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Effect of Selected Tree Species on Maximizing Soil Organic Carbon Sequestration in Imo State, Nigeria

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Abstract: The world is currently experiencing a period of warming and the role of soil carbon pools for mitigation of greenhouse gases has encouraged the need for more knowledge on the tree species effects on soil organic carbon. The study was conducted to evaluate the effect of tree species on maximizing soil organic carbon sequestration in Imo State, Nigeria. Four tree species (Teak*, Tectona grandis,* linn*,* Gmelina*, Gmelina arborea* Roxb*,* Rubber plant*, Hevea bransiliensis* Mull. Arg. and Black velvet*, Dialium guineense* Wild) were chosen for the study. Random soil sampling was used in field studies. Soil samples were collected at the depth of 0-15cm and 15-30cm. these soil samples were prepared and subjected to routine laboratory analysis. Soil organic carbon sequestration was calculated and relationships between soil organic carbon sequestration and soil properties were obtained by simple correlation. Results showed that *Tectona grandis* of sequestration value 154.1 and 116.8 at top soil and subsoil respectively provides the best option for maximizing carbon sequestration in the soil, followed by *Hevea bransiliensis* (147.4 and 91.1), *Gmelina arborea* (134.1 and 81.1) and least was in *Dialium guineese* (108.1 and 60.1) at all depth. There was significant ($P = 0.01$) positive correlation between base saturation, calcium, total nitrogen with soil organic carbon sequestration at r –values of 0.77, 0.74 and 0.97 respectively. Hence, negative correlation existed between soil pH, clay fraction potassium with soil organic carbon sequestration with r-values of – 0.37, -0.68 and -0.54 respectively. It can be concluded that soil organic carbon sequestration decreases with decreasing depths and were greatly affected by tree species, soil properties and management practices.

Keywords: Tree Species, Soil Organic Carbon Sequestration, Soil Properties, Management Practices

1. Introduction

The world is currently experiencing a period of warning and it is widely accepted that the cause of this warming is a direct result of the increased levels of carbon dioxide (CO_2) in the atmosphere, caused by both natural and anthropogenic factors, such as industrial development, deforestation, agricultural improvements, increased use of cars and release of green house gases (CH_4, CO_2, N_2O, etc) are the major contributing factors to the depletion of the ozone layer and its associated global warming and climate change. Carbon exists in many forms, predominantly as plant biomass, soil organic matter and as the carbon dioxide (CO_2) in the atmosphere. Soil especially the forest soil is one of the main sinks of carbon on earth because these soils normally contain higher soil organic matter. It has been propounded that one method to reduce atmospheric carbon dioxide (CO_2) is to increase the global storage of carbon in soils. Soils are the largest carbon reservoirs of the terrestrial carbon cycle. It contains twice the amount of carbon in the atmosphere as carbon dioxide and thrice the amount in global vegetation [1].

Interest in the ability of forest soils to sequester atmospheric carbon dioxide has increased because of the threat of projected climate change. Thus, understanding the mechanisms and factors of soil organic carbon dynamics in forest soils is important to identify and enhance natural sinks for carbon sequestration to mitigate the climate change. Soil carbon sequestration is the process of transferring carbon dioxide from the atmosphere into the long lived pools (soil) through plant residues and other organic solids, and in a form that is not immediately remitted [2]. Put simply, soil carbon sequestration involves the transfer of atmospheric carbon dioxide into soil organic carbon pool [3]. This transfer or “sequestering” of carbon helps off-set emissions from fossil fuel combustion and other carbon-emitting activities while enhancing soil quality and long-term agronomic productivity.

The role of soil carbon pools for mitigation of greenhouse gases has encouraged the need for more knowledge on the tree species effects on soil organic carbon. Forest management, including a change in tree species, has been accepted as a measure for mitigation of atmospheric carbon dioxide in national green house budgets [4]. Hence, carbon sequestration by forest plantations is being proposed as one method of positively affecting the balance of atmospheric levels of carbon dioxide. [5]; [6]. One of the most effective activities to improve soil carbon sequestration is choosing suitable forest tree species; unfortunately, there is limited knowledge of it [7]. Therefore, this study will aid us to understand the forest plantation that provides the best option for maximizing carbon accumulation in the soil in order to enhance the natural sink of green house gases, reduce the rate of soil organic carbon depletion there by reducing atmospheric carbon dioxide that contributes to global warming and climate change.

2. Materials and Methods

2.1. Description of the Study Area

The study was conducted in three different locations of four different forest plantations in Imo State, Imo state lies between latitude $4^0 45^1$ and $5^0 50^1$N and longitude $6^0 35^1$ and $7^0 30^1$E. The three locations of the plantations are Ohuba, Umudike – 11, both in Ohaji/Egbema Local Government Area, and Federal University of Technology Owerri (FUTO) in Owerri West Local Government Area in Imo State, southeastern Nigeria. It has a humid tropical climate, characterized by bimodal rainfall pattern with mean annual rainfall ranging from 1800 to 2500mm and mean annual temperature ranging from 26^0C to 31^0C [8]. [9] showed that the underlying geological material are coastal plan sand (Benin Formation) and the Bende-Ameki formation. It consists of mainly friable sands with minor intercalations of clay.

2.2. Selection of the Study Forest Plantations

The study area consists of four forest plantations and they are as follows:

1) *Gmelina arborea* forest plantation site was established in the year 2004. It covers about five (5) hectares of land. The site was originally a fallow land, which was cleared through manual bush clearing followed by burning. After which, the seedlings of *Gmelina arborea* gotten from Ohaji/Egbema forest reserve was introduced to the site with 11 x 17 spacing. There is no special management practice such as beaten up, fertilization, pruning etc given to the growing seedlings except clearing of the weeds/bushes which is mainly *Panicum maximum* and few of *chromoleana odorata*. Fuel-wood harvesting and hunting were observed in the plantation. Presently, the trees have attained appreciable height and have a lot of plant debris on the floor.
2) *Tectona grands* forest plantation was established on the same land area of *Gmelina arborea* in the year 2004. It has the same management practices with *Gmelina arborea*. The only different is in their growth sizes.
3) *Hevea brasilinensis* plantation site of study was established in the year 1965 and was registered with the government in 1968. The site was originally a farmland under yam cultivation, before it was cleared through manual cuttings followed by bush burning. Then, *hevea brasiliensis* seedlings were collected from Federal Government and planted using 11 x 22 spacing in an area of about 6 hectares of land. Planted seedlings were raised with NPK fertilizer and other locally made compost, weeding, beaten-up were also observed. Presently the stands are well matured with fruits/seeds which falls and germinate thus alters the original spacing. Pruning, thinning, and bush clearing are always carried out in the site for maintenance purposes, also tapping of latex from about 15 years old plants and fetching of fuel-wood were also observed in the site.
4) *Dialium guineense* is a dominant tree species in a secondary forest beside River Otamiri in Federal University of Technology Owerri (FUTO). The area is characterized by mostly plant species, arranged in storey, with close canopies, highly depleted by anthropogenic activities such as fuel-wood harvesting, deforestation, hunting and gathering from wildlife.

2.3. Soil Sampling Techniques

Soil samples were randomly collected from each plantation at varying depths of 0 – 15cm and 15 – 30cm with an aid of soil auger. The soil samples were randomly collected at five different points in each plantation (five replicates). The collected soil samples were bagged in a polyethene bags and carefully labeled according to the plantation types, replicate number and depth. A total of forty (40) samples were collected from four forest plantations at two (2) varying depth. Core samples were also used to collect soils at each plantation in two (2) varying depths for bulk density determination. A total of eight (8) undisturbed core soil samples were carefully packaged and labeled accordingly.

2.4. Laboratory Analysis

The soil samples were air-dried at room temperature, crushed and sieved using 2mm sieve. The composite soil samples were taken to the laboratory for determination of the physical and chemical properties. Particle size distribution was determined by hydrometer method [10]. Bulk density was determined by the core method using [11]. Textural class was determined by [12]. Soil pH was measured using pH meter [13]. Soil organic carbon was determined by the Walkley-Black method described by [14]. Soil organic matter was determined by [15]. Total nitrogen was determined by the Kjeldahl method [16]. Available phosphorus was determined using Bray 1 method [17] Cation exchange capacity was obtained using the procedure described by [18]. Base saturation was calculated as total exchangeable bases divided by effective cation exchange capacity multiply by 100 percent.

2.5. Data Analysis

Data collected were statistically analyzed using Genstat Discovery (3rd Edition). The relationship between soil carbon sequestration and soil properties were determined using simple linear correlation ($P \leq 0.05$) and ($P \leq 0.01$). Soil organic carbon sequestration was calculated according to [20].

Soil organic carbon sequestration (SOCS) = BD (g/cm^3) x SOC (g/kg) x soil depth (cm)

Where; BD = Bulk density

SOC = Soil organic

Carbon.

3. Results

Table 1 and 2 show the physical and chemical properties of the topsoil and subsoil in the four forest plantations of the study. The soils are generally sandy sand at 0 – 15cm depth except for D*ialium guineense* which is sandy loam. At 15 – 30cm depth, soils of *Tectona grandis* and *Dialium guineese* are sandy loam with sand value of 784gkg^{-1} and 824gkg^{-1} respectively, and clay value of 156gkg^{-1}. *Gmelina arborea* is sandy clay loam with sand value of 704gkg^{-1}, clay value 276gkg^{-1}. *Hevea bransiliensis* is loamy sand with sand value of 844gkg^{-1}, and clay value 136gkg^{-1}. However, [20], states that soil texture affects soil carbon sequestration due to its influence on soil microbial community and soil respiration.

Table 1. *Soil Physical Properties of the Study Locations*

Plantation Site	Depth (cm)	Sand (g/kg)	Silt (g/kg)	Clay (g/kg)	Textural Class	Bulk Density (g/cm^3)
Gmelina arborea	0–15	844	60	96	Sandy Sand	0.868
Hevea branisiliensis	0–15	884	20	96	Sandy Sand	0.936
Tectona grandis	0–15	864	40	96	Sandy Sand	0.849
Dialium guineense	0–15	804	40	156	Sandy Loam	0.775
	Mean	849	40	11	Sandy Sand	0.857
Gmelina arborea	15-30	740	20	276	Sandy Clay Loam	0.858
Hevea branisiliensis	15-30	844	20	136	Loamy Sand	0.832
Tectona grandis	15-30	784	60	156	Sandy Loam	0.916
Dialium guineense	15-30	824	20	156	Sandy Loam	0.761
	Mean	789	30	181	Sandy Clay Loam	0.84175

Table 2. *Soil Chemical Properties of the Study Locations*

Plantation	Depth (cm)	pH (H_2O)	pH (kcl)	Org. Carbon (g/kg)	Org. Matter (g/kg)	Total N (g/kg)	C/N	Avail. P (mg/kg)	Ca	mg	K Cmol/kg	Exc Na	H	Al	CEC	BS %
Gmelina arborea	0–15	5.03	4.05	10.3	17	0.8	12.9	6.36	3.2	1.6	0.19	0.11	0.1	0.4	5.6	91
Hevea bransiliensis	0–15	4.47	3.64	10.5	18.2	0.9	11.7	3.61	2.4	1.6	0.24	0.14	0.3	0.4	5.08	86.2
Tectona grandis	0–15	5.05	4.05	12.1	21	1	12.1	2.75	3.2	1.6	0.09	0.26	0.4	0.2	5.75	89.5
Dialium guineense	0–15	5	4.1	9.3	16.2	0.8	11.6	0.95	2	1.2	0.16	0.07	0.3	0.8	4.53	75.7
	Mean	4.89	3.96	10.55	18.1	0.88	12.08	3.42	2.7	1.5	0.17	0.15	0.28	0.45	5.24	85.6
Gmelina arborea	15-30	5.58	3.97	6.3	11.0	0.55	11.5	7.61	2.6	2	0.2	0.09	0.1	1	6	81.6
Hevea bransiliensis	15-30	4.36	3.76	7.3	12.7	0.6	12.2	6.82	2	1.2	0.29	0.11	0.2	0.7	4.5	80
Tectona grandis	15-30	4.63	3.8	8.5	14.8	0.7	12.1	5.42	2	1.2	0.12	0.23	0.2	0.8	4.55	78
Dialium guineense	15-30	5.25	4.38	5.3	9.3	0.4	13.3	0.86	1.2	0.8	0.26	0.12	0.5	0.3	3.18	74.8
	Mean	4.96	3.98	6.85	9.48	0.56	12.28	5.18	1.9	1.3	0.28	0.14	0.25	0.7	4.56	78.6

The bulk density of the soils differed among the forest plantations of study. The highest value of bulk density at 0 – 15cm depth was recorded on soils of *Hevea bransiliensis* (0.936g/cm^3) and the least value was on *Dialium guineense* (0.775 g/cm^3). At 15 – 30cm depth, the highest value of bulk density was recorded on soils of *Tectona grandis* (0.916 g/cm^3) while the least value was also on *Dialium guineense* (0.761 g/cm^3). The soils were acidic with pH value ranging from 4.36 – 5.58. It was observed that *Hevea bransiliensis* plantation is more acidic than others both in the topsoil (4.47) and subsoil (4.36). This may be attributed to the management practice in the *Hevea bransiliensis* plantation such as application of fertilizer. [21] observed that continuous application of fertilizers such as ammonium sulphate $(NH_4)_2SO_4$ and urea to improve soil fertility without lime decrease the pH of the soil. The organic matter content of the soils ranging from (21 – 9.3g/kg), *Tectona grandis* plantation recorded the highest values in the topsoil (21g/kg) as well as subsoil (14.8g/kg). *Dialium guineense* has the least values both in the topsoil (16.2g/kg) and subsoil (9.3g/kg). However, the higher organic matter level is very important in tropical countries because it is the benchmark upon which forest soil properties depends. It also plays important role in soil quality and enhances agricultural productivity and sustainability. The percentage base saturation of the soils were between (91 – 74.8%). *Gmelina arborea* plantation recorded the highest values both in the topsoil (91%) and subsoil (81.6%). *Dialium guineense* has the lowest values both in the topsoil (75.7%) and subsoil (74.8%). The higher percentage base saturation recorded in *Gmelina arborea* plantation may be attributed to higher clay percentage composition of the *Gmelina Arborea* plantation.

Table 3. *Soil Organic carbon sequestrations among the Plantations at Different Depths*

Plantation Site	Age of Plantation	Depth	Soil Organic Carbon Sequestration ($g^2/cm^2/kg$)
Gmelina arborea	9	0–15	134.1
Hevea branisiliensis	48	0–15	147.4
Tectona grandis	9	0–15	154.1
Dialium guineense	31	0–15	108.1
		Mean	135.93
Gmelina arborea	9	15-30	81.1
Hevea branisiliensis	48	15-30	91.1
Tectona grandis	9	15-30	116.8
Dialium guineense	31	15-30	60.5
		Mean	87.375

Table 4. *Correlation between Soil Organic Carbon Sequestration and Soil Properties*

Soil properties	R	Level of Significance
Available Phosphorus	-0.00576	NS
Bulk Density	0.62044	*
Cation exchange Capacity	0.57173	*
Base Saturation	0.76891	**
C/N ration	-0.27130	NS
Exch. Calcium	0.73675	**
Clay Fraction	-0.67718	*
Exch. Hydrogen	-0.0870	NS
Exch. Potassium	-0.54498	*
Exch. Magnesium	0.42487	NS
Organic Carbon	0.97556	**
pH (H_2O)	-0.37404	NS
Sand Fraction	0.57081	*
Total Nitrogen	0.96684	**

* and ** = significant at 0.05 and 0.01 probability levels respectively, NS = non significant

4. Discussion

Soil organic carbon sequestrations among the plantations at different depths are shown in table 3 above. The result shows that the mean value of soil organic carbon sequestration was highest (135.93) within the topsoil (0-15) with *Tectona grandis* plantation exhibiting the highest value (154.1) followed by *Hevea bransiliensis* plantation (147.4), *Gmelina arborea* plantation (134.1) and least was in *Dialium guineense* of secondary forest (108.1). Within the subsoil (15 - 30), the mean value of soil organic carbon sequestration was (87.38) with *Tectona grandis* value reduces to (116.8), followed by *Hevea bransiliensis* plantation (91.1), *Gmelina arborea* plantation (81.1) and least was also in *Dialium guineense* of secondary forest (60.5). Hence, the soil organic carbon sequestration decreased with depth at all study sites. This is in agreement with earlier findings of [21]. Also, the results indicated that the age of the plantation is not related to its soil organic carbon sequestrations. Since *Tectona grandis* plantation of 9 years, which is one of the youngest plantation has the highest value (154.1) of soil organic carbon sequestration, *Hevea bransiliensis* plantation which is 48 years has the value of (147.4), *Gmelina arborea* plantation of 9 years has a value of (134.1) where as *Dialium guineense* in secondary forest of 31 years has the least value of (108.1). This is in accordance with similar findings by [22], where carbon change of the soil sampled below a depth of 10cm in an afforested area, had no significant relationship with stand age.

Furthermore, the results indicated that tree species affects soil properties as well as soil organic carbon sequestration that is not only natural and anthropogenic factors as documented by [23]. It was observed in the plantations of *Gmelina arborea* and *Tectona grandis* that was established on the same land area, with the same climate factors, given the same management practices, in the same year, yet they sequester carbon differently, *Tectona grandis* (154.1) and *Gmelina arborea* (134.1). This supports the earlier findings by various authors as reported below: [24] states that one the most effective activities to improve soil carbon sequestration are choosing suitable forest tree species. The selection of tree species is one factor to consider if we want to mitigate carbon dioxide emissions to the atmosphere through forest management. [25], [26], [27]. Forest management including a change in tree species, has been accepted as a measure for mitigation of atmospheric carbon dioxide in national green house gas budgets. Moreover, the results of simple correlation analysis are shown in table 4, indicated strong positive correlation between soil organic carbon sequestration and Base saturation (r = 0.76891, P = 0.01). This implies that soil organic carbon sequestration increases with increasing Base saturation. In the chemical properties of the soils shown in table 2, the least value of the base saturation was found in *Dialium guineense* of secondary forest (75.7% and 74.8%) at 0 – 15cm and 15 – 30cm depth respectively. *Dialium guineense* also recorded the least value of soil organic carbon sequestration both in topsoil and subsoil. Again, the results indicated strong positive correlation between soil organic carbon sequestration and total Nitrogen (r = 0.96684, p = 0.01) implying that soil organic carbon sequestration increases with increasing total Nitrogen. This is seen in the chemical properties of the soils, were *Tectona grandis* plantation has highest value of total Nitrogen (1.0g/kg) as well as soil organic carbon sequestration of (154.1) at 0 – 15cm depth. *Dialium guineense* in secondary forest with least value of soil organic carbon sequestration (108.1) and also has least value of total Nitrogen (0.08g/kg) at the same depth. At 15 – 30cm depth, *Tectona grandis* plantation has also the highest value of soil organic carbon sequestration (116.8) and total Nitrogen (0.07g/kg), while *Dialium guineense* in secondary forest with least value of soil organic carbon sequestration (60.5) and also has least value of total nitrogen (0.04g/kg). However, the results indicated negative correlation between soil organic carbon sequestration and exchangeable potassium (r = -0.54498, p = 0.05) implying that soil organic carbon sequestration decreases with increasing exchangeable potassium. That is the higher the value of soil organic carbon sequestration the lower its exchangeable potassium. This is seen in the results of the chemical properties in table 2 above, while *Tectona grandis* plantation with the highest value of soil organic carbon sequestration (154.1 and 116.8), has the least value of exchangeable potassium (0.09 and 0.12cmol/kg) at 0 – 15cm and 15 – 30cm depth respectively.

5. Conclusion

Soil organic carbon sequestration varied among the four plantations of study with maximum concentration in the *Tectona grandis* plantation, followed by *Hevea bransiliensis*, *Gmelina arborea* plantation and least concentration was found in *Dialium guineense* of secondary forest. It was ascertained that individual tree species had influence on the rates of soil organic carbon sequestration. Hence, *Tectona grandis* tree species provides the best option for maximizing carbon sequestration in the soil. Also it was observed that soil organic carbon sequestration decreased with decreasing soil depths. The highest concentration was found within the topsoil as compared to subsoil in all the plantations, due to high concentration of humus at the topsoil layers, as a result of large amount of plant litter deposit at the topsoil surfaces etc. Furthermore, it was discovered that age of the individual tree species/plantations does not affect its soil organic carbon sequestration concentration. *Hevea bransiliensis* plantation of 48 years old should have the highest concentration of soil organic carbon sequestration, followed by *Dialium guineense* in secondary forest of 31 years old when compared with *Tectona grandis* and *Gmelina arborea* plantations of 9 years old. But reverse was almost the case. *Tectona grandis* plantation was highest in soil organic carbon sequestration concentration followed by *Hevea bransiliensis, Gmelina arborea* and least was *Dialium giuneense*. In addition, some activities in the plantations such as latex tapping as performed in *Hevea bransiliensis* plantation affects soil organic carbon sequestration according to earlier findings by [28]. The carbon sequestration decreased significantly at early stages of latex tapping which stabilizing during the continuous harvesting and finally increased when latex harvest ceased. Soil disturbances, deforestation, erosion, fuel-wood harvesting, land degradation, leads to reduction in soil quality, decrease in soil organic matter which result in a decrease in soil organic carbon and sequestration.

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