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Geotechnical Properties of Soils as Influenced by Land Use in a Humid Environment

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Abstract: We investigated some geotechnical properties of soils of Port Harcourt in 2009 under three land use types, namely mechanically cleared land, on-going building constructions and fallow land. A combination of target and random soil survey techniques guided field studies. Five soil samples were collected in each land use, giving a total of 15 soil samples which were air-dried and sieved. These soil samples were subjected to routine laboratory analysis and resulting data were analyzed statistically using means and correlation analysis. Soils were sandy, of slight to neutral acidity (pH_{water} = 5.9-7.6). Disturbed soils were older (silt-clay ratio= 0.13-0.50) when compared with fallow having a mean value of 2.1. Plasticity index values were low (< 35%) and differed due to the land use: 11.63% (building site), 12.29% (mechanically cleared land) and 14.57% (fallow). There was low colloidal activity: 0.36 (building site), 0.40 (fallow) and 0.41 (mechanically cleared land). Highest recorded maximum dry density was found in building site (2.03 Mg m^{-3}), while 24.87% optimum moisture content was obtained in fallow soils. Plasticity index showed good relationships with moisture, clay and colloidal activity in the study sites.

Key words: Atterberg limits % Clay activity % Land use % Tropics

INTRODUCTION

Soil serves engineering apart from agronomic, environmental and recreational function [1]. Soil properties vary according to the types of land use. Land use influences bulk density [2], pedality [3] soil structure and hydraulic conductivity [4], soil strength [5], surface ponding [6], water retention and flow dynamics.

Engineering activities influence volume change which is related to water content [7] and this is an indicator of compressibility [8]. Land use affects stability of soils [9] for future agricultural and non-agricultural enterprises. Any land use that affects soil structure and water potential influences soil mechanical properties and stability [10]. Soil structure is affected by altering the water table possibly resulting from change in soil-water-air ratios [11].

Soil deformation occurs when crystals or domains are able to separate and move relative to each other. Changes in pore space resulting from the above movement of individual or grouped particles are the result of long term use of soils for agronomic and engineering activities. Foth [12] reported varying effects of wheel, recreation, logging traffic, tree growth, flooding and puddling on soil physical properties. Consequent upon the above, the major objective of this study was to investigate the effects of land use type on some geotechnical properties. Information gathered from this study is hoped to equip soil managers in sustained management of studied soils, more so with the study site having influx of humans whose activities vary.

MATERIALS AND METHODS

Study Area: The study was conducted at Elelenwo, Port Harcourt, Nigeria in 2009. The area lies between latitudes 4° 40' and 4° 50'N and longitudes 6° 50' to 7° 10'E. Soils are derived from coastal plain sands, marine and deltaic deposits. The location lies in the humid tropics, with total mean annual rainfall greater than 2500 mm. It belongs to the lowland geomorphology of Southern Nigeria with an elevation of less than 20 m above mean sea level. The area is dominated by mangrove swamp although the northern part has thick tropical rainforest vegetation.

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The vegetation is arranged in storeys. The Atlantic Ocean and Niger River Delta govern the hydrology of the area. Socio-economic activities include fish farming, hunting, arable farming, oil exploration and several engineering related enterprises.

Field Sampling: Three geospatially-related land use types namely, mechanically cleared arable land, on-going building construction and fallow (control) were identified. Target soil survey technique guided location of land use. Five soil samples were randomly collected from each type of land use. Soil samples were air-dried and sieved using 2 mm sieve.

Laboratory Analyses: Particle size distribution was determined by hydrometer method [13]. Soil pH was measured electrometrically by glass electrode in distilled water using a soil: liquid ratio of 1:2.5 [14]. Soil organic carbon (SOC) was estimated by wet digestion [15]. Cation exchange capacity (CEC) was determined by ammonium acetate technique [16]. Exchangeable basic cations were extracted with ammonium acetate. Calcium and magnesium were measured by ethylene-diametetra acetic acid titration method while potassium and sodium were estimated by flame photometry [16]. Base saturation was computed as total exchangeable bases divided by CEC multiplied by 100 percent. Exchangeable Na percentage was calculated as exchangeable Na divided by CEC multiplied by 100 percent. Atterberg limits were determined using Cassagrande method and plasticity index (PI) was calculated as liquid limit minus plastic limit [17] in accordance to clause 4.5 and 5.3 part 2 of BS 1377 and BS 1990, respectively.

Statistical Analysis: Mean values of soil data were obtained while relationship between soil and geotechnical properties was estimated using correlation analysis.

RESULTS

Sand-sized particles dominated other primary particles in the study site irrespective of land use type (Table 1). Highest clay values were recorded on soils affected by building construction activities. Soils from fallow land recorded highest silt-clay ratios (mean value = 2.1). Soils were slightly acidic to neutral as shown in Table 2, bearing some soil chemical properties. Soil organic carbon decreased from soils of fallow land through mechanically-cleared land to soils affected by building construction activities. CEC and base saturation followed the same trend as soil organic carbon.

Table 1: Particle Size Distribution of Studied Soils (N = 15)

Sample No	Total Sandg/kg	Silt g/kg	Clay g/kg	Textural Class	Silt / Clay
Mechanically Cleared Land					
1	820	33	147	Loamy Sand	0.22
2	880	40	80	Loamy Sand	0.50
3	860	40	100	Loamy Sand	0.40
4	880	40	80	Loamy Sand	0.50
5	850	30	120	Loamy Sand	0.25
Mean	**858.0**	**36.6**	**105.4**		**0.37**
On-Going Building construction					
6	768	26	206	Sandy Loam	0.13
7	848	66	97	Loamy Sand	0.68
8	828	65	107	Loamy Sand	0.61
9	768	26	206	Sandy Loam	0.13
10	790	60	150	Sandy Loam	0.40
Mean	**800.4**	**48.6**	**153.2**		**0.39**
Fallow (Control) Site					
11	920	40	40	Sand	1.00
12	900	60	40	Sand	1.50
13	935	53	12	Sand	4.42
14	955	33	12	Sand	2.75
15	890	50	60	Loamy Sand	0.83
Mean	**920.0**	**47.2**	**32.8**		**2.1**

Table 2: Selected Chemical Properties of Studied Soils (N = 15)

Sample No	pH (Water)	OC g/kg Mechanically Cleared	CEC Cmol/kg Land	Exch. Na Cmol/kg	Bsat %
1	6.0	12.4	15.0	2.8	45.0
2	6.2	17.1	15.6	0.8	29.6
3	5.9	13.5	13.7	1.6	35.0
4	6.2	17.3	15.6	0.9	30.4
5	6.1	16.9	14.8	1.3	40.0
Mean	**6.1**	**15.4**	**14.9**	**1.5**	**36.0**
On-Going Building construction					
6	5.1	10.1	13.7	1.2	25.5
7	6.9	15.6	12.7	1.1	20.5
8	7.4	14.3	10.2	1.4	26.0
9	7.5	17.2	12.6	0.9	24.0
10	6.0	16.6	11.2	1.3	20.0
Mean	**6.6**	**14.8**	**12.1**	**1.2**	**23.2**
Fallow (Control) Site					
11	6.5	21.0	18.6	0.4	50.5
12	6.9	18.9	20.1	0.4	48.5
13	7.3	19.2	19.3	0.4	52.0
14	6.5	18.6	21.6	0.3	50.0
15	7.6	20.4	19.2	0.5	51.0
Mean	**7.0**	**19.6**	**19.8**	**0.4**	**50.4**

OC = Organic carbon, CEC = cation exchange capacity, Exch. Na = exchangeable sodium, Bsat = base saturation

Table 3: Selected Geotechnical Properties of Studied Soils (N = 15)

Sample No	LL (%)	PL (%)	P1 (%)	Activity (A) Cmol / kg	Max Dry Density (Mg m^{-3})	Optimum Moisture Content (%)
Mechanically Cleared Land						
1	36.00	24.26	11.74	0.41	2.04	15.50
2	35.00	22.84	12.16	0.40	2.00	15.50
3	36.00	23.9	12.01	0.42	1.90	14.30
4	37.00	23.76	13.24	0.41	1.99	15.00
5	36.00	23.71	12.29	0.41	1.99	15.07
Mean	**36.00**	**23.71**	**12.29**	**0.41**	**1.99**	**15.07**
On-going building construction						
6	25.00	12.90	12.10	0.35	2.04	14.50
7	24.00	12.12	11.88	0.37	2.04	13.15
8	45.00	34.35	10.65	0.39	2.06	15.50
9	46.00	34.09	11.91	0.33	2.00	14.50
10	35.00	23.37	11.64	0.35		14.50
Mean	**35.00**	**23.37**	**11.63**	**0.36**	**2.03**	**14.53**
Fallow (Control) Site						
11	22.50	7.04	15.46	0.40	1.00	24.88
12	23.88	9.31	14.54	0.39	0.90	25.40
13	25.00	10.97	14.03	0.41	0.98	24.00
14	25.00	11.50	13.40	0.38	1.90	26.00
15	23.00	7.72	15.28	0.42	0.95	24.10
Mean	**23.88**	**9.31**	**14.57**	**0.40**	**1.15**	**24.87**

LL = liquid limit, PL = plastic limit, P1 = plasticity index

Table 4: Relationships between P1 and Selected Soil Properties (N = 15)

Relationship	P1 vs Clay	Factors P1vs MC	Correlated P1vs Activity (A)	P1 vs OM	P1 vs Na
Mechanically Cleared Land					
r	0.69*	0.71**	0.81*	0.74*	-0.71*
r^2	0.47*	0.50**	0.66*	0.55*	0.50*
$1\text{-}r^2$	0.53	0.50	0.44	0.45	0.50
On-going building Construction					
r	0.68*	0.82**	0.67*	0.11^{NS}	-0.68*
r^2	0.46*	0.67**	0.47*	0.01^{NS}	0.46*
$1\text{-}r^2$	0.54	0.33	0.53	0.99	0.54
Fallow (Control site)					
r	0.71*	-0.64*	0.46^{NS}	0.54*	-0.31^{NS}
r^2	0.50*	0.41*	0.21^{NS}	0.29*	0.09^{NS}
$1\text{-}r^2$	0.50	0.59	0.79	0.71	0.91

P1 = Plasticity index, MC = Moisture content, OM = Organic matter, Na = Sodium,

** = Significant at P = 0.01, * = Significant at P = 0.05

NS = Not significant, $1\text{-}r^2$ = Coefficient of alienation

Geotechnical Properties: Results of geotechnical properties are presented in Table 3. Soils had generally low plasticity as their values were less than 35% using plasticity classification according to Smith [18]. However, PI values ranged from 11.63% (building site) through 12.29% (mechanically cleared land) to 14.54% (fallow land).

Clay activity (A) was low in all sites but higher in soils of fallow land (Table 3). Highest values of maximum dry density were recorded in soils affected by building, while least values were obtained from soils of the fallow land. Optimum moisture content was highest in mechanically cleared land and least in soils affected by building constructions. Relationship between plasticity values and some soil properties are shown in Table 4. Plasticity index was highly significant (P = 0.01) with moisture content with a minimum coefficient of alienation of 4%. Significant (P = 0.05) relationships were recorded between P1 and clay content, activity, organic matter and exchangeable sodium content. However, degree of relationship between P1 and these soil properties varied according to land use type as well as soil property involved.

DISCUSSION

High sand content of soils of the study sites could be attributed to the interaction between climate, parent material and land use on soil properties. This is consistent with the findings of Akamigbo [19] that harsh climate interacts with climate, parent material and land use practices to influence soil properties. Soil texture is an inherent property of soils but can be altered by soil disturbance. Soils that were affected by mechanical clearing and building construction activities had lower silt-clay ratios (<1.2) indicating higher weather ability when compared with soils under fallow. This agrees with the statement of Van Wambeke [20] that soils having silt-clay ratios greater than 1.2 are young soils. This confirms the fact that anthropogenic activities such as engineering and architectural activities, mechanical land clearing and mining re-set soil formation. Highest pH water level recorded in fallow soils is attributed to high water table and consequent saturation of soil micelle with hydroxyl ions [21] coupled with higher organic matter content (Table 2) which could buffer changes in pH. Least value of OC in soils affected by building construction could be the result of desurfacing and movement of epipedal materials to distances away from soils of the site coupled with higher rate of mineralization of organic matter when exposed to the climatic factors. Cation exchange capacity value was highest in fallow soils possibly due to relatively high organic carbon content since the contribution of clay may be low (Table 1).

Low plasticity index values coupled with low activity (A) point to the dominance of 1:1 clay minerals with lower shrinkage values and greater stability of soils. The P1 is an indirect index of the force required to mould soils [22] implying that greater force is required to mould soils of the study sites. The weights of the buildings, building materials and machines increased maximum dry densities in disturbed soils when compared with fallow soils. Consequently, moisture content of soils increased from disturbed to fallow lands.

Very high significant (P = 0.01) relationship between P1 and moisture content (Table 4) could be due to hydrogen bonding between water films and soil particles especially clay-sized types. Plasticity is a function of the number and thickness of water films in a given soil system, as it is caused by forces associated with water films around and between particles [22]. Clay content had a significant (P = 0.05) positive correlation with P1, implying that P1 increases when clay content rises. Clay content determines the amount of surface area that is available for water adsorption. However, the nature of clay influences plasticity of any given soil. Given the activity (A) values ranging from 0.33 to 0.42, it suggests that soils are dominated by kaolinite which ranges from 0.33 to 0.46 [23]. Clay type influences plasticity because of the effect of the ability of clay surfaces to absorb and orient water molecules.

There were significant (P = 0.05) negative correlation between P1 and exchangeable Na in disturbed soils, implying that the monovalent cation could be causing appreciable osmotic swelling and dispersion of the soil system. The OM content significantly correlated positively with P1 at 5% level of significance. It is possible that high absorptive capacity of OM for water could be responsible for this relationship and this relationship may decline when certain moisture retention levels are exceeded.

CONCLUSION

Soil and geotechnical properties differed among land use types. Plasticity index was low (<35%) in all the sites but had significant (P = 0.01, 0.05) relationship with soil moisture, soil clay content and colloidal activity.

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