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INFLUENCE OF PARENT MATERIAL ON ORGANO-MINERAL ASSOCIATION AND SORPTION CAPACITY OF SOILS OF AKWA IBOM STATE, NIGERIA

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ABSTRACT
The influence of parent material on organo-mineral association and sorption capacity of soils of Akwa Ibom State was assessed. The aim was to identify organo-mineral association and sorption capacity of different parent materials that formed soils of the state. Four parent materials (coastal plain sand, sandstone and shale, beach ridge sand and river alluvium) were selected for the study. In each parent material, three profile pits were sited at representative location and soil samples collected from each genetic horizon. A total of 60 soil samples were generated for laboratory analysis. The results showed that beach ridge sand soils had the highest organic carbon associated with clay size fraction in both Ap (61%) and B -horizons (36%). River alluvium soils on the other hand, had the least organic carbon associated with clay size fraction in both Ap (6.9 %) and B-horizons (1.4%). Organic carbon associated with clay size fraction in beach ridge sand soils are less stable, more labile, less highly processed and more readily mineralized because of less surface area and weak bonding (ion exchange, van der waals force and hydrogen bonding) between particle surfaces and organic carbon. On the hand, organic carbon associated with clay fraction in river alluvium are more stable and not readily mineralized because of high surface area and strong bonding (ligand exchange and cation bridging) between soil particles and organic carbon. The trend was as followed: beach ridge sand > coastal plain sand > sandstone and shale > river alluvium. The study also revealed that river alluvium had the highest sorption capacity with high reactivity while beach ridge sand soils had the least with low reactivity. The trend was as followed: river alluvium > sandstone and shale > coastal plain sand > beach ridge sand.

Keywords: Parent material, sorption capacity, organo-mineral association.

INTRODUCTION

Parent material has profound influence on the characteristics of soils. For instance, the texture of the clayey soils is largely determined by the parent material (kind of rock that undergoes weathering and formed the soil) which in turn, determined the downward movement of water into the soil. The chemical and mineralogical composition of the parent material in addition to soil texture determined the sorption capacity and organo-mineral association of the soil (Ibanga, 2006).

Parent material (soil texture) plays important role in the speed with which organic matter undergoes mineralization. A small variation in surface soil texture could have large effect on the rate of organic matter decomposition (Bationo and Buerkert, 2001). Soil organic matter accumulation tends to increase as the clay+ silt content increases through two mechanisms: Firstly, the bonds between the surface of clay particles and soil organic matter (physicochemical adsorption of soil organic matter on soil clay / mineral surface) retard the decomposition process. Secondly, soil aggregates isolate and physically protect soil organic matter against microbial attack thereby preventing organic matter decomposition and promoting organic carbon storage. This is done through the formation of barriers between microbial enzymes and their substrates, by controlling O_2 diffusion, and by influencing food web interactions and consequently microbial turnover (Six *et al.*, 2002). Hence, clayey soils have more capacity for soil organo- mineral association (carbon sequestration) than sandy soils.

Soil organic carbon on the other hand, enhances soil aggregate formation by its action as a binding agent (Tisdall and Oades, 1982; Metay *et al.*, 2007). Soil organic carbon plays an important role in supplying plant nutrients (N, P), enhancing cation exchange capacity, improving soil water retention and supporting soil biological activity (Dudal and Deckers, 1993). Soil organic carbon is not only a major regulator of various processes underlying the supply of nutrients and the creation of a favourable environment for plant growth but also regulates various processes governing the creation of soil-based environmental services. In Akwa Ibom Sate, information on the influence of parent material on organo –mineral association and sorption capacity of soils is grossly inadequate. Therefore, this study was conducted to assess the influence of parent material on organo-mineral association and sorption capacity of soils of the state for effective and efficient soil management and land use planning.

MATERIALS AND METHODS

Description of the study area

The study area is located in Akwa Ibom State, South-eastern Nigeria. The state is within latitudes 4°30′ and 5°30′ N and longitudes 7°30′ and 8°20′ E. The area is underlain mainly by coastal plain sand, beach ridge sand, sandstone, siltstone/shale and alluvial parent materials (Petters *et al.*, 1989). The climate is humid tropical with annual rainfall of about 2500 to 3000 mm with 1 to 3 dry months in the year. Mean annual temperature varies between 27 and 28°C with relative humidity of 75 to 80% (Petters *et al.*, 1989).

Field Work

Four parent materials were selected for the study. They were coastal plain sand, beach ridge sand, sandstone and shale and river alluvium. In each parent material, three profile pits were sited at representative locations. Soil samples were collected from each genetic horizon. A total of 60 soil samples were generated for laboratory analysis.

Laboratory Analysis

The following analyses were carried out: **Particle size analysis** was carried out using the bouyoucos hydrometer method as described by Udo *et al;* (2009). Soil pH was determined in water using a 1:2.5 soil to water suspension and the soil pH was read using a glass electrode. **Organic carbon** was determined by the dichromate wet-oxidation method as described by Nelson and Sommers (1996). The value was multiplied by 1.732 to obtain organic matter content. **Available phosphorus** was determined using the bray P.1 extractant. The phosphorus in extract was measured by the blue method of Murphy and Riley (1962). **Total nitrogen** was determined by kjeldahl digestion and distillation method as described by Udo *et al*; (2009). **Exchangeable bases**: Ca, Mg, Na, K. were extracted using normal ammonium acetate (Thomas, 1996). The exchangeable K and Na were determined by flame photometer while Ca and Mg were determined using atomic absorption spectrometer. **Effective cation exchange capacity (ECEC)** was determined by summing up exchangeable cations and exchangeable acidity.

Determination of organo –mineral association and sorption capacity of soils of the study area: Regression analysis that expresses the relationship between clay size fraction (soil texture) and soil organic carbon was carried out for all the selected parent materials as:

$Y = a + bX$ where

Y = Soil organic carbon

a = Intercept of regression line representing soil organic carbon associated with clay fraction at zero clay fraction (no clay fraction)

b = slope of regression line representing soil organic carbon associated with clay size fraction.

X = Clay size fraction in the soil

RESULTS AND DISCUSSION

Physical and chemical properties of soils of the study Area

Soils of beach ridge sand parent material

The minimum, maximum and mean of soil properties of beach ridge sand parent material are presented in Table 1.The sand fraction varies from 89.9 to 95.9 %, silt varies from 0.06 to 3.9 % while clay varies from 3.9 to 8.2 %, indicating sandy texture throughout the profile. The soil pH varied from 3.2 to 5.4, indicating extremely to strongly acid. Organic matter varied from 1.0 to 4.6 % indicating low to high throughout the profile. Total N varies from 0.04 to 0.1%, indicating very low to moderate. Available P varied from low to moderate (3.3 to 11.9 $mgkg^{-1}$) throughout the profile. Exchangeable Ca (0.7 - 1.6 $cmolkg^{-1}$), Mg (0.7- 1.0 $cmolkg^{-1}$) K (0.05-0.07 $cmokg^{-1}$) and Na (0.04-0.05 $cmolkg^{-1}$) were low throughout the profile. Cation exchange capacity was very low (3.5 – 5.3 $cmolkg^{-1}$) throughout the profile. Base saturation was moderate throughout the profile (41.8 – 60.8 %).

Table 1: The mean, minimum and maximum of soil properties of beach ridge sand parent material

Soil properties	Unit	Mean	Minimum	Maximum
Sand	%	93.7	89.9	95.9
Silt	%	1.13	0.06	3.9
Clay	%	5.2	3.9	8.2
pH		4.4	3.2	5.4
Org. matter	%	2.1	1.0	4.6
Total N	%	0.06	0.04	0.11
Av. P	$mgkg^{-1}$	8.9	3.3	11.9
Ex. Ca	$cmolkg^{-1}$	1.2	0.7	1.6
Ex. Mg	$cmolkg^{-1}$	0.9	0.7	1.0
Ex. Na	$cmolkg^{-1}$	0.04	0.04	0.05
Ex. K	$cmolkg^{-1}$	0.06	0.05	0.07
Ex. Acidity	$cmolkg^{-1}$	2.2	1.4	3.0
ECEC	$cmolkg^{-1}$	4.3	3.5	5.3
Base saturation	%	50.8	41.4	60.8

Soils of coastal plain sand parent material

The minimum, maximum and mean of soil properties of coastal plain sand parent material are presented in Table 2. The sand fraction varies from 60.0 to 94.6 %, silt varies from 1.8 to 18.0 % while clay varies from 4.2 to 26.0 %, indicating sandy loam to sand texture. Soil pH varied from 4.9 to 6.5, indicating strongly to slightly acid throughout the profile. Organic matter varied from low to very high (1.0 - 6.6 %). Total N varied from very low to medium (0.02 - 0.2 %). Available P varied from low to high (3.8 - 71.9 $mgkg^{-1}$) throughout the profile. Exchangeable Ca (2.4 - 4.1 $cmolkg^{-1}$), Na (0.03-0.1 $cmolkg^{-1}$) and K (0.04 - 0.3 $cmolkg^{-1}$) were low. Exchangeable Mg (1.0 – 2.0 $cmolkg^{-1}$) varied from low to moderate. Cation exchange capacity was low throughout the profile (6.1 - 8.8 $cmolkg^{-1}$). Base saturation varied from moderate to high throughout the profile (53.3 - 75.1%).

Table 2: The mean, minimum and maximum of soil properties of coastal plain sand parent material

Soil properties	Unit	Mean	Minimum	Maximum
Sand	%	78.9	60.0	94.6
Silt	%	6.3	1.8	18.0
Clay	%	13.5	4.2	26.0
pH		5.8	4.9	6.5
Org. matter	%	2.7	1.0	6.6
Total N	%	0.07	0.02	0.2
Av. P	$Mgkg^{-1}$	28.1	3.8	71.9
Ex. Ca	$cmolkg^{-1}$	3.2	2.4	4.1
Ex. Mg	$cmolkg^{-1}$	1.4	1.0	2.0
Ex. Na	$cmolkg^{-1}$	0.07	0.03	0.1
Ex. K	$cmolkg^{-1}$	0.1	0.04	0.3
Ex. Acidity	$cmolkg^{-1}$	2.5	2.0	3.4
ECEC	$cmolkg^{-1}$	7.3	6.1	8.8
Base saturation	%	65.4	53.3	75.1

Soils of sandstone and shale parent material

The minimum, maximum and mean of soil properties of sandstone and shale parent material are presented in Table 3. The sand fraction varies from 50.0 to 90.0 %, silt varies from 2.0 - 20.0% while the clay varies from 7.0 to 40.0%, indicating sandy clay to sand. Soil pH varied from 4.0 to 5.6, indicating very strongly acid to moderately acid throughout the profile. Organic matter varied from low to moderate (0.5 - 2.9 %). Total N varied from very low to moderate (0.02 - 0.1 %) throughout the profile. Available P varied from moderate to high (10.1 - 31.0 mg/kg^{-1}). Exchangeable Ca (1.6 - 3.2 $cmolkg^{-1}$), Na (0.03 - 0.2 $cmolkg^{-1}$) and K (0.02 - 0.1 $cmolkg^{-1}$) were low throughout the profile. Exchangeable Mg varied from low to moderate (0.7 - 1.9 $cmolkg^{-1}$). Cation exchange capacity was low throughout the profile (6.1 - 12.0 $cmolkg^{-1}$). Base saturation varied from low to high (23.0 - 65.7%).

Table 3: The mean, minimum and maximum of soil properties of sandstone and shale parent material

Soil properties	Unit	Mean	Minimum	Maximum
Sand	%	69.6	50.0	90.0
Silt	%	6.3	2.0	20.0
Clay	%	24.1	7.0	40.0
pH		5.1	4.0	5.6
Org. matter	%	1.6	0.5	2.9
Total N	%	0.07	0.02	0.1
Av. P	$Mgkg^{-1}$	20.9	10.1	31.0
Ex. Ca	$cmolkg^{-1}$	2.4	1.6	3.2
Ex. Mg	$cmolkg^{-1}$	1.2	0.7	1.9
Ex. Na	$cmolkg^{-1}$	0.07	0.03	0.2
Ex. K	$cmolkg^{-1}$	0.07	0.02	0.1
Ex. Acidity	$cmolkg^{-1}$	2.5	0.8	4.2
ECEC	$cmolkg^{-1}$	8.4	6.1	12.0
Base saturation	%	46.2	23.0	65.7

Soils of Alluvial parent material

The minimum, maximum and mean of soil properties of alluvial parent material are presented in Table 4. The sand fraction varies from 15.8 - 59.8 %, silt varies from 2.0 - 29.4 % while clay varies from 26.8 - 66.8 %, indicating clay to sandy clay loam. Soil pH varied very strongly acid to moderately acid throughout the profile (4.8 - 5.7). Organic matter varied from low to high (0.2 – 2.6 %). Total N varied from low to moderate (0.1 - 0.2 %). Available P varied from low to high (2.7 - 25.1 $mgkg^{-1}$). Exchangeable Ca (0.3 – 10.8 $cmolkg^{-1}$) and Mg (0.7 - 6.7 $cmolkg^{-1}$) varied from low to moderate throughout the profile. Exchangeable Na (0.04-0.09 $cmolkg^{-1}$) and K (0.06 - 0.3 $cmolkg^{-1}$) were low throughout the profile. Cation exchange capacity varied from low to high (7.2 - 29.3 $cmolkg^{-1}$). Base saturation varied from very low to high (7.6 - 87.8 %).

Table 4: The mean, minimum and maximum of soil properties of alluvial parent material

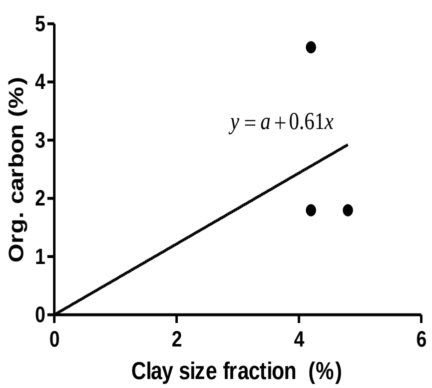
Soil properties	Unit	Mean	Minimum	Maximum
Sand	%	37.9	15.8	59.8
Silt	%	13.7	2.0	29.4
Clay	%	48.2	26.8	66.8
pH		5.2	4.8	5.7
Org. matter	%	1.1	0.2	2.6
Total N	%	0.1	0.1	0.2
Av. P	$Mgkg^{-1}$	11.5	2.7	25.1
Ex. Ca	$cmolkg^{-1}$	3.6	0.3	10.8
Ex. Mg	$cmolkg^{-1}$	2.2	0.7	6.7
Ex. Na	$cmolkg^{-1}$	0.05	0.04	0.09
Ex. K	$cmolkg^{-1}$	0.1	0.06	0.3
Ex. Acidity	$cmolkg^{-1}$	9.2	1.4	15.2
ECEC	$cmolkg^{-1}$	15.1	7.1	29.3
Base saturation	%	35.3	7.6	87.8

Organo –mineral association and sorption capacity of soils of the study area

The regression analysis that expresses the relationship between clay size fraction and organic carbon is presented in Table 5 and Figures 1-4. The results showed that in coastal plain sand soils, 18 % of soil organic carbon was associated with clay size fraction in the Ap –horizon and 12 % in the B-horizon. In beach ridge sand soil, 61 % of organic carbon was associated with clay size fraction in the Ap –horizon and 36 % in the B-horizon. In sandstone and shale soils, 10 % of soil organic carbon was associated with clay size fraction in the Ap –horizon and 3.1 % in the B-horizon. In river alluvium, 6.9 % of soil organic carbon was associated with clay size fraction in the Ap –horizon and 1.4 % in the B-horizon. Organic carbon associated with clay size fraction of the Ap horizon was more than those of the B-horizon in all the parent materials. Across the parent materials, the trend of the content of organic carbon associated with clay size fraction was as followed: beach ridge sand > coastal plain sand > sandstone and shale > river alluvium. The low content of organic carbon associated with clay size fraction of the B-horizon and in river alluvium (mean clay size fraction of 48.2%) compared to beach ridge sand soils (mean clay fraction of 5.2%) could be attributed to the high clay size fraction of the soil with high surface area and strong bonding between particles surfaces and organic carbon by ligand exchange and cation bridging. Ligand exchange is the exchange of acidic hydroxyle group of organic matter for hydroxyl groups of the clay surfaces. Ligand exchange occurs mostly in acid soils and soil rich in Al and Fe oxides (Mikutta *et al.*, 2009). Ligand exchange and cation bridging are very strong and can persist over 100 years in soil (Lutzow *et al.*, 2006). Elliott (1986) found less organic carbon content, less C: N, C: P and N: P ratios in micro-aggregates than the macro-aggregate. Cater (1996) found a high carbon content in aggregates greater than 2000 µm compared to micro-aggregates of > 250 µm in the same soil. Soil organic carbon stored in aggregates with high surface area is more stable than the soil organic carbon stored in aggregates with less surface area. Soil organic carbon associated with aggregates with less sorptive surfaces is more labile, less highly processed and more readily mineralised than that associated with high sorptive surfaces because of less surface area and weak bonding between clay particles and organic carbon by ion exchange, van der waals force and hydrogen bonding (Waters and Oades, 1991). Organic carbon content associated with clay size fraction of high surface area is considered to be highly sequestrated due to chemical adsorption of soil organic carbon on clay and mineral surfaces (Feller and Beare, 1997). The strong bonding between surfaces of aggregates and organic matter retard the decomposition process. Also, soil aggregates physically protect soil organic matter against microbial attack thereby preventing organic matter decomposition and promoting organic carbon storage. The results also showed that beach ridge sand soils had the least sorption capacity with low surface area and weak bonding while river alluvium had the highest sorption capacity with high surface area and strong bonding. The trend was as followed: river alluvium > sandstone and shale > coastal plain sand > beach ridge sand. Therefore, river alluvium soils had the highest organic carbon sequestration capacity, followed by sandstone and shale soils, followed by coastal plain sand soils and followed by beach ridge sand soils.

Table 5: Regression analysis expresses the relationship between clay size fraction and soil organic carbon (Y = a+ bX)

Parent material	Ap -horizon Y =a +bx	B-horizon Y =a +bx	Mean clay Size fraction (%)	Mean organic Carbon (%)
Beach ridge sand	Y =a +o.61x	Y =a +0.36x	5.2	2.1
Sandstone and shale	Y =a +0.10x	Y =a +0.31x	24.1	1.6
Coastal plain sand	Y =a +0.18x	Y =a +0.12x	15.5	2.7
River alluvium	Y =a +0.069x	Y =a +0.014x	48.2	1.1



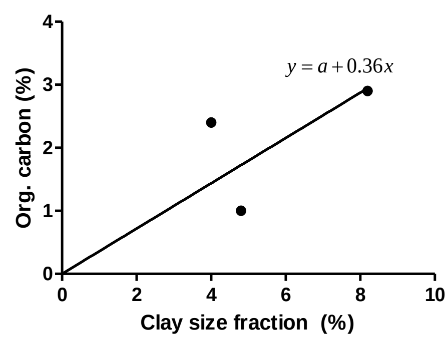


Fig. 1: Beach ridge sand (a) Surface soil (b) subsurface soil

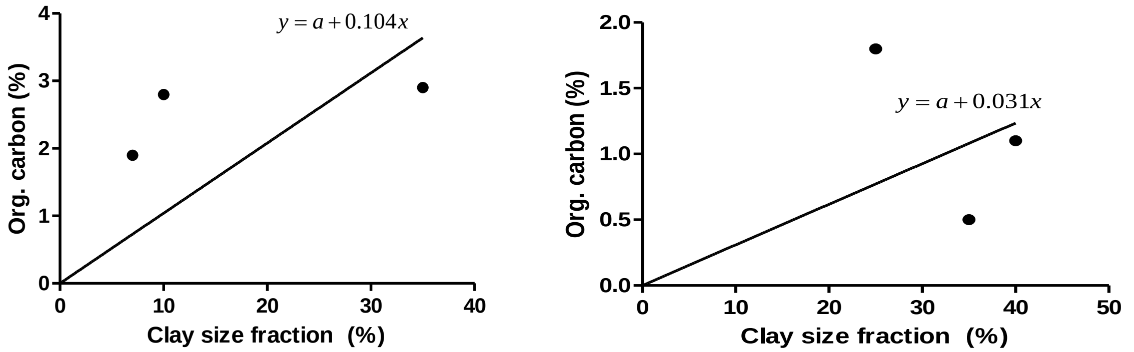


Fig.2: Sandstone and shale (a) surface soil (b) subsurface soil

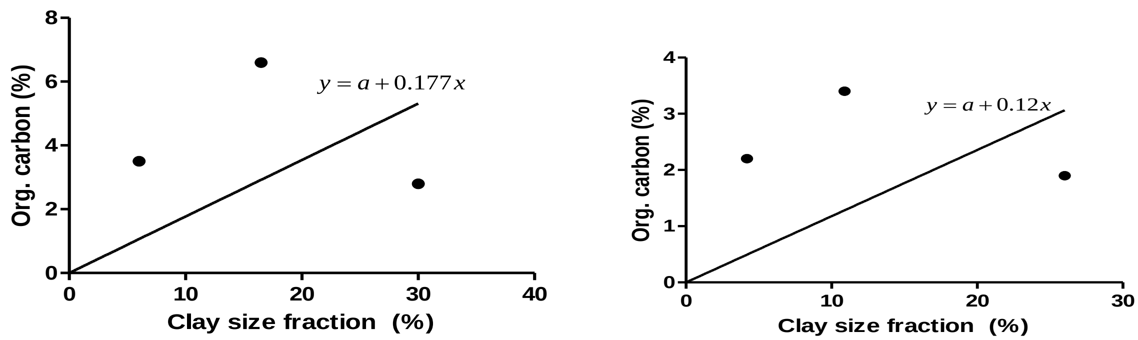


Fig.3: Coastal plain sand (a) surface soil (b) subsurface soil

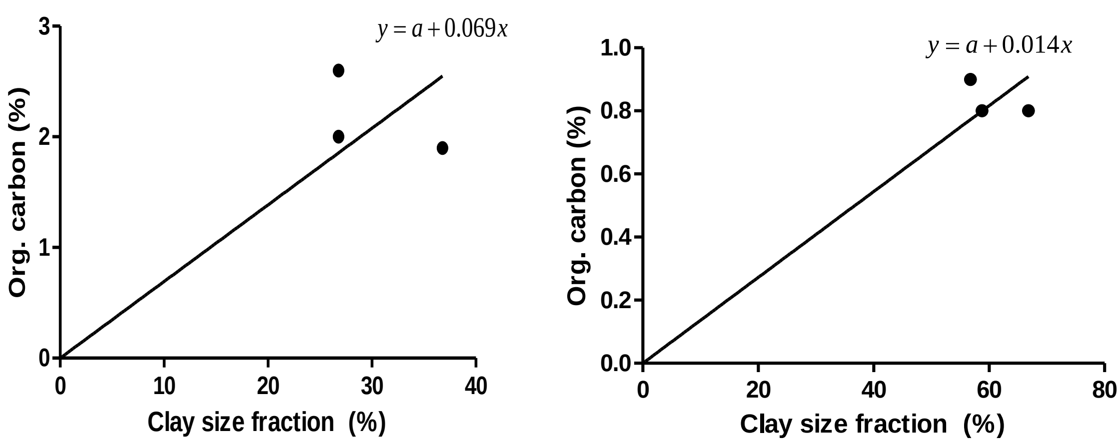


Fig.4: River alluvium (a) surface soil (b) subsurface soil

CONCLUSION

The study showed that beach ridge sand soils had the highest organic carbon associated with clay size fraction because of low surface area and are less stable, more labile, less highly processed and more readily mineralized. River alluvium soils on the other hand, had the least organic carbon associated with clay size fraction because of high surface area and are more stable and not readily mineralized. The trend was as followed: beach ridge sand > coastal plain sand > sandstone and shale > river alluvium. The study also revealed that river alluvium had the highest sorption capacity while beach ridge sand soils had the least. The trend was as followed: river alluvium > sandstone and shale > coastal plain sand > beach ridge sand.

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