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Relative Suitabilities of Soil Groups in Relation to Waste Disposal

E.U. Onweremadu
Department of Soil Science and Technology, Federal University of Technology, P.M.B. 1526, Owerri, Nigeria

Abstract: Aided by a reconnaissance visit, a geological map of southeastern Nigeria was used in January 2006 to identify 6 soil groups based on parent material. A free survey method was used and 5 pedons were sited on each soil group. Routine Laboratory analyses were performed on collected soil samples. Results indicate variability in the suitability of soils for the disposal of waste products. There was higher tendency of surface water flooding in soils formed over shale when compared with other soil groups. Gravimetric soil moisture, bulk density, organic matter and soil texture influenced suitabilities for waste disposal. However soil textural characteristics dominated and related significantly ($p = 0.01$; 0.05) with other soil properties. Principal Component Analysis (PCA) is needed to identify most influential variables and such may be used to attempt a model for waste disposal in the study area.

Key words: Disposal, humid tropics, parent materials, suitability, variability, waste

INTRODUCTION

Soil is a primary recipient of waste products resulting from anthropogenic activities of the modern society. These wastes appear as solids (refuse), liquids (sewage) and gases (particulates). These wastes accumulate from municipal treatment plants, agricultural operations, households and other industries (Ekundayo, 2003). Decomposition of refuse and degradation of sewage lead to the release of organic and inorganic pollutants to the soil, most of which are deleterious to ecosystem health.

Ability of soils in retaining and filtering these pollutants, most of which are heavy metals defines their sanitary functions (Zinck, 1990). Soil resource possesses certain attributes which enhance or deter the passage of waste products through them. Brady and Weil (1999) reported that sandy soils in the humid region are susceptible to nitrate leaching which promote eutrophication. Their studies also revealed that if a soil is not very acidic, heavy metals are bound by the soil system, making them unavailable for the translocatory pedogenetic process of leaching. It implies that sorption characteristics of soils indicate the potential desorbability of soil pollutants. The concept of phosphorus saturation was used as a good environmental indicator of phosphorus availability to runoff and leachate (Kleinman and Sharpley, 2002). Dissolved Organic Carbon (DOC) and the accumulations of aluminium in an iron-rich soil influence movement of pollutants in the soil system (Giesler *et al*., 2005). In addition to this, water retentivity and flow dynamics of agricultural soils are primary drivers of contaminant transport (Maag and Vinther, 1999; Haws *et al*., 2004). Greater mobility of soil contaminants is possible in well-drained soils (Spalding and Exner, 1993), stressing the relevance of soil texture in defining suitability of soils for waste disposal (Sorensen and Amato, 2002).

Based on the above, suitability classification of soils for sanitary purposes is necessary for sustainable and healthful usage of soils for sanitary purposes. This becomes very necessary in the humid tropical region characterized by outstanding heterogeneity in soil groups probably due to variability in their parent materials. The major aim of this study was to investigate suitability of soil groups for waste disposal, considering that wrong site disposal may be ecocidal.

MATERIALS AND METHODS

Study Area

Southeastern Nigeria is in the humid tropics between latitudes 4°30' and 7°30' and longitudes 6°45' and 9°00'E. Six major parents materials in the area are shale (Bende-Ameki formation), lower measures (Mamu formation), upper coal measures (Nsukka formation), coastal plain sands (Benin formation), false-bedded sandstones (Ajalli formation) and alluvium (fluvial and lacustrine deposits). Soils are derived from these parent materials making them characteristically sandy. The region is dominated by lowlands. Bimodal rainfall peak characterized the area, ranging from 1700 to over 2500 mm annually. Annual temperatures range from 27-29°C. The area is dominated by rainforest vegetation, whose density has been altered by anthropogenic activities. Farming, quarrying, hunting, gathering, fishing and mining are major socio-economic activities.

Field Survey

Reconnaissance surveys were done in January, 2006 and this was quickly followed by field soil sampling in the same year. A free survey method was employed and a soil profile pit was sited on each soil group. A soil group or individual here means soils derived from the same parent material. In all, 30 pedons (profile pits) were dug for the study, representing 5 pedons on each parent material. Soil profile pits were described according to the procedure of FAO (1998) and soils were classified using the USDA Soil Taxonomy (Soil Survey Staff, 2003). Three core samples were collected from each horizon for bulk density analysis (Grossman and Reinsch, 2002). Soil samples were air-dried and sieved using 2 mm sieve. A total of 150 soil samples was used for the study while 450 core samples were used for bulk density analysis.

Laboratory Analyses

Bulk density was estimated by core method according to procedure of Grossman and Reinsch (2002). Particle size distribution was determined by hydrometer method (Gee and Or, 2002). Gravimetric moisture content (θm) was obtained by oven drying saturated soil samples for 24 h (Obi, 1990) and results were computed as follows.

$$\text{Gravimetric moisture} = \left(\frac{\text{Mass of water at saturation}}{\text{Oven dry mass of soil}}\right) 100\%$$

Pycnometer method was used to determine particle density (Obi, 1990). Total porosity was calculated from bulk and particle densities. Cation exchange capacity and organic matter were determined according to the procedures of Anderson and Ingram (1998a and b), respectively. Soil pH was measured potentiometrically using 1:1 soil-solution ratio as described by Hendershot *et al.* (1993). Total phosphorus was estimated colourimetrically (ammonium-molybdate/stannous chloride) using a flow injector analyzer (5020 Analyser, Tecator, Hoganas, Sweden) after potassium per-oxo-disulphate digestion.

Statistical Analysis

Soil data were subjected to Analysis of Variance (ANOVA) statistic using the PROC mix-model of SAS (Little *et al.*, 1996). Means were separated using Standard Error of the Difference (SED) at 5% level of probability. Correlation analysis was performed on some soil properties.

RESULTS

Soil Physical Parameters

There were differences in the distribution of soil physical properties at both surface and sub-surface soils (Table 1). In all the soil groups, clay content was higher in subsurface soils when compared to sand sized particles in the study area. Gravimetric moisture content was higher in subsurface soils. Clay content may have influenced the distribution of gravimetric water content and saturated hydraulic conductivity of soils. Bulk density increased with depth but had higher surface values from soils formed over upper coal measures. Expectedly, soils derived from shale had the highest gravimetric moisture contents of 516 and 685 g kg^{-1} at the surface and subsurface soils, respectively, having 33.6 and 53.1 g kg^{-1} clay at surface and subsurface layers, respectively.

Soils were strongly acidic, especially at the surface layers with pH increasing with depth (Table 2). Generally, exchangeable cations increased with depth. Highest CEC values were recorded on soils derived from shale while there was no observed trend in the distribution of organic carbon in the area. Soils formed over alluvium and coastal plain sands had relatively high available phosphorus.

Table 1: Selected physical properties of soils of the dump sites in the study area

	Soil properties					
Soil groups	Clay (g kg^{-1})	Silt (g kg^{-1})	Total sand (g kg^{-1})	BD (mg m^{-3})	θm (g kg^{-1})	Ksat (cm h^{-1})
Surface soil (0-10 cm depth)						
Alluvium	10.4	11	846	1.39	156	7.63
Coastal plain sands	13.8	38	824	1.36	158	7.04
Shale	33.6	186	478	1.39	516	4.81
Lower coal measures	29.0	222	488	1.33	488	5.16
Upper coal measures	8.6	32	882	1.43	142	7.72
Flasebedded sandstones	12.0	96	784	1.42	188	6.18
Subsoil (20-100 cm depth)						
Alluvium	16.1	35	804	1.46	230	6.12
Coastal plain sands	25.7	37	706	1.42	277	4.68
Shale	53.1	117	352	1.55	685	3.47
Lower coal measures	31.8	196	486	1.48	507	4.01
Upper coal measures	14.3	31	826	1.48	214	5.26
Flasebedded sandstones	19.8	67	735	1.48	346	4.25

θm = Gravimetric moisture content; Ksat = Saturated hydraulic conductivity; BD = bulk density

Table 2: Selected chemical properties of soils in the study area

	Soil properties							
	pH	Ca	Mg	K	Na	CEC	C	Av.P
Soil groups	(Kcl)	(cmol kg^{-1})					(g kg^{-1})	(mg kg^{-1})
Surface soil (0-20 cm depth)								
Alluvium	4.0	1.6	0.6	0.1	0.1	8.2	19	27.7
Coastal plain sands	4.1	1.9	0.7	0.1	0.1	7.9	20	28.9
Shale	4.3	4.7	1.4	0.4	0.1	23.8	18	6.7
Lower coal measures	4.2	2.0	0.9	0.3	0.1	6.8	20	9.5
Upper coal measures	3.6	0.9	0.2	0.1	0.0	4.3	07	4.5
Flasebedded sandstones	3.8	0.5	0.5	0.1	0.0	5.4	11	3.0
Subsoil (20-100 cm depth)								
Alluvium	4.1	1.2	0.5	0.1	0.1	6.2	8	12.9
Coastal plain sands	4.2	1.1	0.5	0.1	0.1	4.9	8	9.1
Shale	4.7	6.8	0.8	0.2	0.1	26.3	4	2.0
Lower coal measures	4.4	2.8	0.6	0.3	0.0	6.0	6	1.4
Upper coal measures	4.0	0.8	0.3	0.1	0.0	3.5	4	1.7
Flasebedded sandstones	4.1	0.9	0.4	0.1	0.0	4.3	3	0.8

CEC = Cation Exchange Capacity; Av. P = Available Phosphorus

Table 3: Distribution of selected soil properties among soil groups and depth

Treatments	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})	OM (g kg^{-1})	BD (mg m^{-3})	Ksat (cm h^{-1})
Group						
Alluvium	808.4	42.0	149.6	15.8	1.45	7.40
Coastal plain sands	693.2	73.2	233.6	12.7	1.41	7.60
Shale	376.0	131.2	492.0	16.2	1.45	4.80
Lower coal measures	485.6	201.6	312.8	15.4	1.42	5.10
Upper coal measures	835.2	31.6	133.2	7.6	1.47	7.80
Flasebedded sandstones	744.0	72.8	183.2	11.0	1.46	6.40
SED (p = 0.05)	54.6	25.2	45.8	1.5	0.03	1.20
Depth (cm)						
0-20	719.0	107.0	179.0	25.8	1.36	6.40
20-40	708.0	87.3	209.0	16.9	1.40	6.80
40-60	638.0	90.3	277.0	11.2	1.44	4.10
60-80	615.0	86.7	307.0	7.4	1.48	4.30
80-100	640.0	89.0	281.7	4.3	1.53	4.10
SEU (p = 0.05)	12.7	7.1	12.3	1.0	0.01	0.04
p-values						
Soil Group (SG)	<0.0001	<0.0001	<0.0001	<0.0001	ns	<0.0001
Depth (D)	<0.0001	0.0271	<0.0001	<0.0001	<0.0001	<0.0001
SG×D	<0.0001	0.0006	<0.0001	<0.0001	<0.0001	<0.0001

OM = Organic Matter; BD = Bulk Density; ns: Non Significant

Table 4: Correlation coefficients between selected soil properties (n = 150)

Soil property	Correlation coefficient (r)
Sand vs θm	-0.98*
Clay vs θm	0.86*
Sand vs f	0.91**
Av.P vs f	0.51*
Av.P vs pH	0.66**
Sand vs Ksat	0.88*
Clay vs Ksat	-0.94*
OM vs Ksat	0.82**
OM vs θm	0.68*

f = Porosity; Vs = Versus; θm = Gravimetric moisture content; Av.P = Available Phosphorus; OM = Organic Matter; Ksat = Saturated hydraulic conductivity; **: Significant at p = 0.01; *: Significant at p = 0.05

Analysis of variance performed on some soil properties indicated that soil particle sizes, soil organic matter and saturated hydraulic conductivity of all soil groups varied significantly (p = 0.05) while there was no significant variation in bulk density among soil groups (Table 3). There were good relationships existing among parameters believed to influence movement of waste products in the pedosphere (Table 4). Soil organic matter content had a significant positive correlation (p = 0.01) with saturated hydraulic conductivity and the same trend was found between sand content and porosity.

DISCUSSION

Soil texture has a great influence on the movement of waste products through the soils. Good to excessive drainage results in sandy soil characteristic of the study area as that encourages leaching of major cations and anions to the deeper layers. This increases the possibility of ground water pollution in the site. In these soils, ground water pollution from waste products is very high in soils formed over upper coal measures, alluvium, coastal plain sands and falsebedded sandstones since they were very sandy. However, ground water pollution may be reduced in soils formed over Upper Coal Measures since they are located on the highlands of eastern Nigeria (Onweremadu, 2006). Nonetheless, Brady and Weil (1999) observed that sandy soils of the humid tropics are susceptible to nitrate leaching which promotes eutrophication.

But soils derived from shale had high clay content (336-531 g kg^{-1}) and this encourages surface water flooding and surface pollution. Bulk density values were below 1.5 mg m^{-3} except in the subsoils of soils formed over shale (1.55 mg m^{-3}). High bulk density (greater than 1.5 mg m^{-3}) reduces water infiltration and root penetration resulting in increased surface flooding, poor aeration and surface water pollution (Ekundayo and Fagbami, 1996). Based on this criterion, all studied soils of the area are suitable for waste disposal except Shale soils if subsurface horizons are exposed. High sandiness of soils of the site suggest high macroporosity and this promotes infiltration and possible ground water pollution, but high content of clay in subsurface layers indicate illuviation and argillation which tend to deter further movement of waste products down the pedon.

Moisture contents within the range of 51 to 300 g kg^{-1} are suitable for waste disposal using sanitary landfill method (Bonarius, 1975). By this criterion, soils formed over shale and lower coal measures, having 516 and 488 g kg^{-1} moisture contents are unsuitable for waste disposal at the surface layers. This is worst for subsurface layers and such soils may show surface flooding, ponding and underground pollution (Ekundayo, 2003). Higher bulk densities in the subsurface soils reduce water infiltration due to clogging of pores (Roth, 1997).

Soils are strongly acidic and this does not favour waste disposal as Bonarius (1975) had earlier reported that strongly acidic and strongly alkaline soils are unsuitable for waste disposal. At strong and extreme soil acidity most of the micronutrients and heavy metals become soluble and mobile. Soil pH affects competition among ions in the soil micelle (Giesler *et al*., 2005).

Organic matter content (Table 2) was higher on the topsoils, suggesting higher chelation activities of some waste products including phosphates. Ekundayo and Fagbami (1996) reported that a high level of organic mater (greater than 20 g kg^{-1}) was found to be conducive for heavy metal chelation, increased exchange capacities and increased infiltration of surface water. Higher values of organic carbon in soils over coastal plain sands, lower coal measures, alluvium and shale suggest greater suitability for waste disposal but this may not be conducive as other variables may affect suitability. Low organic matter content (Table 2) in subsurface horizons portend poor chelation activity although aluminium and iron oxides in soils enhance sorption of substances (Nieminen and Jarva, 1996), including waste products. It becomes environmentally unfriendly to expose these subsurface soils. Low to moderate cation exchange capacity favours the use of these soils for sanitary purposes since Bonarius (1975) reported that higher cation exchange capacity lowers infiltration rate, thereby increasing surface flooding.

Variability existing among selected soil properties (Table 3), confirm the possibility of differences in pedogenesis and land use history of soils and with high degree of relationship between most parameters (Table 4). These parameters may be useful for modelling and consequent use in predictions. This will certainly enhance sustainable use of soils for waste disposal without unhealthful consequences on the inhabitants.

CONCLUSIONS

The studied soils vary in their physicochemical properties, implying variability in suitability for waste disposal. However, soil texture had a great influence on suitability of soils for waste disposal as it exhibited good relationships with a great number of studied soil parameters.

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