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Variations in Some Physical Properties and Organic Matter Content of Soils of Coastal Plain Sand under Different Land Use Types

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Abstract: Profile soil samples from five land use types in Owerri, southeastern Nigeria, were used to study differences in soil physical properties and organic matter (OM) content. The land use types were four year bush fallow (FY), grass vegetation (GV), continuously cultivated (CC), forest vegetation (FV) and one year cassava farm (CF) lands. Aggregate stability was measured at the macro level by mean weight diameter (MWD) and at the micro level by dispersion ratio (DR), clay dispersion index (CDI), aggregated silt plus clay (ASC) and clay flocculation index (CFI). Values of MWD was highest in the FY and significantly ($P \leq 0.05$) different from the GV which had the lowest one. At the micro aggregation level, GV appeared to be better than the others. Topsoil textures were sandy loam to loamy sand. Clay content increased with depth while sand decreased. Saturated hydraulic conductivity (K_{sat}) showed an inverse relationship with bulk density (B_D) with the former decreasing as the later increased with depth. Values of K_{sat} showed that it was fairly rapid (0.96 to 1.95 cm min^{-1}) except for the GV were B_D values were higher (1.50 to 1.58 g cm^{-3}). Topsoil B_D was moderate, varying from 1.20 to 1.50 g cm^{-3}, while the subsoil values were higher, ranging from 1.41 to 1.58 g cm^{-3}. Across the land use types, FV retained more water than the others, having the highest available water of 13.8%. The FV was also more porous than the rest with more than 50% total porosity while the CC, having less than 38% total porosity and about 19% micro porosity, was the least porous. Values for OM in all the land use types were high ranging from 2.21 to 3.81% with the FV recording the highest whereas the CC had the lowest one.

Key words: Macroaggregation • Microaggregation • Land use • Coastal plain sands • Soil water constant • Organic matter

INTRODUCTION

Inherent soil properties influence the behaviour of soils. Therefore, knowledge of soil properties is important in determining the use to which a soil may be put [1]. Soil physical properties deteriorate with change in land use especially from forest to arable land. Cropping may lead to erosion and leaching of soil nutrients [2] which in turn, adversely affect the physico-chemical properties of the soil.

Under natural conditions, soil physico-chemical properties rarely deteriorate but structural deterioration may occur along tracks regularly used by foraging animals. Soil structure is affected by intensity of land use and this has effect on the distribution of microbial biomass as well as microbial processes within the aggregates [3]. Mbagwu and Auerswald [4] have shown that land use influenced structural stability more than intrinsic soil properties and that percolation stability of soil increased with increase in OM content. With conventional tillage practices, poorly structured soils become easily eroded [2].

However, with continuous cultivation, physical properties and productivity of many soils commonly decline due to decrease in OM content [5] and soil pH. Intensive cropping has led to disaggregation in surface soils due to a combination of machinery movement and decrease in OM [6]. Also, according to Kutilek, [6] long term use of heavy machinery during tillage operations may cause irreversible soil compaction to a depth of about

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60-70 cm. Therefore, bush fallowing to restore the physico-chemical and biological properties of soil is inevitable [7]. This is considered to be efficient for nutrient recycling and biomass accumulation because it consists of many plant species with different types of root system [8]. Hence, assessment of changes in soil properties which are associated with different land use systems is vital to conclusions on appropriate soil conservation and management practices to be adopted. The objective of the study was to investigate variations in some physical properties and OM content of soil under different land use types.

MATERIALS AND METHODS

The Physical Environment: The study area is located within $5^o 14'$ to $5^o 18'$N and $7^o 5'$ to $7^o 10'$E in southeastern Nigeria. Tropical wet and dry climate prevails in the area. Mean annual rainfall is 2000 mm. Wet season extends from March to October with peaks in June/July and September. Intensities of rainfall may be as high as 50 to 100 mm hr^{-1} [9]. In some years, rainfall may be prolonged while there may be delayed onset in some other years. Maximum and minimum annual mean temperatures are 28 and 21°C [9]. Throughout the year, insolation is high.

The area is geomorphologically plain and nearly flat with gentle slope, while dominant vegetation types are tropical rainforest and derived savanna of the guinea type.

The main occupation of the population is subsistent farming. Food crop cultivation dominates the agricultural landscape. The conservation practices include shifting cultivation, necessitating one-season cropping followed by bush fallowing (4 years); multiple cropping; cover cropping; mulching; and organic manuring, with application of wood ash from burnt wood used as a fuel. Inorganic fertilizer application has not gained ground due to financial constraints and sociological behaviour of the resource-poor farmers.

Field and Laboratory Studies: These included digging of one profile pit each in five land use type areas. Soil samples for laboratory analyses were collected from the profile horizons with trowel and core samplers. Samples for MWD were air-dried and passed through a 4.75 mm sieve while those for micro aggregate stability indices, water retention and OM were sieved with a 2 mm sieve after air-drying.

Measurement of Aggregate Stability: For micro aggregate stability, this involved the determination of the amounts of silt and clay in calgon-dispersed as well as water-dispersed samples using Bouyoucos hydrometer method of particle size analysis described by Gee and Bauder [10]

$$\text{Dispersion ratio (DR)} = \frac{(\%\text{ silt + clay } (H_2O)}{(\%\text{ silt + clay (calgon)}} \times 100 \quad (1)$$

$$\text{Aggregated silt + clay (ASC)} = [\%\text{ clay + silt (calgon)}] - [\%\text{ clay + silt } (H_2O)] \quad (2)$$

$$\text{Clay flocculation index (CFI)} = \frac{[\%\text{ clay (calgon)}] - [\%\text{ clay } (H_2O)]}{[\%\text{ clay (calgon)}]} \times 100 \quad (3)$$

$$\text{Clay dispersion index (CDI)} = \frac{[\%\text{ clay } (H_2O)]}{[\%\text{ clay (calgon)}]} \times 100 \quad (4)$$

Mean weight diameter (MWD) was determined by the wet-sieving method of Kemper and Rosenau [11]. In this method, 25 g of the <4.75 mm soil sample was put in the topmost of a nest of four sieves of 2.00, 1.00, 0.50 and 0.25 mm sizes. Water-stable aggregates(WSA) on each sieve were estimated after wet-sieving and oven-drying and recorded as percentages of the original mass as shown:

$$\text{WSA} = (\text{Mr/Mt}) \times 100 \quad (5)$$

where Mr is mass of resistant aggregates and Mt is the total mass of wet-sieved soil. The WSA were then categorized into 4.75-2.00, 2.00-1.00, 1.00-0.50, 0.50-0.25 and <0.25 mm. MWD of WSA was calculated as:

$$\text{MWD} = \sum_{i=1} X_i W_i \quad (6)$$

where X_i is the mean diameter of the ith sieve size and W_i is the proportion of the total aggregates in the ith fraction.

Saturated Hydraulic Conductivity: Saturated hydraulic conductivity (K_{sat}) was done by the constant head permeameter method. Darcy's equation, as explained by Youngs [12] was used for the computation of K_{sat}.

$$K_{sat} = \frac{QL}{AT\Delta H} \quad (7)$$

where Q is water discharge (cm^3), L is length of soil column (cm), A is the interior cross-sectional area of the soil column (cm^2), ΔH is the head pressure difference causing the flow (dimensionless), T is the time of flow (sec.).

Water Retention: Water retained at field capacity (FC) and permanent wilting point (PWP) was determined using the saturation water percentage-based estimation models of Mbagwu and Mbah [13]. Available water (AW) was computed as the difference between moisture retained at FC and PWP. The models are:

$$FC = 0.79\ (SP) - 6.22\ (r = 0.972) \quad (8)$$

$$PWP = 0.51\ (SP) - 8.65\ (r = 0.949) \quad (9)$$

where FC and PWP are the field capacity (%) and permanent wilting point (%), respectively and SP is the saturation water (%).

For the determination of SP, ceramic crucibles with perforated bottom were used. Duplicate determinations were made per sample. Portions of the air-dried soil sample were transferred into the crucible, a little at a time, with intermittent gentle tappings on the work bench, to consolidate the mixture. The process was continued until the crucible was about four-fifth full. The crucible, with air-dry sample, was weighed. It was then transferred into a basin and water was added into the basin up to a depth of about two-thirds of the height of the crucible. It was allowed to stand for 24 hr to saturate. It was then dried in the oven for 24 hr at 105°C after which the mass of the crucible with oven-dry soil sample was recorded. SP was then calculated as follows:

$$SP = 100 \times \frac{M^{\theta} + (Msa - Mso)}{Mso} \quad (10)$$

$$\text{where } Mso = 100 \times \frac{Msa}{100 + \theta r} \quad (11)$$

In equations 10 and 11, θr is the air-dry (residual) moisture percentage, $M\theta$ is the mass of water absorbed (g), Msa is the mass of air-dry soil (g) and Mso is the mass of oven dry soil.

Bulk Density: Bulk density (B_D) was determined using the core method as described by Anderson and Ingram [14].

Porosity: Total porosity (P_t), the percentage of bulk volume of soil not occupied by

solid particles, was calculated from B_D values, assuming a particle density (P_D) of 2.65 g cm^{-3}:

$$P_t = [1 - (B_D/P_D)] \times 100 \quad (12)$$

Macro porosity (P_{ma}) was computed from volumetric moisture content at FC as described by Mbagwu [15] using the equation shown:

$$P_{ma} = P_t - FC \quad (13)$$

where FC is volumetric moisture content at field capacity.

Micro porosity (P_{mi}) was calculated as the difference between P_t and P_{ma} [15].

Organic Matter: Organic matter was determined by the Walkley and Black method [16].

Statistical Analysis: Analysis of variance (ANOVA) for a Randomized Complete Block Design (RCBD) was used to compare the influence of the land use types on the measured soil physical properties and organic matter content. Where F tests were significant, least significant difference at 5% probability level ($LSD_{0.05}$) was used to separate the means.

Results and Discussion: Some of the physical properties of the soils determined are shown in Table 1.

Particle Size Distribution: The distribution of soil separates in the five land use types studied are shown in Table 2. Results showed that the one year cassava farm (CF), Forest vegetation (FV) and continuously cultivated (CC) lands had higher sand fractions than the four year bush fallow (FY) and grass vegetation (GV) lands. For the silt

fraction, FV and FY contained more than the rest. The land use types were different from each other in clay content.

Increased sand content in all the soils sampled could be attributed to their being derived from unconsolidated sand deposits formed over coastal plain sands and

Table 1: Some physical properties of profiles under different land use types

Profiles	Depth (cm)	Clay (%)	Silt (%)	Sand (%)	K_{sat} (cm min^{-1})	P_t (%)	B_D (g cm^{-3})	AW (%)
FYP (1)	0-10	14	4	82	1.87	47.25	1.32	12.45
	10-15	12	6	82	1.82	47.27	1.35	12.24
	15-30	14	4	82	1.44	46.12	1.36	11.93
	30-79	16	6	78	1.39	45.08	1.39	11.51
	79-120	20	6	74	1.27	43.65	1.41	11.10
GVP(2)	0-11	11	4	85	0.94	45.32	1.50	10.89
	11-21	17	_	83	0.87	43.08	1.50	10.47
	21-61	21	_	79	0.12	47.35	1.55	10.98
	61-101	21	_	79	0.12	48.05	1.58	10.94
CCP(3)	0-11	10	3	87	1.40	39.53	1.30	10.94
	11-20	12	4	84	1.10	38.74	1.31	10.71
	20-88	18	4	78	0.98	37.65	1.31	10.47
	88-140	20	4	76	0.96	37.56	1.34	10.27
FVP(4)	0-13	9	6	85	1.95	51.14	1.20	14.36
	13-29	11	4	85	1.95	52.12	1.24	14.19
	29-48	13	4	83	1.79	51.71	1.26	13.92
	48-126	15	2	83	1.45	50.61	1.29	13.41
	126-147	17	2	81	1.21	49.03	1.29	13.07
CFP(5)	0-11	9	4	87	1.92	49.70	1.22	13.83
	11-27	13	2	85	1.90	48.37	1.24	13.35
	27-48	13	4	83	1.61	47.36	1.28	12.79
	48-74	15	4	81	1.40	47.41	1.31	12.56
	74-111	17	2	81	1.17	46.60	1.33	12.24

FYP(1) = Profile pit in a four year bush fallow land; GVP(2) = profile pit in a grassland; CCP(3) = profile pit in a continuously cultivated land; FVP(4) = Profile pit in a forestland; CFP(5) = profile pit in a one year cassava farmland

Table 2: Particle size distribution of soils studied

	Land use types				
Particles (%)	FY	GV	CC	FV	CF
Sand	79.2	77.2	82.0	84.2	86.6
Silt	5.6	3.2	2.8	6.4	4.8
Clay	15.2	19.6	15.2	9.4	8.6
Texture	SL	SL	SL	LS	LS

FY = four year bush fallow land; GV = grass land; CC = continuously cultivated land; FV = forest land; CF = one year cassava farmland; SL = sandy loam; LS = loamy sand

Table 3: Aggregate stability indices and organic matter content of soils studied

	Land use types					
Properties	FY	GV	CC	FV	CF	$LSD_{(0.05)}$
MWD (mm)	1.8	0.8	1.0	1.2	1.7	0.5
% DR	42.9	47.0	52.2	49.8	38.8	11.3
% CDI	44.4	36.9	46.7	45.6	39.2	9.9
% ASC	11.4	11.6	9.9	8.3	10.6	3.4
% CFI	55.6	63.9	54.1	56.7	60.8	1.3
% OM	3.4	2.8	2.2	3.8	3.2	0.8

MWD = mean weight diameter; DR = dispersion ratio; CDI = clay dispersion index; ASC = aggregated silt + clay; CF = clay flocculation index; OM = organic matter; FY = four year bush fallow land; GV =grass land; CC = continuously cultivated land; FV = forest vegetation; CF =one year cassava farmland

sedimentary rocks [17]. The textures of the soils are related to their parent materials [18.] which accounted for the similarity in particle size distribution obtained. Igwe *et al*. [19] made similar observations as they reported that soils derived from different geologic formations varied in particle size distribution.

Aggregate Stability: At the macro aggregate level, measured by mean weight diameter (MWD), FY was better than the other land use types, closely followed by CF (Table 3). Contrary to expectation, GV and FV had less stable aggregates. Comparing FV and CC, the results supported the observations of Spaccini *et al*. [20], who

Table 4: Water retention characteristics of soils studied

	Land use types					
Properties	FY	GV	CC	FV	CF	$LSD_{(0.05)}$
% SP	33.6	26.8	28.5	40.6	37.6	3.5
% FC	20.3	15.0	16.3	25.9	23.5	
% PWP	8.5	5.0	5.9	12.1	10.5	6.4
% AW	11.8	10.0	10.4	13.8	13.0	0.4

FY; GV; CC; FV; CF as shown in Table 2. SP = saturation percentage; FC = field capacity; PWP = permanent wilting point; TAWC = total available water capacity

Table 5: Bulk density, porosity characteristics and saturated hydraulic conductivity

	Land use types					
Properties	FY	GV	CC	FV	CF	$LSD_{(0.05)}$
B_D (g/cm^3)	1.37	1.54	7.32	1.26	1.28	0.02
P_t %	45.87	45.50	37.92	50.92	47.89	1.79
P_{ma} %	27.75	26.03	21.70	32.41	29.89	1.16
P_{mi} %	18.12	19.47	16.22	18.51	18.01	0.71
K_{sat} (cm/min)	1.56	0.41	1.01	1.61	1.60	0.81

FY; GV; CC; FV; CF as shown in Table 2. B_D = bulk density; P_t = total porosity; P_{ma} = macro porosity; P_{mi} = micro porosity; K_{sat} = saturated hydraulic conductivity

reported reduction in MWD when forest land was converted to arable land. However, the difference in the values between the FY and the FV was significant (P#0.05). Tillage with traditional hoeing and clean weeding together with reduced OM content may explain the low value of MWD observed under CC while the lower content of soil organic matter (SOM) explained low aggregate stability under the GV (Table 3).

At the micro level, measured by dispersion ratio (DR), clay dispersion index (CDI), aggregated silt + clay (ASC) and clay flocculation index (CFI), the stability of the aggregates under the different land use types was irregular. For DR, significant difference (P#0.05) was observed between the CC, which had the highest value and CF with the lowest value, whereas none was observed between the CC and the other three land use types. These other three land use types (FV, GV and FY) were not statistically different from CF. Also, the CC recorded the highest value for CDI while the GV had the lowest one. Considering ASC and CFI, the CC performed poorly. The values obtained with these indices of micro aggregate stability under the CC showed that its stability was lower than the other land use types. This may be connected with the lowest OM content observed under the CC which supported the reports by Igwe *et al*. [24] and Gijsman [19, 20]. Although, no significant differences existed between the land use types, except for DR, the GV appeared to be the best at the micro aggregation level irrespective of the higher values of OM observed in soils under the FY and the FV. It may therefore mean that other factors, apart from OM influenced aggregate stability of the soils studied.

Water Retention Characteristics: Soil water constants such as saturation water % (SP), field capacity (FC), permanent wilting point (PWP) and available water (AW) of soils under the studied land use types are shown in Table 4. Across the land use types, the FV retained more water than the others. In all the parameters measured, the FV ranked best followed by CF. With regard to SP and FC, the differences observed between FV and CF were not significant, but in respect of PWP and AW, significant differences were observed between these two land use types. Also, significant differences were observed between FV and FY, GV and CC in all the parameter measured except for FC where the difference between FV and FY was not significant. The observed trend could be attributed to OM influence on these parameters.

The high moisture retained at FC, PWP and the AW under the land use types was a reflection of their high OM content and a manifestation of the affinity of OM for water [22, 23].

Bulk Density, Porosity Characteristics and Saturated Hydraulic Conductivity: Variations in bulk density (B_D), porosity and saturated hydraulic conductivity (K_{sat}) are shown in Table 5. In all these parameters, FV performed best with the lowest B_D, highest total porosity (P_t), macro porosity (P_{ma}) and the most rapid K_{sat}. These results may be due to the high content of OM which reduced B_D and increased porosity and K_{sat}. Although, with regard to B_D, there were significant differences between land use types, no regular pattern of relationship between B_D and OM content was observed. This however, negated decreases in B_D due to increases in OM and was not consistent with the reports of other researchers [24, 25, 26].

Significant differences in P_t were observed between the land use types but not between FY and GV. The FV recorded over 50% P_t, while the CC recorded just above 37%. With respect to FV, GV and CC, OM could be inferred to have played a role in the P_t of the soils. As OM content decreased in these land use types, from the FV to the CC the P_t reduced (Table 5). This is consistent with the observations of Oguike *et al*. [26]. Also, Ekeh *et al*. [27] observed enhancements in both P_t and P_{ma} with improved OM status. In this study, P_t and P_{ma} followed the same trend while micro porosity (P_{mi}) was highest under the GV.

The K_{sat} observed was fairly rapid, possibly as a result of the coarse texture of the soils. Values ranged from 0.41 cm min^{-1} to 1.67 (24.60 to 100.20cm hr^{-1}) under GV and FV, respectively. The most likely explanation would be the percent sand content which was highest under the FV and lowest under the GV. Also P_{ma} was highest under FV explaining further, the rapid K_{sat}. This observation agreed with those of Ekeh *et al*. [27] and Oguike *et al*. [26-28]. No significant differences were observed between FV, CF and FY but these were statistically different from GV and CC.

Organic Matter: Values of OM in all the land use types were high. The highest value was recorded under the FV while the lowest one was under the CC. There were significant differences between the OM content under FV, GV and CC. The higher OM values recorded in FV and FY may be as a result of plant litter abundantly returned to the soil in these environments. Although, CC was comparatively lowest in OM content, the value was high [29] probably due to the organic wastes which the peasant farmers in the area continually used as soil amendment. For CF, the relatively high value could be as a result of the leaf litter [30].

The values recorded for OM under these land use types drastically differed from observations of some researchers [19, 24, 31, 32] while confirming the results reported by Machado and Gerzabek [33].

CONCLUSION

Land use significantly influenced soil physical properties, especially structure parameter. Changes in land use such as conversion of natural forest to crop land contributed to land degradation that manifested in losses of soil organic matter and reduced stability of the soil aggregates. Since the physical properties and OM content of the soils under the land use types varied, it indicated that the results of this study were land use type-specific.

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