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RESEARCH ARTICLE

Impact of Land Use Systems and Parent Materials on Soil Quality Indicators in Soils of Akwa Ibom State, Nigeria

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ABSTRACT

A study on the impact of parent materials and land use on soil quality indicators in soils of Akwa Ibom State was conducted. The aim was to evaluate the impact of parent materials and land use systems on soil quality indicators. Three parent materials (coastal plain sand, sandstone/shale, and beach ridge sand) and three land use types (cultivated land, fallow land of 3–5 years, and oil palm plantation) were selected for the study. In each land use type per parent material, six composite soil samples were collected from the representative location within the three land use types using soil auger within 0–30 cm soil depth. Undisturbed core samples were also collected for bulk density and saturated hydraulic conductivity determinations. A total of 52 soil samples were generated for laboratory analysis. Results showed that among the parent materials, coastal plain sand soil had the highest silt + clay fraction, organic matter, total N, available P, and exchangeable K, followed by sandstone/shale while beach ridge sand soil had the least. Among the land use types, oil palm plantation had the highest silt + clay fraction, organic matter, exchangeable Ca and K, followed by fallow land while cultivated land had the least. The combination of parent material and land use indicated that cultivated, fallow and oil palm plantation of coastal plain sand soils had the highest water and nutrient holding capacity, high rooting volume, good aeration status, less erosion threat, higher exchange sites, more available nutrients for plant uptake, more biological activity, etc., followed by sandstone/shale while beach ridge sand had the least in the study area. The application of more organic and less inorganic fertilizers will improve the soil quality of the study area.

Key words: Akwa Ibom state soils, land use, parent material, soil indicators

INTRODUCTION

Different authors define soil quality differently, each reflecting a different perspective on the use and value of soils. [1] defined soil quality as the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation. [2] defined soil quality as the ability of a soil to fulfil its functions in the ecosystem, which are determined by the integrated actions of different soil properties. [3] defined soil quality as the potential utility of soils in landscapes resulting from the natural combination of soil chemical, physical, and biological attributes. [4] defined soil quality as the capability of soil to produce safe and nutritious crops in a sustained manner over the long-term, and to enhance human and animal health, without impairing the natural resource base or harming the environment. For the purpose of this study, soil quality can therefore be defined as the capacity of a specific kind of soil to produce safe and nutritious crops in a sustained manner over a long-period of time, and to enhance human and animal health, without impairing the natural resource base or harming the environment.. Therefore, soil quality can be defined as the capacity of a specific

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kind of soil to produce safe and nutritious crops in a sustained manner over a long period of time, and to enhance human and animal health, without impairing the natural resource base or harming the environment. The ability of the soil to perform ecosystem function depends on the integrated actions of different soil properties called soil quality indicators.[2]

Soil quality indices or indicators are simple attributes or characteristics of the soil which may be measured to assess soil quality with respect to a given function (e.g., sustainable crop management). They are measurable soil attributes that influence the capacity of soil to perform crop production or environmental functions. An appropriate indicator is one which provides a quantitative measured of the magnitude and intensity of environmental stress experienced by plant and animals. These indices based on properties and processes can be assessed by field and laboratory analyses or predicted by modeling.[5] Attributes that are most sensitive to management are most desirable as indicators.[5] Many researchers reported that land use such as continuous cultivation, plantation, and deforestation; grazing and mineral fertilizer application as well as parent materials can cause depletion or addition of nutrients to the soil and eventually, increase or reduction in output.

Some land use systems often result in the depletion of soil nutrients while others add nutrient to the soil. The conversion of forest into cropland is known to deteriorate soil physical properties and making the land more susceptible to erosion since macroaggregates are disturbed.[6] Soil erosion can modify soil properties by reducing soil depth, changing soil texture, and by loss of nutrients and organic matter.[7] Loss of organic matter is expected to destabilize soil aggregates, and consequently, the finer particles are transported by erosion[8] evaluated the effects of land use change on loessial hillslope soils of the Shastkola District in Golestan Province, northern Iran, with the following land use systems: (1) Natural forest, (2) cultivated land, (3) land reforested with olive, and (4) land reforested with Cupressus. They reported that clearing of the hardwood forest and tillage practices led to a decrease in soil organic matter (SOM) by 71.5%. Cultivation of the deforested land decreased mean weight diameter (MWD) by 52% and increased sand content by 252%. The reforestation of degraded land with olive and Cupressus increased SOM by about 49% and 72%, respectively, compared to the cultivated soil. Reforestation with olive increased MWD by 81% and reforestation with Cupressus increased MWD by 83.6%. The study showed that forest clearing followed by cultivation of the loessial hilly slopes resulted in the decline of the soil quality attributes, while reforestation improved them in the study area.

Information on the impact of land use and parent material on soil quality indicators in soils of Akwa Ibom State is grossly inadequate. Therefore, the objective of this study was to assess the impact of land use systems and parent materials on soil quality indicators in soils of Akwa Ibom State.

MATERIALS AND METHODS

The study area

The study was conducted in Akwa Ibom State which lies between latitudes 4π 30″ and 5π 30″ North and longitudes 7π 30″ and 8π 20″ East.[9] Akwa Ibom State is underlain mainly by coastal plain sands, the beach ridge sands, sandstone/shale, and alluvial deposits.[10] The annual rainfall varies from 3000 mm along the coast to 2250 mm at the extreme north. Mean annual temperature varies between 27 and 28°C with relative humidity of 75–80%.[10] The study area lies within the rainforest area of the state which has been reduced to secondary forest of oil palm and rubber plantations. In addition, a variety of food crops such as maize, cassava, melon, plantain/banana, yam, vegetables, and a variety of tree crops including mango, citrus, and cashew are grown.

Field sampling

Three parent materials (coastal plain sand, sandstone/shale, and beach ridge sand) and three land use types (cultivated land, fallow land of 3–5years, and oil palm plantation) were selected for the study. In each land use type per parent material, six composite soil samples were collected from the representative location within the three land use types using soil auger within 0–30 cm soil depth. Undisturbed core samples were also collected for bulk density and saturated hydraulic conductivity determinations. A total of 54 soil samples were generated for laboratory analysis.

Laboratory analysis

The soil samples were air-dried, sieved using a 2 mm size-sieve and the following determinations were carried out using appropriate standard procedures. Particle size distribution was determined by the modified Bouyoucos hydrometer method as described by Gee and Or.[11] Soil pH was determined in 1:2.5 soils: water ratio using a pH meter.[12] Organic carbon was determined as described by Nelson and Sommers.[13] Total nitrogen was determined by the regular macro-Kjeldahl digestion and distillation method as described by Nelson and Sommers.[13] Total Nitrogen was determined by the regular Macro-Kjeldahl digestion and distillation method as described by Bremner and Mulvaney.[14] Available phosphorus was determined by the Bray-1 method as described Udo *et al.*[15] Exchangeable cations were extracted with 1 M NH_4OA_C (pH 7.0), and the concentration of Ca and Mg in the extract was determined by EDTA titration method, K and Na by flame photometer.[15] Exchangeable acidity was extracted with 1 M KCl and titrated with 0.01 NaOH.[12] Effective cation exchange capacity (ECEC) was obtained by the summation of exchangeable bases (Ca^{2+} + Mg^{2+} + K^+ + Na^+) and exchangeable acidity (Al^{3+} + H^+). Base saturation was calculated as percentage of total ECEC occupied by Ca, Mg, K, and Na.

RESULTS AND DISCUSSION

Influence of parent materials on soil quality indicators in the study area

The influence of parent materials on soil quality indicators in the study area is presented in Table 1. There were textural variations among the three parent materials under consideration. The mean sand fraction of beach ridge sand (95.0%) was significantly higher ($P < 0.05$) than that of coastal plain sand soils (73.2%) which was not different from that of sandstone/shale soils (89.3%). Mean silt fraction was significantly higher in coastal plain sand soils (2.8%) than sandstone/shale soils (2.0%) and beach ridge sand soils (1.0%). Mean clay fraction was also significantly higher ($P < 0.05$) in coastal plain sand soil (17.0%) than sandstone/shale soils (8.8%), which in turn significantly higher than beach ridge sand soils (4.8%). The soil texture of coastal plain sand and sandstone/shale soils was loamy sand within 0–30 cm depth and sand in beach ridge sand soils. Texture is intrinsic soil property; therefore, the variation could be attributed to variation in parent rocks as well as rate of weathering of the parent rocks.[16]

Bulk density was significantly higher ($P < 0.05$) in coastal plain sand (1.6 g/cm^2) and sandstone/shale soils (1.6 g/cm^2) than beach ridge sand soils (1.0 cm^2). However, the values were not up to the level that could limit roots growth, gas exchange, and availability of less mobile essential plant nutrients (P and K).[17] The rate of water flow was significantly higher in beach ridge sand (0.11 cm/h) than coastal plain sand (0.04 cm/h) and sandstone/shale (0.03 cm/h), which was not different from each other. The rates of water flow were moderate in beach ridge sand and slow in coastal plain sand and sandstone/shale soils.

The mean soil pH of the surface soil of three parent materials under consideration was slightly acid and not significantly different from each other. Mean organic matter was very high in coastal plain sand soils and high in sandstone/shale and beach ridge sand soils.Although mean total N was generally very low in the study area but when the values are compared among parent materials under consideration, coastal plain sand soils was significantly higher ($P < 0.05$) in total N than sandstone /shale and beach ridge sand soils. Available P was significantly higher in coastal plain sand soils (30.4 mg/kg) than sandstone/shale (7.1 cm/kg) and beach ridge sand soils (8.6 mg/kg). The high mean organic carbon, total N, and available P of the coastal plain sand soils compared to others could be attributed partially to the high biomass production and seasonal addition of organic materials from plant.[18] Furthermore, aggregates in coastal plain sand isolate and protect SOC against microbial attack and thereby increase their resident time.

Mean exchangeable K and Na were significantly higher in coastal plain sand soils than sandstone/shale and beach ridge sand soils. There was no significant difference between means exchangeable Ca, Mg, ECEC, and base saturation percentage within 0–30 cm soil depth in coastal plain sand, sandstone/shale, and beach ridge sand.

Influence of land use on soil quality indicators in the study area

The influence of land use on soil quality indicators in the study area is presented in Table 2. Sand fraction was significantly higher ($P < 0.05$) in

Table 1: Influence of parent materials on soil quality indicators in the study area

Soil properties	Coastal plain sand	Sandstone/shale	Beach ridge sand
Sand (%)	73.2^{a}	89.28^{b}	95.0^{b}
Silt (%)	2.8^{a}	2.0^{b}	1.0^{c}
Clay (%)	17.0^{a}	8.8^{b}	4.8^{c}
Silt + cay (%)	17.6	10.8^{b}	5.0^{a}
Texture	Loamy sand	Loamy sand	Sand
Bulk density (g/cm^3)	1.63^{a}	1.57^{a}	1.01^{b}
Coarse sand (%)	51.2^{b}	77.8^{c}	25.1^{a}
Porosity (%)	0.38^{b}	0.41^{b}	0.46^{b}
Ks	0.04^{a}	0.03^{a}	0.11^{b}
pH	6.3^{a}	6.4^{a}	6.4^{a}
Total N (%)	0.09^{a}	0.07^{b}	0.07^{b}
Org. matter (%)	3.8^{a}	2.8^{b}	2.9^{b}
Av. *P* (mg/kg)	30.4^{a}	7.1^{b}	8.6^{b}
Exh. Ca (cmol/kg)	3.6^{a}	4.4^{a}	3.7^{a}
Exh. Mg (cmol/kg)	1.3^{a}	1.5^{a}	1.3^{a}
Exh. Na (cmol/kg)	0.06^{a}	0.05^{b}	0.05^{b}
Exh. K (cmol/kg)	0.12^{a}	0.07^{b}	0.10^{c}
ECEC (cmol/kg)	7.5^{a}	5.9^{a}	6.4^{a}
Base saturation (%)	4.9^{a}	5.9^{a}	5.1^{a}

Means with the same letter along the same row are not significant at 5% level

Table 2: Influence of land use on soil quality indicators in the study area

Soil properties	Cultivated land	Fallow land	Oil palm plantation
Sand (%)	89.6^{a}	89.4^{a}	87.6^{b}
Silt (%)	3.2^{a}	1.8b	3.4^{a}
Clay (%)	7.2^{a}	8.8b	8.9^{b}
Silt + cay (%)	10.0^{a}	9.3a	12.3^{b}
Bulk density (g/cm^3)	1.6a	1.2b	1.3^{c}
Ks (cm/hr)	0.0047^{ab}	0.0059^{b}	0.0043^{a}
pH	5.8^{a}	5.5^{b}	5.5^{b}
EC	0.0^{a}	0.03^{a}	0.04^{a}
Org. matter (%)	3.7^{a}	4.9^{b}	4.5^{b}
Total N (%)	0.09^{a}	0.12^{b}	0.13^{b}
Av. *P* (mg/kg)	10.9^{a}	12.7^{a}	10.4^{a}
Exh. Ca (cmol/kg)	2.7^{a}	3.7^{b}	4.8^{c}
Exh. Mg (cmol/kg)	1.1^{a}	1.1^{a}	1.4^{a}
Exh. Na (cmol/kg)	0.05^{a}	0.05^{a}	0.05^{a}
Exh. K (cmol/kg)	0.06^{a}	0.06^{a}	0.07^{b}
Exch. acidity (cmol/kg)	1.2^{a}	1.5^{a}	1.9^{b}
ECEC (cmol/kg)	5.0^{a}	6.5^{a}	8.2^{b}
Base saturation (%)	77.2^{a}	76.9^{b}	76.8^{b}

ECEC: Effective cation exchangeable capacity

cultivated land (89.6%) and fallow land of 3–5 years period (89.4%) than oil palm plantation (87.6%). Clay (8.9%) and silt (3.4%) fractions of oil palm plantation were significantly higher than that of cultivated land (7.2 and 3.2%) and follow land (8.8 and 1.8%, respectively). Clay was significantly higher in fallow land than cultivated land. The higher clay and silt fractions in oil palm plantation could be attributed to more binding effect due to higher organic matter content in oil palm plantation compared with cultivated land and fallow land on the same parent material. The binding effect reduced the removal of the fine particles by water erosion, thereby accounting for the higher content in the soil.[19] Bulk density was significantly higher ($P < 0.05$) in cultivated land (1.6 g/cm^3) than fallow land (1.2 g/cm^3) and oil palm plantation (1.3 g/cm^3). The trend was as follow: Cultivated > oil palm plantation

> fallow land. The loss of SOM combined with poor aggregation probably accounted for the higher bulk density under cultivation compared to the oil palm plantation and fallow land. Similar findings were reported by Celik[6] that deforestation and subsequent tillage practices resulted in increase in bulk density for surface soil in southern highlands of Turkey.

Soil pH was significantly higher in cultivated land (5.8) than fallow land (5.5) and oil palm plantation (5.5). The low soil pH in fallow land and oil palm plantation could be attributed to intense leaching of basic cations resulting in these acidic conditions.[20] Organic matter (3.7%) and total N (0.09%) were significantly lower in cultivated land than fallow land (4.9 and 0.12%) and oil palm plantation (4.5 and 0.13%, respectively). This was expected because cultivated soils generally have low organic matter content compared to native ecosystems. Disturbance of soil can alter temperature, moisture, and aeration, which enhances decomposition rate of SOM.[20] Available P was not significantly difference among the land use types under consideration. Exchangeable Ca (4.8 cmol/kg) and K (0.07 cmo/kg) were significantly higher ($P < 0.05$) in oil palm plantation than cultivated land (2.7 and 0.06 cmol/kg) and fallow land (3.7 and 0.06 cmol/kg, respectively). Exchangeable Mg and Na were not significantly different ($P < 0.05$) among the three land use types under consideration. The high content of Ca and K in oil palm plantation could be attributed to the oil palm leaves and others which are constituent of the organic matter. Effective cation exchangeable capacity (ECEC) was not significantly different ($P < 0.05$) among the three land use types under consideration. Total exchange sites occupied by acidic cations were significantly higher in oil palm plantation (1.9 cmol/kg) than fallow land (1.5 cmol/kg) and cultivated land (1.2 cmol/kg). Total exchange sites occupied by basic cations, on the other hand, were significantly higher in cultivated land (77.2%) than oil palm plantation (76.8%) and fallow land (76.9%). The low basic cations occupying the total exchange sites in fallow land and oil palm plantation could be attributed to erosion, leaching, and crop removal of the bases in the past years.[21]

Influence of parent material and land use on soil quality indicators in the study area

The interaction of parent material and land use on soil quality indicators is presented in Tables 3-5. The cultivated farmland of beach ridge sand soil had the highest sand fraction (94.4%), followed by fallow land (92.4%) while cultivated farmland of coastal plain sand soil (83.1%) had the least sand fraction followed by oil palm plantation (84.4%). Clay fraction was the highest in oil palm plantation of coastal plain sand soil (13.5%) and the least in cultivated farmland of beach ridge soil (4.2%) in the study area. The silt + clay fraction was highest in cultivated farmland of coastal plain sand soil (16.3%), followed by oil palm plantation (15.6%), while cultivated farmland of beach ridge soil (5.6%) had the least silt + clay fraction. This shows that cultivated and oil palm plantation of coastal plain sand soil had the highest water and nutrient holding capacity, high rooting volume, and good aeration status, as well as less erosion threat compared to others.[22]

Cultivated farmland of sandstone/shale soil had the highest pH (6.1), followed by oil palm plantation (6.0) while cultivated farmland of beach ridge sand soil (5.4%) had the least soil pH. Fallow land of coastal plain sand soil had the highest organic matter content, while cultivated farmland of beach ridge sand soil (2.3%) had the least organic matter content. Cultivated farmland of coastal plain sand soil had the highest available P (24.9 mg/kg) while the fallow land of beach ridge sand soil (2.8 mg/kg) had the least. Oil palm plantation of coastal plain sand soil had the highest exchangeable Ca (5.2 cmol/kg) while cultivated farmland of beach ridge sand soil (1.7 cmol/kg) had the least exchangeable Ca in the study area. This shows that cultivated farmland, fallow and oil palm plantation of coastal plain sand, and sandstone/shale soils generally had higher exchange sites, more available nutrients for plant uptake, more biological activity, etc., than that of beach ridge sand soils in the study area.[22]

CONCLUSION

The study revealed that among the parent materials, coastal plain sand soil had the highest silt + clay fraction, organic matter, total N, available P, and exchangeable K, followed by sandstone/shale while beach ridge sand soil had the least. Among the land use types, oil palm plantation had the highest silt + clay fraction, organic matter, exchangeable Ca and K, followed by fallow land while cultivated land had the

Table 3: Influence of parent material and land use on soil physical indicators

Parent material × land use	Soil quality indicators					
	Sand (%)	Silt (%)	Clay (%)	Silt + clay (%)	Bulk D. (g/cm^3)	Ks (cm/h)
BRS cultivated	94.4	1.4	4.2	5.6	1.4	0.04
Fallow land	92.4	1.4	6.2	7.6	1.1	0.06
Oil palm plantation	87.7	3.4	8.9	12.3	1.1	0.05
CPS cultivated	83.1	4.1	12.9	16.3	1.7	0.05
Fallow land	85.1	2.7	12.2	14.9	1.1	0.06
Oil palm plantation	84.4	2.1	13.5	15.6	1.4	0.05
SSS cultivated	91.4	4.1	4.5	8.3	1.6	0.05
Fallow land	90.7	1.4	7.9	5.7	1.5	0.04
Oil palm plantation	90.7	4.7	4.5	8.9	1.2	0.05
LSD (0.05)	0.016*	0.016*	0.009*	0.01*	0.77	0.77

*Significant at 5% level, BD: Bulk density, Ks: Saturated hydraulic conductivity, BRS: Beach ridge sand, CPS: Coastal plain sand, SSS: Sandstone/shale, LSD: Least significant difference

Table 4: Influence of parent material and land use on soil chemical and biological indicators

Parent material × land use	Soil quality indicators					
	pH (water)	EC (ds/m)	OM (%)	TN (%)	Av. *P* (mg/kg)	Ex. Ca (cmol/kg)
BRS cultivated	5.4	0.02	2.3	0.1	4.2	1.7
Fallow land	5.5	0.02	3.6	0.2	2.8	4.0
Oil palm plantation	5.5	0.03	4.4	0.1	4.3	4.1
CPS cultivated	5.9	0.03	5.1	0.06	24.9	4.5
Fallow land	5.5	0.04	5.8	0.09	22.2	4.8
Oil palm plantation	4.8	0.05	5.1	0.2	18.2	5.2
SSS cultivated	6.1	0.05	3.5	0.09	3.7	2.0
Fallow land	5.7	0.05	5.1	0.1	13.3	4.9
Oil palm plantation	6.0	0.04	4.2	0.1	8.3	2.4
LSD (0.05)	0.001*	0.03*	0.03*	0.03*	0.02*	0.09*

EC: Electrical conductivity, OM: Organic matter, TN: Total nitrogen, BRS: Beach ridge sand, CPS: Coastal plain sand, SSS: Sandstone/shale, LSD: Least significant difference

Table 5: Influence of parent material and land use on soil chemical indicators

Parent material × land use	Soil quality indicators					
	Ex. Mg (cmol/kg)	Ex. Na (cmol/kg)	Ex. K (cmol/kg)	EA (cmol/kg)	ECEC (cmol/kg)	BS (%)
BRS cultivated	1.2	0.06	0.07	0.9	3.9	77.4
Fallow land	1.6	0.05	0.07	1.6	6.9	76.9
Oil palm plantation	1.2	0.05	0.06	1.7	7.1	76.8
CPS Cultivated	1.4	0.05	0.05	1.8	7.8	76.9
Fallow land	1.4	0.05	0.06	1.9	8.3	76.8
Oil palm plantation	1.7	0.06	0.07	2.1	8.9	76.8
SSS cultivated	0.6	0.05	0.05	0.8	3.5	77.2
Fallow land	1.2	0.05	0.06	1.0	4.2	77.1
Oil palm plantation	0.5	0.06	0.07	2.0	8.5	76.8
LSD (0.05)	0.6	0.02*	0.06	0.15	0.15	0.23

EA: Exchangeable acidity, BS: Base saturation, EC: Electrical conductivity, BRS: Beach ridge sand, CPS: Coastal plain sand, SSS: Sandstone/shale, ECEC: Effective cation exchange capacity, LSD: Least significant difference

least. The combination of parent material and land use indicated that cultivated, fallow and oil palm plantation of coastal plain sand soils had the highest water and nutrient holding capacity, high rooting volume, good aeration status, less erosion threat, higher exchange sites, more available nutrients for plant uptake, more biological activity, etc., followed by sandstone/shale while beach ridge sand had the least in the study area.

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