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Soil Carbon Accumulation and Soil Microbial Biomass in Two Use Types as Influenced by Parent Material

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Abstract: The researchers studied soil carbon accumulation and soil microbial biomass under forest and arable land use types in soils of dissimilar lithology origin in Southeastern Nigeria. Soil samples were randomly collected from each land use type among the soil groups. Soil cores were collected for bulk density determination while moist soil samples were used for the estimation of soil microbial biomass. Standard techniques were used in the laboratory analysis of selected parameters. Soil data were statistically analyzed using standard deviation, coeffient of variation and one way Analysis of Variance (ANOVA). Least significant difference at 5% probability was used to identify significance among means. Means values of Soil Organic Carbon (SOC) were highest in soils under forest land use. About 59.3-70.2 ton ha^{-1} bit when compared with values from arable land use (39.3-46.8 ton ha^{-1}). Stock of soil differed among parent materials. There were significant ($p \leq 0.05$) differences in Soil Microbial Biomass Carbon (SMBC) and Soil Microbial Biomass Nitrogen (SMBC) among land use types and soil groups.

Key words: Carbon storage, land use, lithology, soil biomass, parent material, Nigeria

INTRODUCTION

Increasing importance has been placed on the use of agricultural soils in mitigating atmospheric carbon dioxide through sequestration of soil carbon (Wright and Hons, 2004). Earlier, Jenkinson (1990) observed that the soil carbon is sensitive to land use effect. Soil carbon stock with increases in soil organic carbon is referred to as soil carbon accumulation (Powlson *et al*., 2008).

Han *et al*. (2010) reported increase in soil organic carbon when arable soils were converted to grass land Northern Loess Plateau of China. Soil organic carbon is lost when trees are felled (Saarsalmi *et al*., 2010) and when soils are plonghed (Wu *et al*., 1998).

Soil organic accumulation varies with depth. Goulding and Poulton (2005) reported approximately 18 ton ha^{-1} increases in soil organic carbon in topsoil over a 35 years period after a conversion of arable land to permanent grass. Increase in soil organic carbon were recorded in soil horizons to a depth of at least 40-69 cm in rothamsted soils (Poulton *et al*., 2003). Soil physiochemical and biological properties and conditions influence addition of soil organic carbon to soils (Johnston *et al*., 2009). Bulk density affect soil organic carbon addition to soil (Johnston *et al*., 2009). Bulk density affects soil organic carbon addition to soils (Baker *et al*., 2007). Specific surface area of particle size fractions among the clays influence soil organic matter content (Feller *et al*., 1992). Content and composition of clay minerals are related with soil organic matter (Stevenson, 1994). Water repellance of soil and clay fractions was found to be positively co-related with soil organic matter content (Mataix-Solera and Doerr, 2004). These soil properties vary among parent materials.

Soil microbial biomass comprises 2-4% of total soil organic carbon and 3-5% total N (Jenkinson and Ladd, 1981) and is responsible for decomposition and turnover of soil organic matter (Witter *et al*., 1993). Soil microbial biomass mobilizes organic substrates, thus acting as an intermidiate source (Lovell *et al*., 1995) and an active fraction of soil organic matter (Parton *et al*., 1989). Soil microbial biomass is a more sensitive early warning indicator than total soil organic matter for predicting environmental impacts such as effects of increasing concentrations of greenhouse gases on soil ecosystem. Land use affect activity of soil microbial biomas and CO_2 emission (Inubushi *et al*., 2011). Land use influences the production and consumption of the gases through vegetation type (Raich and Tufekcioglu, 2000), root density, N input (Skiba *et al*., 1998) and management

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(Flechard *et al*., 2005). This study aimed to estimate the amount of soil organic carbon accumulated (organic carbon stock) in soil as well as soil microbial biomass content of two soil groups influenced by arable agriculture and forests.

MATERIALS AND METHODS

Study area: The study was conducted in four locations of Owerri, Okigwe, Ajata and Uturu in Imo and Abia states of Southeasten Nigeria (Latitude 4°45' and 5°50' N and Longitude 6°40' and 8°15' E). Soils are derived from coastal plain sands (Owerri), falsebedded sandstone (Okigwe), shales (Ajata) and lower coal measures (Uturu). Soils are dominated by ultisols (Onweremadu, 2006).

The study area has a humid tropical climate with total annual rainfall ranging from 1800-2500 mm with a total annual temperature rang of 26-30°C. It has a rainforest vegetation, comprising many forms of plants arranged in tiers. Typical plant species include oil palms (*Elaeis guineensis*), mango (*Mangifera indiga*), plantain (*Musa paradisiaca*), banana (*Musa sapientum*), yams (*Dioscorea* sp.), cassava (*Manihot esculenta*), maize (*Zea mays*), native pear (*Dacryodes edulis*), spear grass (*Imperata cylindrica*) and oranges (*Citrus* sp.). Hydrological resources include Imo, Mbaa, Otamiri, Mamu and Ibu river and Oguta lake. Farming, fishing, hunting, gathering from the wild and cottage industries are major socio economic activities in the area. Land cleaning is by slash-and-burn while soil fertility replenishment that is traditionally by bush fallow while modern approach involves the use of inorganic fertilizers.

Field studies: Four lithogical materials namely, coastal plain sands (Owerri), falsebedded sandstones (Okigwe), shale (Ajata) and lower coal measures (Uturu) were identified. In each location, two land use types namely arable farms and forest were sampled. The arable farms are owner-managed multiple-cropped farms characteristically dominated by maize and cassava (Table 1).

Conventional tillage practices are adopted in the arable farms. Inorganic fertilizers are used in augmenting natural fertility of soils. Weeds are controlled by hoeing. Each of the location investigated covered an area of >20-30 km^2 and from each, samples of surface soil (0-20 cm) were collected with soil cores. Total porosity was estimated from bulk density while Micro Porosity (Ma P) was calculated thus:

$$\text{Ma P} = \text{Vol. of wapr drained at 60 cm tension/ vol. of bulk soil}$$

Table 1: Description of sampling units (Arable farms*)

Lithological units	Location	MAR (mm)	MAT (°C)	Elevation	Management
CPS	Owerri	2500	28	101	Mixed cropping
FBS	Okigwe	2000	29	248	Mixed cropping
S	Ajata	2100	28	96	Mixed cropping
LCM	Uturu	1850	30	255	Mixed cropping

CPS = Coastal Plain Sands; FBS = False Bedded Sandstone; S = Shale; LCM = Lower Coal Measures; MAP = Mean Annual Precipitation; MAT = Mean Annual Temperature; *Forest lands from soil samples were collected are situated beside each arable farm

After the determination of bulk density, the soil cores are bulked. Each bulk sample comprised 20 soil cores. The bulk samples were air-dried at room temperature and sieved using 2 mm sieve and roots were removed. Moist sub-samples were used for the estimation of soil microbial biomass before air-drying.

Laboratory analysis: Bulk density was estimated by core procedure. Particle size distribution was determined by hydrometer method (Gee and Or, 2002). Soil pH was obtained potentiometrically in a 1; 2:5 soil to water ratio with a glass electrode pH meter. Organic carbon was got by Walkley and Black wet digestion method (Nelson and Sommers, 1982) and total nitrogen was estimated by Kjeldahl digestion procedure (Bremmer and Mulvaney, 1982). The organic carbon stock in the surface layer (0-20 cm) was calculated as (Wu, 2011):

$$DOC = Z \times Co \times Ds$$

Where:

DOC = Organic carbon stock
Co = Concentration of soil organic carbon ($g\ kg^{-1}$)
Ds = Mean value of bulk density for each land use

Soil Microbial Biomass Carbon (SMBC) and Soil Microbial Biomass Nitrogen (SMBN) were estimated by fumigation extraction method in which field fresh moist soil samples were subjected to extraction within 5 h of field sampling (Mazzarino *et al*., 1993). Microbial C was estimated by multiplying the difference in extractable between fumigation and unfumigated samples by a conversion factor of 2.64 (Vance *et al*., 1987) while the SMBN was obtained by multiplying the differnces in extractable N between fumigated and unfumigated samples by a conversion factor of 1.46 (Brookes *et al*., 1985). Results of the SMBC and SMBN were expressed in an oven dry soil basis.

Data analysis: Soil data were analysed using standard deviation and coefficients of variation. Significant differences between SOC stocks between land (Arable and forest) and lithological units (Coastal plain sands, falsebedded sandstones, shale and lower coal measures) were analyzed using analysis of variance followed by LSD tests at 0.05 level of significance.

RESULTS AND DISCUSSION

Soil organic carbon accumulation: Results of soil organic stocks at 0.20 cm depth are shown in Table 2. In all soil groups, forest soils accumulated more soil organic carbon (59.3±1.3 to 70.2±6.3 ton ha^{-1}) than arable soils (39.3±7.7 to 46.8, 9.6 ton ha^{-1}). High values of soil organic carbon in forest soils could be attributed to less exposure of soils to high temperature. Rates of chemical and microbial processes increase exponentially with temperature as long as other factors are not limiting (Meixner and Yang, 2006). Among parent materials, forest soils over shale accumulated more organic carbon than forest soils of other soil groups. These differences could be attributed to differences in soil texture, soil moisture, soil temperature, soil bulk density and degree of aeration. These soil physical attributes may have influenced variation in soil organic carbon in arable lands. The SOC increases in forest soils relative to arable soils were in this order: Shale>Lower Coal Measures>Falsebedded Sandstone>Coastal Plain Sands.

Least soil carbon accumulation in soils derived from coastal plain sands could be attributed to sandy textures (Table 3). Sandy textures have profound influences on soil moisture content, soil temperature and aeration properties which influences soil organic carbon accumuation. Sandy textures are warmer than clayey soils resulting to increased microbial activity and mineralization.

There were numerical differences in the distribution of soil macro porosity with soils developed over coastal plain sands having highest value of 19.66% under forest use followed by forest soil formed over falsebedded sandstone (Table 3). Arable soils formed over shale had a low macroporosity of 4.18% (Table 3).

These values imply variation in the ability of these soils to retain water and air in the pore spaces. Higher macroporosity will promote greater aeration and gas diffusivity, especially during drier conditions and lower soil moisture retention. Generally, higher macroporosity recorded in forest soils relative to arable soils (Table 3) suggest higher microbial activity in the former.

The significant ($p = 0.05$) efects of land use on SMBC and SMBN are shown in Table 4. The mean values of SMBC ranged from 270-131 mg kg^{-1} which are lower than mean values earlier obtained (243-255 mg kg^{-1}) by Wardle (1992) in some soils. The variation could be due to differences in soil moisture content, availability and solubility of dissolved organic carbon which vary over parent materials and land use. Mean values of SMBN ranged from 39.13-15.64 mg kg^{-1}, the trend of which is slightly lower than values of 25-43 mg kg^{-1} SMBN reported by Singh and Singh on some tropical soils (Table 4).

Table 2: Average values of SOC stocks at 0.20 cm depth

Lithological	Land use	SOC stocks/ ton ha^{-1}	SOC stock increase (%)
Coastal plain sands	Arable	4.68±9.6	
	Forest	68.6±7.2	46.6
Falsebedded sandstone	Arable	40.3±6.7	
	Forest	59.3±1.3	47.1
Shale	Arable	41.8±2.6	
	Forest	70.2±6.3	67.9
Lower coal measure	Arable	39.3±7.7	
	Forest	65.8±3.2	67.7

Table 3: Selected soil properties of this study sites

Lithological units	Land use	Sand	Silt	Clay	Texture	TP	Ma P	pH water
Coastal	Arable	710	45	165	Sandy loam	45.10	9.75	5.2
Plain sands	Forest	800	40	160	Sandy loam	51.00	19.66	4.8
Falsebedded	Arable	780	50	170	Sandy loam	46.15	17.88	5.5
Sandstone	Forest	800	60	140	Sandy loam	40.06	18.63	5.0
Shale	Arable	500	100	400	Sandy clay	46.01	4.18	6.1
	Forest	510	190	300	Sandy clay	48.82	8.06	5.9
Lower	Arable	605	85	310	Sandy clay loam	48.82	8.12	5.6
Coal measure	Forest	630	55	315	Sandy clay loam	49.02	12.87	5.3

Table 4: Analysis of variance of effects of land use types on microbial biomass of soil of dissimilar lithology

Lithological units	Land use	SMBC	SMBN
Coastal plain sands	Arable	216^{bc}	29.51^{b}
	Forest	149^{d}	21.11^{c}
Falsebedded sandstone	Arable	190^{c}	26.00^{b}
	Forest	131^{d}	15.64^{d}
Shale	Arable	168^{c}	22.82^{bc}
	Forest	240^{b}	35.14^{a}
Lower coal mearures	Arable	270^{a}	39.13^{a}
	Forest	176^{c}	24.26^{b}
SE standard deviation		3.88	1.37
Level of significance		**	*

SMBC = Soil Microbial Biomass Carbon; SMBN = Soil Microbial Biomass Nitrogen; **Significance at $p = 0.01$; *Significant at $p = 0.05$

Although, forest soils showed higher values of SMBC and SMBN, those derived from lower coal measures and shale yielded significantly ($p = 0.05$) higher values. This could be attributed to other factors such as soil pH, soil temperature, soil moisture and level of microbial activity. Smith and Paul (1990) observed that soil acidity suppresses growth and activity of native microflora which imposes a stress factor on microbial biomass involving lower yield efficiency of the biomass and increased mortality rate of these organisms (Witter *et al.*, 1993).

CONCLUSION

This study revealed that there was greater soil carbon accumulation in forest soils when compared with arable soils irespective of lithological differences. However, forest soils developed over shale showed highest soil carbon accumulation and percent SOC stock increase than other soil groups. There were significant ($p = 0.05$) differences in SMBC and SMBN due to parent materials and land use.

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