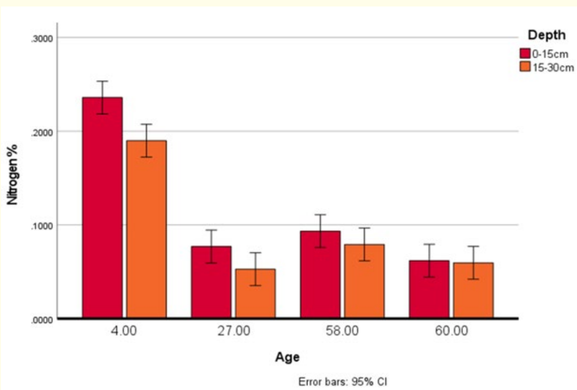

Figure 3: Average nitrogen percentage of soil samples (±CL) for each plantation age (n=4) and depth of sample (n=2).

At both depths there is a greater percentage of nitrogen in the soil samples taken at the plantation of 4 years old when compared to the other ages of plantation. At the plantation aged 4, the nitrogen content of the soil measured at the plantation aged 4 was 0.16%, 0.14% and 0.17% greater than that measured at plantations aged 27, 58 and 60, respectively. The greatest difference in nitrogen content between the two depths was measured at plantation aged 4, with a 0.046% difference- this decrease between the depths was seen at all plantation ages. However, the decrease between the nitrogen content and plantation age is not completely linear as the nitrogen content at age 27 is 0.016% and 0.026% lower than at age 58 for depths 0-15cm and 15-30cm respectively. Overall, there was a statistically significant difference between the nitrogen percentage in the soil and the age of the plantation (ANOVA, $p<0.001$), and between the nitrogen percentage in the soil and the depth at which the sample was taken (ANOVA, $p=0.001$). The interaction between the age of the plantation and the depth of the sample taken was significant at the $p<0.1$ level but not at the $p<0.05$ level (ANOVA, $p= 0.093$) (Figure 3).

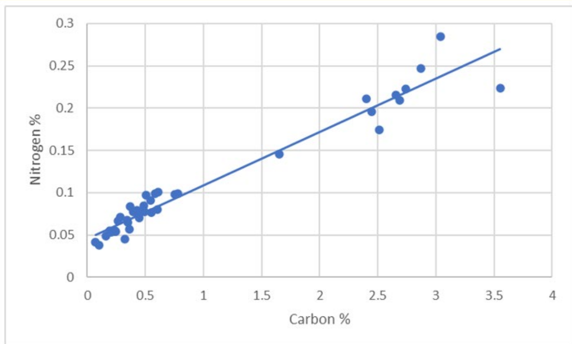

Figure 4: Relationship between the percentage of carbon and nitrogen in the soil samples measured (n=40). N= 0.63C + 0.046.

The percentage of carbon and the percentage of nitrogen measured in the soil samples were found to be positively correlated, as the carbon content of the soil increases the nitrogen content also increases (Linear Regression, $F_1 = 729.706$, $p<0.001$, $R^2 = 0.951$) (Figure 4).

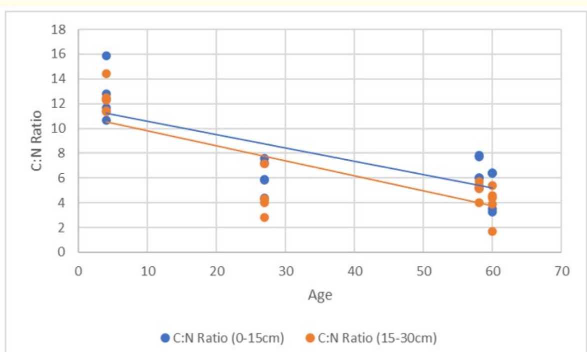

Figure 5: Relationship between the age of the plantation and the C:N ratio of the soil samples measured (n=40). C: N(0-15cm) = 11.636 - 0.107Age, C: N(15-30cm) = 11.018 - 0.121Age.

C:N ratio and age of plantation were found to be negatively correlated. At the 0-15cm depth the average C:N ratio for plantation aged 4 was 6.28, 6.12 and 7.49 greater than the C:N ratio for ages 27, 58 and 60, respectively. At the 0-15cm depth the average C:N ratio for plantation aged 4 was 7.88, 7.3 and 8.4 greater than the C:N ratio for ages 27, 58 and 60, respectively. Overall, the younger plantation has a greater C:N ratio in the soil than the older plantations at both 0-15cm and 15-30cm depth (Linear Regression, $F_1 = 25.316$, $p<0.0001$, $R^2 = 0.584$) (Linear Regression, $F_1 = 28.084$, $p<0.001$, $R^2 = 0.609$) (Figure 5).

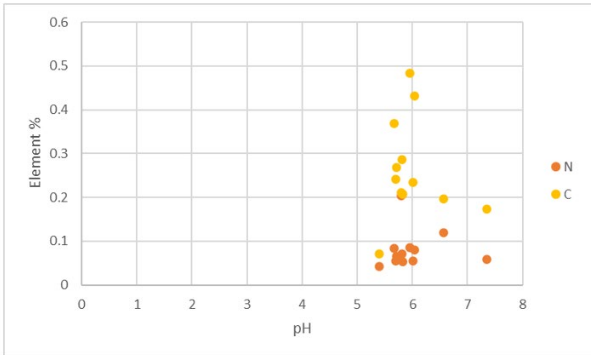

Figure 6: Relationship between the pH of the soil samples and the percentage of carbon and nitrogen measured (n=12). C= 0.0101 + 0.033pH, N= 0.171 - 0.018pH.

There was a weak positive relationship between pH and the percentage of carbon, and a similar relationship between the pH and the percentage of nitrogen measured in the soil samples (Linear Regression, $F_1 = 2.355$, $p=0.156$, $R^2 = 0.191$) (Linear Regression, $F_1 = 6.595$, $p=0.028$, $R^2 = 0.397$) (Figure 6).

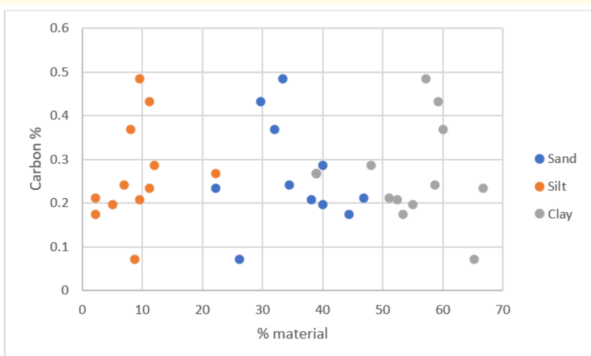

Figure 7: Relationship between the percentage of sand, silt and clay in the soil and the amount of carbon measured in the soil (n=12). C= -0.0023Sand + 0.3449, C= 0.0056Silt = 0.2133, C= -0.0007Clay + 0.3004.

There is a negative correlation between the percentage of the soil made up by sand and the percent of carbon content, as the percentage of sand that make up the soil sample increases the carbon content of the soil generally decreases ($p<0.0001$, $R^2 = 0.0208$). There is also a weak relationship between the percentage of the soil made up by clay and the percent of carbon content, as the percentage of clay in the soil increases the carbon content decreases ($p=0.837$, $R^2 = 0.0018$). Alternatively, there is a positive correlation between the percentage of silt that makes up the soil and the carbon content of the soil, which is significant at the $p<0.1$ level but not at the $p<0.05$ level ($p= 0.430$, $R^2 =0.0677$) (Figure 7).

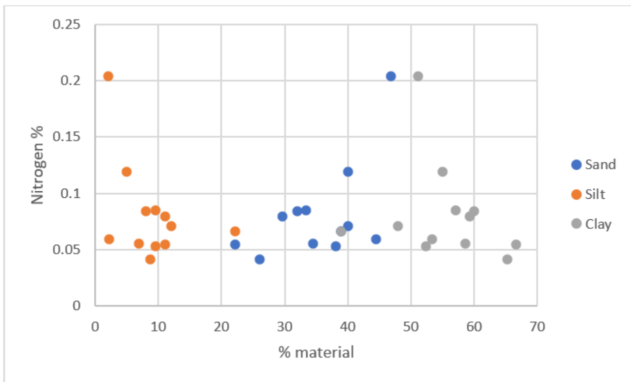

Figure 8: Relationship between the percentage of sand, silt and clay in the soil and the amount of nitrogen measured in the soil (n=12). $N= 0.0033Sand – 0.0369$, $N= -0.0035Silt + 0.1129$, $N= -0.0014Clay + 0.1563$.

There is a positive correlation between the percentage of sand that makes up the soil measured and the nitrogen content, as the percentage of sand increases the nitrogen content of the soil increases ($p> 0.0001$, $R^2 = 0.3055$). However, for silt there is a weak negative correlation between the percentage of silt and the nitrogen content, which is significant at $p<0.1$ level but not at the $p<0.05$ level ($p= 0.059$, $R^2 = 0.1806$). There is a weak relationship between the clay percentage in the soil and the nitrogen content of the soil, so generally as the clay content of the soil increases the nitrogen content of the soil decreases ($p= 0.126$, $R^2 = 0.055$) (Figure 8).

Discussion

The percentage of carbon measured in the soil samples differs depending on the age of the plantation. As shown in figure 2, the greatest difference in value and therefore where the statistical difference lies is between the 4-year-old plantation and the other 3 plantations. These results were not expected, as it was predicted that the greater the age of the plantation and subsequently the age of the agroforestry system, the greater the soil carbon stocks. This trend was found in a global meta-analysis of agroforestry systems, that concluded soil carbon stock increased with tree age. It also found that this ability to increase soil carbon varied along climatic zones, with levels peaking quickly in tropical zones (Ma et al, 2020). The quick peak in soil carbon content could explain why the increase of carbon at the 4-year-old plantation is then followed by a non-statistically significant difference between the plantations of ages 27, 58 and 60. Furthermore, in the study conducted by Shi et al (2018) it was found that there was the highest change in soil carbon from younger (less than 20-years), fast-growing tree species that quickly increase litter inputs by tree pruning and thus accumulate soil organic carbon at the early stages (Shi et al, 2018). Similarly, a study conducted on tea agroforestry systems saw a significant difference in the soil carbon stocks, with the highest carbon stocks measured at the 20-year-old plantation (Kalita et al, 2020). Where this study was limited with the oldest plantation measured being only 20 years old, the samples taken in Nigeria were limited by the large age gaps in the plantations measured. To gain a better understanding of how agroforestry age can impact soil carbon content, soil samples need to be taken from a greater number of plantation ages- specifically between the ages of 4 to 27 to analyze where carbon content peaks and subsequently begins to decrease.

However, this does not explain why the carbon content of the soil samples measured decreases with age. Several studies have found that the most important factors influencing carbon stocks in soil were the previous land use and the long-term management regimes of the plantation (Paul et al, 2002). Cassava was planted among the oil palm at plantations ages 27, 58 and 60 and despite it being a stable crop that is important for food security in Nigeria the farming of cassava can have severe environmental impacts such as soil erosion and depletion of nutrients if not correctly managed (Shackelford et al, 2018). Erosion of soil leads to the oxidation of soil organic carbon stocks and releases CO_2 into the atmosphere, thus negatively affecting the amount of carbon sequestered (Olson et al, 2016).

Furthermore, It has been found that land where there is no active tillage there are higher carbon stocks than land undergoing conventional tillage and overall, the annual carbon sequestration rate is higher. This is due to tillage breaking up the soil structure, speeding up the decomposition and loss of organic matter and increasing the threat of soil erosion (Conceição et al, 2013). Therefore, the type of crops grown among the oil palm trees and the subsequent land management greatly affects the carbon content of the soil. To eliminate the factor of previous land management and the types of crops grown among the oil palm trees, there is potential for this study to be carried out again as part of a long-term field study. The results from each year would be compared to see how the soil carbon changes over time at each individual plantation. This would ultimately fill the research gap of the long-term system level sustainability.

All the plantations where soil samples were taken used oil palm trees within the systems, which have a deep extensive root system that has been found to improve soil carbon stocks (Lorenz and Lal, 2014). However, it has been suggested that an increased tree species diversity, opposed to mono-tree, which is seen in the agroforestry systems sampled, can result in higher soil organic content. This is due to a potential increase in fine root production and a flux of carbon and other nutrients from the plants into the soil (Lorenz and Lal, 2014). Additionally, planting multiple tree species in agroforestry systems leads to faster biomass carbon stocks and accumulated biomass carbon than systems with a single tree species. This increase in biomass carbon combined with the increased soil carbon stocks can contribute to the overall ability of agroforestry systems to sequester carbon (Ma et al, 2020). To increase potential soil carbon stocks in agroforestry systems the most appropriate crops should be grown with a diverse species of trees with deep root systems, and management of the land is to be carried out carefully.

The carbon content of the soil followed the same pattern regardless of the depth the sample was taken at (Figure 2). Another study, researching the soil organic carbon stock in different soil layers under different land uses found that the soil organic carbon stock also decreased from 0-15cm to 15-30cm. This study measured soil samples up to 150cm, whereas the soil samples taken in Nigeria were only taken up to 30cm, however it was found that the carbon stocks continued to decrease as soil depth increased (Kukal and Bawa, 2014). This is further supported by a study measuring the soil organic content of aged tree agroforestry systems that calculated a significant variation between the soil organic carbon concentration and the depth of the soil- this occurred for each of the plantation ages measured (Kalita et al, 2020). It was hypothesized that the opposite trend would have been shown as carbon stored at the surface decomposes at a greater rate than deep carbon, which is more stable and thus an important long-term carbon sink (Battelle, 2019) and soil organic carbon in subsoil has a three to ten times longer mean residence time than in topsoil (Kaiser et al, 2010).

The nitrogen content measured in the soil follows the same trend as the carbon content (Figure 3). This trend was not expected as meta-analysis of agroforestry systems showed that nitrogen content of soil was greater than the treeless control plots and thus the increase would continue as the trees age (Bayala et al, 2018). It was also found that the nitrogen content of the soil decreased as the depth of the soil sample increased. In support of this, another study found that total nitrogen significantly varied with soil depth and agroforestry age as the total nitrogen concentration decreased with an increase in soil depth in all agroforestry ages (Kalita et al, 2020).

The carbon-nitrogen ratio (C: N) is an important indicator of soil fertility as it can significantly impact on soil functions such as the activity of microorganisms (Deng et al, 2020). Of the soil samples measured, the highest C:N ratio was found at the youngest plantation for the 0-15cm depth (Figure 5). The C:N ratio is expected to be between 9 to 12 and considered high at 18. For site 4 the C:N ratio varied from 11 to 16, which indicates good fertility. However, at sites 1-3 the C:N ratio averaged below 8, thus indicating poor fertility. The good soil fertility seen at site 4, due to increased carbon and nitrogen content, has the potential to increase crop yield and ultimately improve the food security for Nigeria. One study found that an increase of 1 ton of soil carbon can increase the yield of cowpea between 0.5 to 1 kg/ha (Lal, 2004). Furthermore, nitrogen availability directly affects carbon sequestration which influences the soil C:N ratio (Tian et al, 2006) thus, the soils with the greatest nitrogen content sequester the greatest amount of carbon and therefore are represented by a high C:N ratio.

The agroforestry systems analyzed in this study all consisted of the same soil type- Sandy Clay Loam. However, there are slight differences in the percentage of sand, silt and clay that made up each of the soils. The percentage of each, and thus the composition of the soil can affect the amount of carbon and nitrogen stored. From the results, there is no clear trend shown between the carbon content of the soil and the percentage of sand, silt and clay measured (Figure 7). However, it has been found that silt and clay play an important role in stabilizing carbon in the soil whereas sandy soils have a limited capacity to stabilize organic compounds thus affecting the capacity, magnitude, and rate of carbon storage (Gruba and Socha, 2019). It has been shown that soil organic carbon stocks and the clay content of soil both increased simultaneously in one study. Additionally, the soil organic carbon decomposition is shown to decrease as the clay content increases (Zhong et al, 2018). The carbon accumulation is lower in sandy soils as there are higher carbon losses through leaching and macro-faunal activity due to differences in pore size distribution (Sugihara et al, 2012). Although the soils sampled have high clay content, the percentage of carbon in the soil is generally low.

Conclusion

The planting of trees initially increases the carbon and nitrogen content of the soil in young oil palm agroforestry systems located in Nigeria. The increase does not continue for the agroforestry systems over 27 years as the carbon and nitrogen content begins to decrease. However, the large gaps in age between the plantations analyzed limit the ability for these results to form a significant trend. Although this study fills a research gap for older plantations (58 and 60 years) there is still a need for a greater range of ages in plantations to be studied. This is particularly true for plantations between 4 and 27 years to determine the optimum age for trees to increase carbon and nitrogen in the soil. There was not enough variation in the soil texture and pH of the samples analyzed therefore it cannot be concluded if these factors have a greater contribution to the soil carbon and nitrogen content than agroforestry age. However, the age of the agroforestry system may not be the greatest factor contributing to the carbon and nitrogen content of the soil and the land management of each individual plantation may have a greater effect. There is potential for the same study to be carried out again in a set number of years as the agroforestry system ages and for the results to be compared with the results previously recorded. This will show how the carbon and nitrogen content of the soil changes over time, while eliminating the variables of land management and historical use of the land. Overall, the results of this study combined with the results of similar studies indicate that young agroforestry systems, with careful land management practices, have the potential to increase carbon and nitrogen in the soil. Therefore, agroforestry could be utilized as a climate change mitigation practice for Nigeria, but more research is needed to see how these levels change with time.

Recommendations

- If agroforestry systems are to increase carbon sequestration and be utilized as a climate change mitigation measure, the carbon content in deep soil needs to be greater. This study and many other current studies are limited to measuring only up to 30cm (shi et al, 2018) and so future research should focus on sampling soil to a greater depth.
- There is also potential for soil samples to be used in thermal analysis, I.e., thermogravimetry (TG), differential scanning calorimetry (DSC) and evolved gas analysis (EGA), as it has been proved to be a useful technique for interpreting soil organic carbon stability. It can determine the energy, through heat, necessary for combustion of carbon and thus the energy barrier to soil organic carbon decomposition (Peltre et al, 2013). Therefore, soil samples up to 150cm from the study area could be taken for thermal

analysis to investigate how the thermal stability of carbon varies through the soil horizon. Thus, giving more reliable results for the long-term sustainability of carbon in the soil at agroforestry systems.

- The high C:N ratio seen at the youngest site provides further evidence that the younger agroforestry system with effective soil and land management practices has a higher potential to sequester carbon and be utilized as a practice for climate change mitigation.
- To accumulate a greater amount of carbon, agroforestry systems should be implemented in silty-clay soils rather than sandy clay soils seen in this study. Therefore, a greater variety of soil types, with varying silt, sand and clay content need to be investigated to determine if the soil texture is an important factor in the carbon stocks of agro-forestry systems and to obtain a significant result.

References

1. Batelle. What Role Do Deep Soil Minerals Play in Carbon Storage? (2019).
2. Bationo A., et al. "Soil organic carbon dynamics, functions and management in West African agro-ecosystems". Agricultural systems 94.1 (2007): 13-25.
3. Bayala J., et al. "Soil organic carbon and nitrogen in agroforestry systems in sub-Saharan Africa: a review". Improving the profitability, sustainability and efficiency of nutrients through site specific fertilizer recommendations in West Africa agro-ecosystems (2018): 51-61.
4. Bensemann M., et al. "Land use effects on soil carbon and nitrogen stocks and dynamics in North Germany". Farming and Management 3.2 (2018): 110-122.
5. Berthrong ST., et al. "Soil C and N changes with afforestation of grasslands across gradients of precipitation and plantation age". Ecological Applications 22 (2012): 76-86.
6. Conceição PC, Dieckow J and Bayer C. "Combined role of no-tillage and cropping systems in soil carbon stocks and stabilization". Soil and Tillage Research 129 (2013): 40-47.
7. de Carvalho WR., et al. "Short-term changes in the soil carbon stocks of young oil palm-based agroforestry systems in the eastern Amazon". Agroforestry systems 88.2 (2014): 357-368.
8. Deng X., et al. "Spatial and temporal trends of soil total nitrogen and C/N ratio for croplands of East China". Geoderma 361 (2020): 114035.
9. Friggens NL., et al. "Tree planting in organic soils does not result in net carbon sequestration on decadal timescales". Global Change Biology 26.9 (2020): 5178-5188.
10. Google Earth Version 7.3.4 Acharu, Dekina, Kogi, Nigeria (2021).
11. Gruba P and Socha J. "Exploring the effects of dominant forest tree species, soil texture, altitude, and pHH2O on soil carbon stocks using generalized additive models". Forest Ecology and Management 447 (2019): 105-114.
12. Han X., et al. "Effects of plantation age and precipitation gradient on soil carbon and nitrogen changes following afforestation in the Chinese Loess Plateau". Land Degradation & Development 30.18 (2019): 2298-2310.
13. Isaac ME., et al. "Temporal changes in soil carbon and nitrogen in west African multistrata agroforestry systems: a chronosequence of pools and fluxes". Agroforestry Systems 65.1 (2005): 23-31.
14. iSDA. "iSDAsoil" (2022).
15. Jones A., et al. Soil Atlas of Africa. European Commission, Publications Office of the European Union, Luxembourg (2013): 176.
16. Kaiser C., et al. "Belowground carbon allocation bytrees drives seasonal patterns of extracellular enzyme activities byaltering microbial community composition in a beech forest soil". New Phytologist 187 (2010): 843-858.
17. Kalita RM., et al. "Ecosystem carbon stocks in different aged tea agroforestry systems: implications for regional ecosystem management". Tropical Ecology 61.2 (2020): 203-214.
18. Kemmitt SJ., et al. "pH regulation of carbon and nitrogen dynamics in two agricultural soils". Soil Biology and Biochemistry 38.5 (2006): 898-911.
19. Kukal SS and Bawa SS. "Soil organic carbon stock and fractions in relation to land use and soil depth in the degraded Shiwaliks

hills of lower Himalayas". Land Degradation & Development 25.5 (2014): 407-416.

20. Lal R. "Soil carbon sequestration impacts on global climate change and food security". Science 304.5677 (2004): 1623-1627.
21. Liao K, Wu S and Zhu Q. "Can soil pH be used to help explain soil organic carbon stocks?". CLEAN-Soil, Air, Water 44.12 (2016): 1685-1689.
22. Liu X., et al. "Changes in soil nitrogen stocks following vegetation restoration in a typical karst catchment". Land Degradation & Development 30 (2018): 60-72.
23. Lorenz K and Lal R. "Soil organic carbon sequestration in agroforestry systems". A review. Agronomy for Sustainable Development 34.2 (2014): 443-454.
24. Ma Z., et al. "Carbon accumulation in agroforestry systems is affected by tree species diversity, age and regional climate: A global meta-analysis". Global Ecology and Biogeography 29.10 (2020): 1817-1828.
25. Milne E., et al. "Soil carbon, multiple benefits. Environmental Development". 13 (2015): 33-38.
26. Muchane MN., et al. "Agroforestry boosts soil health in the humid and sub-humid tropics: A meta-analysis". Agriculture, Ecosystems & Environment 295 (2020): 106899.
27. Olson KR., et al. "Impact of soil erosion on soil organic carbon stocks". Journal of Soil and Water Conservation 71.3 (2016).
28. Owombo PT, Idumah FO and Adepoju AO. "Analysis of farmers" perception and adoption of agroforestry technology as climate change mitigation strategy in Edo State, Nigeria". World News of Natural Sciences (2018).
29. Paul KI., et al. "Change in soil carbon following afforestation". Forest ecology and management 168.1-3 (2002): 241-257.
30. Peltre C., et al. "Relationships between biological and thermal indices of soil organic matter stability differ with soil organic carbon level". Soil Science Society of America Journal 77.6 (2013): 2020-2028.
31. Riggs CE., et al. "Nitrogen addition changes grassland soil organic matter decomposition". Biogeochemistry 125 (2015): 203-219.
32. Sawyer J. Nitrogen loss: How does it happen? Integrated Crop Management. Iowa State Univ. Ext., Ames (2007).
33. Scharf P. "Managing Nitrogen for Crop Production". John Wiley & Sons 166 (2020).
34. Shackelford GE., et al. "Cassava farming practices and their agricultural and environmental impacts: a systematic map protocol. Environmental Evidence". 7.1 (2018): 1-7.
35. Shi L., et al. "Agroforestry systems: Meta-analysis of soil carbon stocks, sequestration processes, and future potentials". Land Degradation and Development 29.11 (2018): 3886-3897.
36. Sugihara S., et al. "Effects of land management on CO2 flux and soil C stock in two Tanzanian croplands with contrasting soil texture". Soil Biology and Biochemistry 46 (2012): 1-9.
37. Tao H., et al. "Factors affecting nitrogen availability and variability in cornfields". Agronomy Journal 110.5 (2018): 1974-1986.
38. Tian H., et al. "Patterns of soil nitrogen storage in China". Global Biogeochemical Cycles 20.1 (2006).
39. Tuschora H and Cherubini F. "Co-benefits and trade-offs of agroforestry for climate change mitigation and other sustainability goals in West Africa". Global Ecology and Conservation (2020).
40. van der Salm C., et al. "Estimation of nitrogen losses via denitrification from a heavy clay soil under grass". Agriculture, ecosystems & environment 119.3-4 (2007): 311-319.
41. Wang C., et al. "Precipitation gradient determines the tradeoff between soil moisture and soil organic carbon, total nitrogen, and species richness in the Loess Plateau, China". Science of the Total Environment 575 (2017): 1538-1545.
42. Wolkowski RP, Kelling KA and Bundy LG. "Nitrogen management on sandy soils". University of Wisconsin—Extension 3634 (1995).
43. World Bank Group. Climate Change Knowledge Portal (2021).
44. Zhong Z., et al. "Relationship between soil organic carbon stocks and clay content under different climatic conditions in Central China". Forests 9.10 (2018): 598.

Volume 4 Issue 6 June 2023