Original Research Article

Land use effects on Soil organic Carbon Index and Nitrogen Pools of a Tropical Coastal Plain Sands in Southern Nigeria

ABSTRACT

Land use types can of considerable interest in efforts to quantify soil organic C and nitrogen (N) cycling, both of which are important for soil stability and fertility. A study was carried out on a tropical rainforest soils in southern Nigeria to quantify soil organic carbon and nitrogen pools and other indices under forested, 5-year fallow, cocoa plantation and a 5-year continuous cassava land uses. Soil samples were collected at 0-15 cm and 15-30 cm depths for measurement of these indices. Results revealed that total organic carbon (TOC and total nitrogen (TN) varied significantly among the different land uses. TOC of 30.2 g kg^{-1} was higher ($p<0.05$) in forested soils at in the 0-15 cm top soil and 22.3 g kg^{-1} in the subsoil. Total N was statistically significant ($p<0.05$) at 2.61 and 2.01 in forested and 5-year fallowed soils, respectively. The carbon pool index (CPI) was significant at 1.63 in forested soils, while nitrogen pool index (NPI) 1.30 in similar soil ($p<0.05$) in 0-15 cm topsoil. In 15-30 cm subsoil, CPI and NPI values were in the order of forested > cocoa plantation > 5-year cassava cultivation, with the least values of 0.44 CPI and 0.35 NPI found in 5-year cassava plots. It was concluded that CPI and NPI are valuable indicators for analyzing changes in soil quality induced by maintaining a 5-year fallow. It was found that forested and 5-year fallow land uses can be used to improved C and N stock, as well as the structural and hydraulic properties of the soils.

Key words: Carbon pool index; nitrogen pool index; N-stock; C-stock; mean weight diameter

1. INTRODUCTION

Soil organic carbon (SOC) is a critical component of the soil system and a primary predictor of agricultural sustainability and environmental quality [1]. Land use and cropping systems are the primary determinants of SOC and nitrogen pools in diverse land use systems. Changes in SOC storage and dynamics can alter the ecosystem C balance and determine whether soils are C sources or sinks on local to global scale [2]. SOC is strongly linked to most soil properties and functions such as nutrient and water storage and cycling [3], and is frequently used as a general indicator of soil quality, and soil health condition [4]. It is the main component of soil organic matter, which is a continuum of compounds with different chemical compositions, origin, degree of microbial processing and decomposition, and turnover times [5]. An important function of the SOC is to maintain soil structural stability, increase infiltration of water, maintain porosity, and prevent erosion [6]. The dynamics of soil quality are determined by changes in soil organic matter (SOM), and SOC indices under crop cultivation. The primary constituents of SOM, SOC, and total nitrogen (TN) are strongly linked to a wide range of physical, chemical, and biological properties of soil. Therefore, SOC and TN pools are used as important indicators of soil quality [7, 8]. Since forms of C and N are particularly sensitive to changes caused by agricultural practices, they are often employed to quantify SOM [8].

The total N content in the soil is the sum of all N pools in soil, most of which are organic in form and turn inorganic upon decomposition of SOM. For many arable crops, organic N mineralization is the primary process of N nutrition, and its potential in soil is regarded as a superior measurement of soil fertility. Therefore, derived C and N indices such as carbon/N ratio, carbon pool index (CPI), and nitrogen pool index (NPI) may be used to analyze changes in SOM [9, 6]. Knowledge of variations in SOC and TN pools and indices under contrasting land uses is required to understand the feasibility of applying conservation techniques to maintain soil quality and safeguard the environment. CPI and NPI are good early indicators of whether or not a specific agricultural system is contributing to better soil quality. This way, land use systems can have an enormous influence on soil C storage. However, very little knowledge is available on quantification of soil organic C and TN pools and indices under dominant land use types for sandy coastal plain sand soils of southern Nigeria.

The current interest is to study the impact of land use types on soil organic C and N pools, as well as CPI and NPI. Information on CPI have been used for modeling SOC dynamics and forecasting changes in SOC pools as a response to land-use change, management, and climate change [10, 11]. It can be useful in informing agricultural management at the farm scale, and in the design of climate change and soil security policies at the state and national level. The objectives of this study were to assess the effects of different land use types on temporal variations in soil organic C and N pools in tropical coastal plain sand of southern Nigeria, and provide input data on CPI and NPI as indicators of C and N changes in various land use types. This knowledge would enable farmers to cultivate these and similar soils appropriately for long-term sustainability.

2. MATERIALS AND METHODS

2.1 The Study Area

The study was carried out in a 310 ha land in Ikwuano in Abia State, Nigeria, a major food producing area (latitudes 5° 20’ and 5° 30’N, Longitudes 7° 28’ and 7° 42’E). The climate is of a rain forest climate characterized by heavy tropical rainfall that may cause severe erosion problems to hill slope soils [12]. The rainy season is from March to November; with two peaks in July and September. The average annual rainfall ranges between 1,800 and 2,500 mm, with the peaks in July and August and the mean annual maximum temperature is 31°C [13]. Four land use types viz: Forested, 5-year fallow, cocoa plantation, and 5-year cassava plot (Table 1)

Table 1. Land-use history of the study area

Land use	**Land use history**
Forested	More than thirty years, covered with trees, wild oil palm trees, shrubs and under growth. Vegetation is more or less of a secondary forest type and very tall wild oil palms scantly distributed.
5-year fallow	The fallow site has been fallowed for five years dominated with velvet tamarind (*Dialiumguineese*) shrub.
Cocoa plantation	Cocoa plantation has been for over thirty years, dominated with goad weed as under growth
5-year cassava cultivation	Under continuous cassava cultivation for five years.

2.2 Soil Sampling and collection

Transects were selected in each of the land-use. In each transect, five (5) samples were collected from each land use at 50 m blocks. A total of forty (40) disturbed and forty (40) undisturbed soil samples were collected at 0-15 cm and 15-30 cm depths. The samples were labeled in polythene bags, and transferred to the laboratory for analysis. The undisturbed core samples were collected separately for determination of dry bulk density (BD), total porosity (TP), and water holding capacity (WHC).

2.3 Laboratory Analyses

2.3.1 Determination of Total and Organic Carbon and Nitrogen Indices

Soil samples collected at 0-15 and 15-30 cm depths across the land use types were air-dried at room temperature, slightly crushed and sieved to < 2 mm mesh; and used for determination of organic carbon (OC) concentration. Total organic carbon (TOC) was determined using acid dichromate wet-oxidation procedure [14]. Carbon pool index (CPI) was calculated using the procedure of Blair *et al.*, (1995) where the 5.year continuous cassava cultivated treatment was the reference soil as:

$$\text{Carbon Pool Index (CPI)} = \frac{\text{Total C in Sample (g kg}-1)}{Total\ C\ in\ reference\ Soil\ (\ g\ kg-1)} \qquad (1)$$

Higher CPI (CPI > 1) or lower (CPI < 1) indicate higher OC accumulation or loss respectively [15]

Total nitrogen content was determined by the modified macro Kjeldhahl method [16]. Nitrogen pool index (NPI) was calculated using [17] as:

$$\text{Nitrogen Pool Index (NPI)} = \frac{\text{Total N in Sample (g kg}-1)}{Total\ N\ in\ reference\ Soil\ (\ g\ kg-1)} \qquad (2)$$

2.3.2 Carbon and Nitrogen Stock

The SOC and N stock was calculated by multiplying their respective TOC and TN value with BD and depth of soil [18] as:

$$C \text{ stock (kg m}^{-2}) = \text{TOC (or TN) (g kg}^{-1}) \times BD \times \text{p x 10} \qquad (3)$$

where: p is the thickness of the soil layer (m), BD is the bulk density of the soil layer (kg m^{-3})

2.3.3 Soil pH, Particle Size Analysis, Bulk Density and Water Holding Capacity

Soil pH was determined in distilled water using the Bechman’s Zeromatic pH meter in a soil: water ratio of 1: 2.5. Particle size distribution was analyzed following the modified hydrometer method, using sodium hexameta-phosphate as a dispersant [19]. Bulk density was determined by the method [20] as:

$$\text{Bulk density} = \frac{mass\ of\ oven-dried\ soil\ (g)}{bulk\ volume\ of\ soil\ (cm3)} \qquad (4)$$

Water holding capacity (gravimetric) at saturation (0 kPa) after 24 h was calculated as:

$$\text{WHC} = \frac{\text{Mw} - \text{Md}}{Md} \qquad (5)$$

Where $W^{.}H^{.}C$ = water holding capacity (g g^{-1}), M_w = Mass of wet soil (g), and M_d = Mass of oven dried soil (g).

2.4 Data Analysis

Data collected were analysed by general analysis of variance using the procedure [21]; while means were separated by Fisher least significant difference (LSD) at 5% probability level.

3. RESULTS

3.1. Soil Texture, Total Organic and Total Nitrogen

The forested and cocoa plantation soils are sandy clay loam at 0-15 cm and 15-30 cm depths, and sandy loam to sandy clay loam at 15-30 cm depth. The soils were generally slightly acidic and showed a non-significant different $p>0.05$ Total organic carbon (TOC) and total nitrogen (TN) varied significantly among the land-use types. TOC was significantly higher in forested soils at 30.2 g kg^{-1} in the 0-15 cm top soil and 22.3 g kg^{-1} in the subsoil ($p<0.05$) (Table 1). This was followed by Cocoa plantation soils with 19.8 g kg^{-1} at 0-15 cm and 18.2 g kg^{-1} at 15.30 cm depths. Total N was significantly higher at 2.61 and 2.01 in forested and 5-year fallowed soils, respectively (Table 2). The 5-year continuous cultivated soils showed consistently low TOC and total N.

3.2 Organic carbon and Nitrogen indices

Soil carbon and nitrogen storage of the soils varied significantly among the land use types in (Table 3). Soil C-stock was significantly higher at 8.15 kg m^{-2} in forested soil in 0-15 cm topsoil ($p<0.05$). This was followed with 3.79, 3.98, and 2.06 kg m^{-2} carbon storage for 5-year fallow, Cocoa plantation, and 5-year continuous cassava plots, respectively. In the 15-30 cm subsoil, the highest C-stock value of 8.97 kg m^{-2} was also found in forested soils ($p<0.05$). Results further showed that 5-year fallow and cocoa plantation stored greater carbon than in the 5-year continuous cassava cropping. N-stock followed similar trend as that of the topsoil being significantly higher ($p<0.05$) in forested at 0.51 and 0.94 kg m^{-2} in 0-15 cm and 15-30 cm depth. The 5-year continuous cassava cultivation had the least C- and N-stock (Table 3). The carbon pool index (CPI) and nitrogen pool index (NPI), an indication of the amount of C and N pool in the different land use compared with that of the 5-year fallow plots, showed that CPI and NPI were significant at 1.65 and 1.30, respectively in forested soils at 0-15 cm topsoil, and similar trend in the 15-30 cm subsoil (Table 3). At 15-30 cm subsoil, CPI and NPI values were in the order of forested > cocoa plantation > 5-year cassava cultivation, with the least values of 0.44 CPI and 0.35 NPI, were found in 5-year cassava cultivation plots. The C: N ratio was not significantly different in forested, cocoa plantation and 5-year cassava in the 0-15 cm topsoil. In the 15-30 cm subsoil, C: N value of 14.9 was significant ($P<0.05$).

Table 2 Soil texture, pH, total organic carbon and total nitrogen of the soils

Land use	Sand ($g\ kg^{-1}$)	Silt ($g\ kg^{-1}$)	Clay ($g\ kg^{-1}$)	Texture	pH (H_2O)	TOC ($g\ kg^{-1}$)	TN ($g\ kg^{-1}$)
0-15 cm							
5-year fallow	728a	124b	148b	SL	5.8a	18.3b	2.01a
Forested	548b	202a	250a	SCL	6.3a	30.2a	2.61a
Cocoa Plantation	603b	128b	269a	SCL	5.9a	19.8b	1.78b
5-year cassava	738a	139b	123b	SL	5.2a	9.2c	0.92c
15-30 cm							
5-year fallow	671a	117b	212b	SCL	5.3a	17.0b	1.95a
Forested	536a	191a	271a	SCL	6.2a	22.3a	2.33a
Cocoa Plantation	582a	123b	295a	SCL	5.8a	18.2b	1.22b
5-year cassava	668a	131b	201b	SCL	5.1a	7.5c	0.67c

Means followed with the same letters were not significantly different at $p < 0.05$, TOC- total organic carbon, TN- total nitrogen, SCL- sandy clay loam, SL- sandy loam

Table 3 Soil organic carbon and total nitrogen indices of the soils

Land use	C-stock (kg m^{-2})	N-stock (kg m^{-2})	CPI	NPI	C:N
0-15 cm					
5-year fallow	3.79b	0.42b	1.00	1.00	9.1b
Forested	8.15a	0.51a	1.65a	1.30a	11.6a
Cocoa Plantation	3.98b	0.36b	1.08b	0.89b	11.1a
5-year cassava	2.06c	0.21c	0.50c	0.46c	10.0a
15-30 cm					
5-year fallow	7.14b	0.82a	1.00	1.00	8.7b
Forested	8.97a	0.94a	1.31a	1.20a	9.6b
Cocoa Plantation	7.54b	0.51b	1.07b	0.63b	14.9a
5-year cassava	3.40c	0.31c	0.44c	0.35c	12.1a

Means followed with the same letters were not significantly different at $p < 0.05$, CPI-carbon pool index, NPI- nitrogen pool index

3.3. Some hydraulic properties of the soils under the different land use

Land use significantly influenced the mean weight diameter (MWD) of water stable aggregates, permeability (K_{sat}) and water holding capacity of the soils (Table 4). The MWD of water stable aggregates were significantly improved ($p<0.05$) in forested, cocoa plantation and 5-year fallow plots at 1.79 and 1.8, and 1.67 mm, respectively in 0-15 cm topsoil. Saturated hydraulic conductivities in 0-15 cm soil were moderately rapid, slow and rapid in 5-yer fallow, forested and cocoa plantation, 5-year cassava cultivation plots. At 15-30 cm, K_{sat} values were 10 c cm h^{-1} for 5-year fallow, compared with 19.6 cm h^{-1} for 5-year cassava cultivation. Water holding capacity (WHC) ranged between 32% in 5-year cassava plots and 47% in cocoa plantation. This was an indication that the significantly high K_{sat} in the 5-year cassava plots did not translate to higher WHC values. Bulk densities were significantly improved in forested, 5-year fallow and cocoa plantation. Bulk density values ranged between 1.28 g cm^{-3} in forested soils, and 1.49 g cm^{-3} in 5.year cassava cultivation at 0.15 cm soil.

Table 4 Aggregate stability, saturated hydraulic conductivity and water holding capacity of the soil

Land use	MWD (mm)	K_{sat} (cm h^{-1})	WHC (%)	Bulk density (g cm^{-3})	Permeability class
0-15 cm					
5-year fallow	1.67a	16.3b	34b	1.38b	Moderately rapid
Forested	1.79a	9.2c	44a	1.28b	Slow
Cocoa Plantation	1.80a	7.1c	47a	1.34b	Slow
5-year Cassava	0.764c	25.4a	32b	1.49a	Rapid
15-30 cm					
5-year fallow	1.46a	10.3b	35b	1.40b	Moderately slow
Forested	1.25a	7.2b	46a	1.34b	Slow
Cocoa Plantation	1.62a	5.2b	48a	1.38b	Slow
5-year Cassava	0.76b	19.6a	34b	1.51a	Moderately rapid

Means followed with the same letters were not significantly different at $p < 0.05$, MWD- mean weight diameter, Ksat- saturated hydraulic conductivity, WHC- water holding capacity

4. DISCUSSION

The soil hydraulic characteristics along with measured C and N indices varied significantly depending on the land use, but the magnitude changes remained similar within depths. The impact of land use on particle size distribution (PSD) was not significant, except the slight increase in sand contents in 5-year cassava cultivation. Although soil PSD is usually a reflection of the dominant parent materials [22], previous studies [23] reported of marginal increased in sand content continuous cultivated coastal plain sands due to removal of fine particle fractions. In all land uses, the impacts of land use on soil pH were not significant. Due to vegetation and organic matter input into the soil, the forested soil and 5-year fallow were found to have a considerable impact on TOC and TN of the soils, similar to earlier report by [8]. In the forested soils, TOC and TN were higher in 0-15 cm topsoil, than in the lower depth. However, it could be concluded that the root density and soil management approaches may have resulted in higher organic C buildup in all land uses than the 5-year cassava cultivated land. Authors had suggested that land use changes can have a significant influence on SOC dynamics and carbon transport [24-26], and linked it to vegetative growth, root proliferation, organic matter breakdown, and subsequent organic matter retention in soil aggregates. The higher TN in forested and 5-year fallow soils might be attributed to the higher organic carbon, which came from the return of plant and root biomass as well as residues to the soil system [24]

The C and N pool sizes varied significantly among land use types, with the forested soils storing greater C and N. However, sensitivity indices measured by CPI and NPI demonstrated that their susceptibility to change was comparable to total pools [17], and could be employed as a sensitive indicator for SOC and N changes. Although the TOC and TN decrease in depth, physical attributes of the soils such as clay content, soil bulk density, amount of macro- and micro-pores may exert the protection of the carbon contained in the soil [27], leading to increases in carbon stocks in depth. On the other hand, it could be inferred that the 5-year cassava cultivated soil, tended to be more unstable in the soil carbon storage that may be released to the atmosphere more easily. The C: N ratio was essentially low in 5-year fallow due to possible contributions from the return of plant and root biomass as well as plant residues returned to the soil system, consistent with [24].

The difference in bulk density (BD) with soil depth was found to be substantial, with the 15-30 cm depth having a greater BD than the 0-15 cm topsoil, because of the overlying soil's weight, which produces compaction and a decrease in SOM content [28]. The significantly higher MWD of water stable aggregates in the forested, 5-year fallow and Cocoa plantation was possible to explain the roles of SOM in macro aggregate formation and stability [29]. On the other hand, the low saturated hydraulic conductivity (K_{sat}) in forested soils was not surprising because previous studies had attributed the formation of biological mat in the forest floor as a consequence of low K_{sat} usually found in forest soils [30].

5. Conclusions

Conclusions drawn from this study are that land use and soil depth influenced soil TOC and TN and other C and N indices. The C and N pools were substantially responsive to land use types. The Forested and 5-year follow plots had greater TOC and TN than the 5-year continuous cultivated soil, showing a large potential for adopting these land uses to adsorb SOC and TN in these soils. The 0–15 cm topsoil of forested and 5-year fallow soils contained the majority of SOC and TN. The C and N pool indices can be used to assess their utility and detect changes in SOC and N storage caused by land use changes. Thus, CPI and NPI demonstrated to be a valuable indicators for analyzing changes in soil quality induced by maintaining at least a 5-year fallow of sandy loam soil. The study found that land use types that promote surface soil organic matter resulted in considerable improvements in C and N stock, and can greatly influence the sequestration of both SOC and TN, improve MWD of water stable aggregates and saturated hydraulic conductivity.

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