

A COMPARISON OF SOIL pH, ORGANIC MATTER, EXCHANGEABLE BASES AND SODIUM ADSORPTION OF SOILS UNDER DIFFERENT LAND USE

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ABSTRACT

Land use changes implemented locally could have worldwide implications on soil physio-chemical properties, soil fertility, and soil erosion sensitivity. The effects of oil palm plantation, forest, rubber plantation, mixed cropping, sole cassava and waste dump site soils were studied. Results showed that soil organic matter was higher oil palm plantation and forest soils (32.5 g kg⁻¹ and 28.2 g kg⁻¹) respectively. Mixed cropping increased soil acidity by 45% compared to oil palm plantation and forest soils. Available P and total N were 35.2 mg kg⁻¹ and 1.3 g kg⁻¹ respectively in oil palm plantation soils. These values were 42.5% and 68.5% higher than that of rubber plantation soils. Exchangeable bases were significantly higher ($p < 0.05$) in oil palm plantation, forested, and rubber plantation soils than mixed cropping and waste dumpsite soils. Low base status in mixed cropping soils was attributable to constant removal of these elements by plants over the years.

Exchangeable sodium percentage (ESP) as high as 21.11% and 10.11% were found in waste dump site and soil cassava cultivated soils. There was generally, high tendency of clay deflocculation in waste dump site, sole cassava, and mixed cropping soils, with adverse implications on infiltration rate and flooding due to elevation values of sodium adsorption ratio (SAR) and ESP. Oil palm and rubber plantations can be enhances soil organic matter and can be used for arable crop production.

Keywords: Soil organic matter, soil fertility, sodium adsorption ratio, exchangeable sodium

INTRODUCTION

The impact of land use types on soil properties can provide essential information for assessing sustainability of land for agriculture and its impact on overall environment quality. It is one of the major drivers of environmental changes in local and global scale (Deckor, 2012). Land use and management practices may include methods that land users tend to the land, cultivate a particular crop or care for livestock (Heluf and Wakene, 2006). On pasture land, these practices include animal stocking, rotational grazing, and weed control. While on cultivated land, management practices include crop selection and rotation, tillage method, residue management, fertilizer and other nutritional amendments, weeding, pest control and water management (Shepherd *et al.*, 2001).

It is widely speculated that soil properties deteriorate with land use changes, especially, when forest is converted to arable land (Oguike and Mbagwu, 2009). It is also expected that soil physical, chemical and biological properties and their equilibrium are continuously influenced by land use. For example, soil pH which regulates almost all chemical and biological reactions in the soil can be significantly influenced by land use type(s) (Mohammed *et al.*, 2005; Eyayu, *et al.*, 2009). Therefore, information regarding distribution of soil pH measured in water and Kcl for different land use type could be a useful index of weathering status, potential nutrient holding capacity and fertility of soil types.

Continuous cultivation, application of chemical fertilizers and excessive rainfall as found in the humid tropics can affect pH of the soil profile, which invariably may determine the exchangeable properties of the soil. Accumulation of soil organic matter (SOM) within the soil is usually a balance between the return or addition of plant residues and their subsequent losses through microbial decomposition. A number of studies had reported on the positive influence of SOM on cation exchange capacity (CEC), base saturation, pH, and buffering capacity of soils. (Senjobi and ogunkunle, 2010). It is also agreed that intensive cultivation involving use of fertilizers and pesticides could lead to deterioration in soil health and productivity with adverse environmental effects (Wells *et al.*, 2000; Chen *et al.*, 2010). A few other studies showed that forest clearing, urbanization, and cultivation and pasture introduction altered the pH, exchangeable bases, sodium adsorption ratio of loess-derived soils in Iran (Khormoli *et al.*, 2009). In some humid tropical soils, the effect of land use with changes in some chemical properties of soil is not well known. There is poor understanding of variability between soil pH properties of soils under forest clearing, cultivation, waste dump site and tree crop planting. Havlin *et al.* (2002) provided information relating variability in available P and soil nitrogen to land use and other soil properties such as clay content, soil organic matter returned to the soil and the slope position.

While Brady and Weil (2002) found that continuous cultivation resulted in more loss of P than in soils with sufficient cover and relatively undisturbed forest and natural grass land.

Land use change is an important factor controlling soil organic matter storage, since it affects the quantity and quality of litter inputs, litter decomposition rate and processes of SOM stabilization. Soil organic matter stabilization on the other hand is related to nutrient adsorption at the exchange complex (Udom and Akamigbo, 2010). In this study, we investigated variations in soil pH measurements and exchangeable cations and also tested the relationship between sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP). This information is needed to enable land users and farmers manage the soil to prevent degradation of soil resources.

MATERIALS AND METHODS

The study was conducted on six land use types in Port Harcourt within the humid tropical zone of the Niger-Delta of Nigeria (04°15'N and 07°30'E). The soil is derived from the Coastal Plain sand and classified as Typic kandistult (USDA, 2008). Mean annual rainfall is in excess of 2000 mm. Rainy season has two peaks in July and September. Mean temperature at wet season ranged between 26°C and 33°C, and at dry season between 26°C and 36°C (Okpon *et al.*, 1998). Soil samples were collected in four (4) replicates at 0-30 cm depth. The land use types used in the study and their characteristics are shown in Table 1.

Table 1: Land use area under study and their characteristics

Land use	Area coverage	Site characteristics
10-year oil palm plantation	10 hectares	dense undergrowth with shrubs and grasses such
15-year forest land	30 hectares	dominated with tree species such mahogany, teak and <i>Alchornea cordifolia</i>
10-year rubber plantation	10 hectares	dense undergrowth with spear grass and guinea grass
10-year continuous cropped cassava field	10 hectares	applications of organic manures have been in practice
10-year mixed cropping field	20 hectares	cultivated to maize, fluted pumpkins, cassava and okra
7-year waste dumpsite	2 hectares	characterized by dumping of municipal wastes, electronic wastes, and heterogeneous household wastes

Laboratory Studies

Determinations of Particle-size Distribution, pH and Organic Matter

Particle size distribution was determined with air-dried soil sample sieved through 2 mm mesh using the method of Gee and Bauder (1986). Soil pH was measured with a glass electrode in a 1:2:5 soil/water and 1N KCl solution (McLean, 1982). Organic carbon was determined by the Walkley and Black wet dichromate oxidation method (Nelson and Sommers, 1996) and was converted to organic matter by multiplying the total organic carbon values by the Van Bemmelen factor of 1.724 (Van der ploeg *et al.*, 1999).

Determination of Total Nitrogen, Available Phosphorus and Exchangeable Ca, Mg, Na, K

Total nitrogen was determined by the modified macro Kjedal procedure as described by Bremner and Mulvaney (1982). Available phosphorus was determined by Bray II soil extracting procedure (McLean, 1982). Exchangeable Ca and Mg were determined using the EDTA complexometric titration method as described by McLean (1982) while exchangeable Na and K were determined by flame photometry (McLean, 1982).

Sodium Adsorption Ratio and Exchangeable Sodium Percentage

Sodium adsorption ratio (SAR) was calculated according to the United State Salinity Laboratory Staff manual (USSLS, 1980) as:

$$SAR = \frac{Na+}{\sqrt{\frac{Ca + Mg}{2}}} \quad (1)$$

and exchangeable sodium percentage (ESP) was calculated as:

$$ESP = \frac{Na+}{CEC} \times \frac{100}{1} \quad (2)$$

The relationship between ESP and SAR for the soils was validated using the McBride (1994) model as:

$$\frac{ESP}{100-ESP} = 0.015 SAR \quad (3)$$

Data Analysis

Data obtained from the study were subjected to statistical analyses using the SAS software (SAS, 2001). T- test of paired comparison at $n = 12$ (the means from six duplicate samples) was used to detect differences between means in the land use types. Significance differences between the means were done using the Fisher's least significant difference (LSD) at 5% probability level.

RESULTS AND DISCUSSION

The soil pH (H₂O) ranged from 4.2 in mixed cropping to 6.2 in oil palm plantation soils (Table 2). The relatively low pH (KCl) was not surprising because, Anon (1993) also found increased in soil acidity due to pH measurement in KCl and adduced it to the presence of high potential acidity. The lowest pH value under mixed cropping soils explained continuous removal of basic cations by harvested crops over the years and higher microbial oxidation that produced organic acids, which yielded H⁺ ions to the soil solution and lowered pH of the soil. This is consistent with Wells et al. (2011) who found substantial reduction in pH of surface soils subject to long term cultivation compared to the uncultivated site. The high mean pH value in oil palm plantation soils could be a reflection of the enhanced soil organic matter usually obtained in oil palm plantation which according to Woormer *et al.* (1994) increased the capacity of soils to buffer changes in pH.

The highest soil organic matter content was found in oil palm plantation and the lowest in sole cassava plot (Table 2). Soil organic matter was in the order of oil palm > forested > rubber plantation > waste dump site > mixed cropping > sole cassava. It is possible that the roots of oil palm and fungal hyphae in forested soils contributed to the higher amount of total organic matter found in these soils (Urioste *et al.*, 2006).

Table 2: Some chemical properties of the 0-30 cm soil under the different land use

Land use	pH (H ₂ O)	pH (KCl)	Av. P (mg kg ⁻¹)	Total N (g kg ⁻¹)	OM (g kg ⁻¹)	Ex. Acidity (cmol kg ⁻¹)
Oil palm	6.2	4.1	35.2	1.3	32.5	3.8
Forested	4.9	4.2	31.6	0.9	28.2	3.2
Rubber Plantation	4.5	4.1	24.7	0.8	25.1	3.1
Sole cassava	4.3	3.9	26.3	1.0	14.4	3.0
Mixed cropping	4.2	3.9	28.4	1.1	18.3	2.8
Waste dump site	4.6	4.6	25.4	0.5	24.4	3.6
LSD (0.05)	1.31	NS	10.16	0.28	7.11	0.92

Available P and total N were also higher in oil palm plantation (35.2 mg kg^{-1} 1.3 g kg^{-1}) respectively. The non-significant different ($p > 0.05$) in available P among land use types may be due to the inherent high soil available P associated with most tropical soil. It is also possible that phosphorus availability in the soils might have been favored by the warm climatic condition of the study area along with the preferred pH range.

Exchangeable Bases, Cation Exchange Capacity and Base Saturation

The highest exchangeable Ca^{2+} was found in rubber plantation while the highest exchangeable Mg^{2+} was found in forested soils (Table 3). Exchangeable K^{+} was low in all the soils, ranging from 0.2 to 0.4 Cmol kg^{-1} soil. Exchange Na^{+} was significantly ($p < 0.05$) higher in waste dump site (2.8 Cmol kg^{-1}) soil while the lowest CEC was found in this soil. Base saturation ranged from 73.8% to 94.3% with the highest percent base saturation found in the oil palm plantation soils. The observed variation in CEC among the six land use types was probably due to strong association of CEC with soil organic matter and soil texture, indicating that the high sand content reduce the overall CEC of the soils. Basically, CEC of soil depends on the relative amount and type of colloidal substances (OM and Clay) as both provide negatively charged surfaces that play important role in the exchange processes.

Table 3: Exchangeable cations and base saturation of the soils under different land use

Land Use	Ca (Cmol kg^{-1})	Mg (Cmol kg^{-1})	K (Cmol kg^{-1})	Na (Cmol kg^{-1})	CEC (Cmol kg^{-1})	BS (%)
Oil palm	7.5	3.9	0.4	0.5	9.20	77.3
Forested	9.9	4.5	0.4	0.8	10.61	82.2
Rubber plantation	6.6	2.7	0.3	0.5	8.24	85.4
Sole cassava	5.9	2.6	0.2	0.8	7.91	72.3
Mixed cropping	3.5	2.7	0.2	0.6	7.03	75.7
Waste dump site	2.3	1.4	0.2	0.8	3.79	73.8
LSD (0.05)	2.04	2.02	NS	0.21	2.02	6.51

CEC- cation exchange capacity, BS- base saturation

Similarly, the soil CEC values in cultivated sole cassava and mixed cropping soils decreased significant ($p < 0.05$) mainly due to the reduction in organic matter content. This tend to agree with Nega and Heluf (2009) who earlier report found low CEC in low soil organic soils due to cultivation. The high Na^+ found in waste dump site soils could lead to high clay dispersion and low flocculation index (Udom and Nuga, 2014). The trend agreed with the assertion of Bohn *et al.* (2001) that the cations in agricultural soils are usually present in the order $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+ > \text{Na}^+$ and deviation from this order can create problem of ion-imbalance for plants.

Comparison of actual and estimated SAR and ESP of the Soil

Sodium adsorption ratio and exchangeable sodium percentage are indices for measuring clay flocculation and dispersion of soils. In Table 4, actual sodium adsorption ratio (SAR) showed significant different ($p < 0.05$) in waste dump site, mixed cropping and sole cassava soils. Whereas, estimated values obtained from McBride (1994) empirical model in equation 3 showed no significant different among land use types. Generally, SAR was I the order of waste dump site $>$ sole cassava $>$ mixed cropping $>$ forested $>$ rubber plantation $>$ oil palm plantation. Exchangeable sodium percentage (ESP) showed similar trend as the SAR, with the actual and estimated values as high as 21.11% and 27% respectively in the waste dump site soils (Table 4). There is high tendency of clay de-flocculation in waste dump site, sole cassava, and mixed cropping soils, with adverse implications on infiltration rate and flooding (Udom and Akamigbo, 2010). In these soils, growth and yields of many crops sensitive to elevated salt may be restricted. Such levels of SAR and ESP according to Magesin *et al.* (2000) could interfere with the absorption of water by plants through reduction in soil osmotic water potential, thereby decreasing the amount of water that is readily available to plants.

Table 4: Actual and estimated sodium adsorption ratio and exchangeable sodium percentage of the soils

Land use	actual SAR	SAR ^a	t-values	actual ESP	ESP ^a	t-values
Oil palm	0.21	0.032	2.98*	5.44	5.8	0.94 ^{ns}
Forested	0.30	0.045	2.88*	7.54	10.30	2.71 ^{ns}
Rubber plantation	0.23	0.035	3.01*	9.54	10.60	2.11 ^{ns}
Sole cassava	0.39	0.059	3.14**	10.11	11.30	0.59 ^{ns}
Mixed cropping	0.34	0.051	3.52**	8.54	9.30	0.97 ^{ns}
Waste dump site	0.59	0.089	2.85*	21.11	27.00	5.32**
LSD (0.05)	0.11	NS		4.32	6.21	

^a estimated values using McBride (1994) empirical model, * significant at $p < 0.05$,

** significant at $p < 0.01$, ns- non-significant at $p > 0.05$

Test of paired comparison between the actual and estimated ESP showed non-significant different for oil palm, forested, rubber plantation, sole cassava and mixed cropping soils. (Table 4). This way, the model could be used to predict ESP in soils with slight to moderate exchangeable Na^+ relative to CEC. On the other hand, the model is adequate for use in estimating ESP in waste dump site. Testing the model for calculated SAR, indicated that the model was not reliable for predicting SAR in these soils since the model was not formulated with a wide range of soils, including the coastal plain sands. The model works well when the ions are of equal charge, such as Ca^{2+} - Mg^{2+} exchange (McBride, 1994). It is expected that Na^+ does not form a bridge in coastal plain sands, of which the swelling process in a sodium-dominated exchange process can lead to dispersion and soil clogging, giving rise to the high ESP and SAR found in the waste dump site soils.

CONCLUSION

Land use and management affected the soil chemical properties and sodium adsorption characteristics. Continuous cropping as in mixed cropping and sole cassava plots lowered the soil pH due to removal of basic cations by harvested crops over the years. Oil palm plantation and forest enhanced soil organic matter and increased the buffering capacity of the soil which led to increased cation exchange capacity, pH and base saturation. High exchangeable sodium in soils of waste dump site and sole cassava can lead to poor structural characteristics, crusting, poor drainage, and tendency to erosion. The McBride (1994) model was about 98.2% valid for used to calculate the ESP these soils, while the model was not suitable in calculating the SAR at least in the studied soils and land use.

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