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Physical and chemical composition of soil collected from different habitats of Dumbi Inselberg in Zaria, Northern Guinea savanna, Nigeria

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ABSTRACT

For effectively functioning ecosystems, soil conservation in the means of physical and chemical properties is essential. Granite ecosystems have not received much attention in research and therefore, this study was carried out at an inselberg in Zaria in Nigeria. In the scope of this research, soils samples were collected at four locations (farmed lands, windward side, leeward side and the top of the inselberg) at depths 0 to 15 cm, 15 to 30 cm and 30 to 45 cm. The samples were analyzed for soil textural class, pH value, Organic Carbon and Exchangeable Cations. The study revealed higher percentage of clay and silt (28.93 and 12.90% respectively) in the windward samples which differed significantly ($p < 0.05$) with the other samples. Increase in clay contents with depth was statistically significant ($p < 0.05$). Silt in windward, leeward and inselberg did not differ significantly ($p > 0.05$), however the 3 samples differ significantly ($p < 0.05$) with the farmland. Sand distribution showed significant ($P < 0.05$) decrease with depth. The windward and cultivated soil samples had sand-clay-loam soil while the leeward and the rock outcrop had sandy-loamy soil. The soil pH ranged between 5.4 and 6.0 in all the samples. The pH in the cultivated plot differed significantly ($P < 0.05$) with the other 3 plots. The Organic Carbon (OC) was moderate (10.58 kg^{-1}) in the leeward plot very low (<10 gkg^{-1}) in the other plots. OC showed a significant ($P < 0.05$) decrease with depth. Exchangeable Magnesium differed significantly ($p < 0.05$) with depths but not with plots. The higher acidic reaction of cultivated soil compared to the other plots was probably caused by the use of inorganic fertilizer during crop farming. The medium soil organic content at the top soil was expected because organic debris often accumulated at the top soil. Significant increase in magnesium with depth was probably due to leaching. The soil characteristics of the study site revealed the nutrients level to be lower than expected of a forest outlier, rather, it correspond with other soils of the savanna wood land. This is an indication that inselberg's habitats are currently witnessing degradation. Further studies on other inselbergs are hereby recommended.

Keywords: Soil, inselbergs, conservation, ecosystem, physical and chemical parameters, organic contents.

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INTRODUCTION

The conservation and proper management of soil organic matter is essential to soil functions in any ecosystem. This is because soil organic matter provides services, which can be described both as soil fertility and environmental functions from the perspective of farmers and the society respectively (Feller et al., 2001). Appropriate management of soil organic matter ensures soil fertility and minimizes agricultural impact on the environment through carbon sequestration, ensure erosion control and preservation of soil biodiversity (Six et al., 2002). Soil organic carbon is known to have a direct relationship with Electrical conductivity, pH, Cation exchange capacity and phosphorus (Fagwalawa et al., 2014).

Land degradation and the effects of soil organic matter loss are particularly critical in arid, semi-arid and sub-humid areas of the tropical regions, where the risk of desertification is great. Reduction in precipitation and increase in temperature associated with global warming will further undermine the integrity of these ecosystems. One possible effect of global warming will be to accelerate soil organic matter decomposition thereby, releasing carbon-dioxide (CO_2) to the atmosphere, which will further enhance the glasshouse effect (Jenkinson et al., 1991).

Land use and land use changes are widely recognized as the key drivers of the global carbon dynamics. Good and appropriate land use practices have the ability to substantially reduce potential carbon sink in soils. In the past, farmers in dryland ecologies maintained equilibrium with the agroforestry systems of farming (Ganry et al., 2001). However, increased radiative forces arising from anthropogenic emission of gases to the atmosphere, along with population increases and reduced fallow periods upset the balance of the soil physical and chemical characterisitics. Land use such as afforestation, reforestation, grazing and conversion of natural to managed ecosystem alters the availability of organic matter inside the soil in both possible ways, by building up and decomposition. Organic matter apart from their nutrient content also has the effects of improving soil texture, aeration, water retention capacity and to regulate soil temperature (Uwah et al., 2012)

Sustainable management and restoration of degraded soils is necessary in order to reverse the negative effects and to protect terrestrial ecosystems. Afforestation of degraded land can potentially enhance carbon sequestration (Johnson, 1992).

The Nigerian Guinea Savanna is currently witnessing increasing intensities of crop and livestock production. Nomads and semi-nomads raise livestock by employing a free grazing feeding pattern (Odunze et al., 2004). This free grazing pattern was very obvious during the study. International Livestock Research Institute, ILRI (1997) and Odunze et al. (1996) reported that this over-grazing, has its attendant problems such as enhanced soil erosion, de-vegetation of the land area and desert encroachment. Crop production in the zone involves ploughing, harrowing and ridging. This is done with no special attention to conservation measures against soil nutrient depletion, soil erosion or runoff. Inselbergs in the past were considered waste lands because of the difficulty in ploughing the soil. Today, increasing cost and erratic availability of mineral fertilizer limits farmers' capacity to access to sufficient and appropriate fertilizer for crop production (ILRI, 1997; Longtau et al., 2002). This alongside population drastic increased has led farmers to explore lands initially considered waste. In recent times human activities became obvious at inselbergs. With the exploration of inselbergs by humans, this granite has always been given less attention in scientific studies especially the aspect of soil ecology (Tanko, 2012).

Odunze (2003) opined that the soils in the Northern Guinea Savanna have dominantly Kaolite clays and are sandy to sandy-loam in texture. They have low available soil moisture retention capacity and encourage leaching of nutrients away from the rooting depth of most crops. The soils therefore become degraded due to effects of soil erosion, deforestation, overgrazing, nutrient mining and poor soil management strategies applied by farmers. This study therefore aimed at the bridging gap in the knowledge of soil ecology of Inselbergs in the Nigerian Guinea savanna.

MATERIALS AND METHODS

Study site

Dumbi inselbergs are located near Dumbi village about 19 kilometers away from Zaria along the Zaria-Kaduna highway. It is located on Longitude 07°39.21′ E to 07°39.23′ E and Latitude 10°32′54" N to 10°56′.98" N and has an altitude of 756.82 m above sea level and 111.56 m above the surrounding area. The area has two major seasons, the dry season which usually starts in October and lasts till early April and the rainy season which commences from late April and ends in October.

The area normally experiences Harmattan during the dry season which starts in December to late February when the lowest annual temperature of 25.6°C is recorded. Shortly after the Harmattan is a period of extreme heat which lasts for about 2 months and that is the period during which the highest annual temperatures of 38°C was recorded.

Determination of the mineral composition of the soil

A total of 16 soil samples were collected at four locations with a soil auger at depths 0 to 15 cm, 15 to 30 cm and 30 to 45 cm depth at both the unfarmed windward, unfarmed leeward and the cultivated plots along two diagonals of the study plot. However, soil from the Inselbergs was taken from 0 to 15 cm and 15 to 30 cm depth only because the soil on the Inselbergs was usually not up to 45 cm deep. Location 1 comprised soil in the windward side of the main rock outcrop, the second location was soil from the leeward side of the main rock outcrop, the third location was soil that had collected on the rock surface and the forth location was soil from a cultivated land adjacent to the main rock outcrop. Soil samples were homogenized, air dried, ground and sieved through 2.0 mm sieve to obtain subsamples less than 2.0 mm in diameter (Smart, 2012). The smaller than 2mm fractions were used for soil pH, particle size distribution, cation exchange capacity, exchangeable bases and exchangeable acidity determination.

Analytical procedures

Analytical procedures are given in Table 1.

Statistical analysis

Data obtained were subjected to Analysis of Variance (ANOVA) using the General Linear Model procedure of SAS 9.3 software (SAS, 2011). Differences between means were separated using

Table 1. Analytical procedures.

Physical and chemical parameters	Techniques/procedures used
Particle size distribution	Bouyoucos hydrometer method (Gee and Bauder, 1986; Jackson and Raw 1996). Where core samples could not be obtained, clod method of Blake (1965) was used
Textural classes	These were obtained from textural triangle using USDA (1975) approach.
Soil pH	pH meter techniques by Day (1965) and Bates (1954). This was done by dipping the pH meter in water and 0.01 M $CaCl_2$
Electrical conductivity	pH meter technique by Day (1965)
Soil organic carbon	This was determined by dichromate oxidation method as described by Nelson and Sommers (1982)
Cation exchange capacity	Exchangeable Cation were extracted with 1N NH_4 OAc saturation method (Chapman, 1965).
Exchangeable Calcium and Magnesium	These were determined by EDTA titration method (Agbenin, 1995; Smart, 2012),
Potassium and sodium	Determined using flame photometry (Anderson and Ingram, 1993).
Exchangeable acidity	Determined by shaking soil in 0.01 M KCl and filtrate was titrated with 0.1MNaOH (Agbenin, 1995).
Sodium Absorption Ratio, SAR	SAR = Exchangeable $\{Na^{+} / \sqrt{1/2}\ (Ca^{2+}\ Mg^{2+})\}$ (Oster and Posito, 1980)
Exchangeable Sodium Percentage, ESP	ESP= Exchangeable {Na / Ca+ Mg + K + Na} × 100 (Oster and Posito, 1980)

Duncan Multiple Range Test at 5% level of probability.

RESULTS

Physical and chemical characteristics of the soils

Particle size and textural class of soils

There was higher percentage of clay (28.93%) in the windward plot followed by the cultivated plot (23.40%), while the soil on the rock outcrop had the least clay content. The high clay content in the windward plot differed significantly ($P < 0.05$) from the clay content of the leeward plot, rock outcrop plot and the plot in cultivated land. Clay content was seen to increase with depth from 0 to 45 cm and this variation in clay content between the depths was significantly different ($P < 0.05$) as shown in Table 1.

Silt content was also higher (12.90%) in the windward plot and was least in the cultivated plot (3.61%). The percentage silt in the windward, leeward and the rock outcrop plots did not differ significantly but there was significant difference ($P < 0.05$) between these three plots and the cultivated plot. Silt was higher in the top-soil (0 to 15 cm) than in the sub-soil, but this difference was not significant ($P > 0.05$) as seen in Table 2.

Percentage sand was higher in the cultivated plot (72.99%) while the windward plot had the lowest (58.17%) percentage sand. Percentage sand in the windward plot differed significantly ($P < 0.05$) from that of the leeward plot, rock outcrop and the plot in the cultivated farmland. Sand distribution in the soil profile showed that percentage sand decreased significantly ($P < 0.05$) with increase in depth. Table 2 is the soil textural class.

The windward plot and the plot in the cultivated farmland had similar textural class (sandy-clay-loam), while the leeward and the rock outcrop both had sandy-loam soils. With respect to depth, the top soil was sandy-loam, while the sub-soil was sandy-clay.

Chemical composition of the soils

The pH of the soils ranged between 5.4 and 6.0 in all the four sample plots. The pH of the soil in the cultivated farmland differed significantly ($P < 0.05$) from the soil pH

Table 2. Distribution of particle size and textural class of the soils of the study site.

Treatments	%Clay Mean ± SE	%Silt Mean ± SE	%Sand Mean ± SE	Textural class USDA.NRCS (1992)
Bulk soil				
Windward site plot	28.93 ± 0.020^{A}	12.90 ± 0.020^{A}	58.17 ± 2.060^{B}	Sandy Clay Loam
Leeward site plot	20.11 ± 0.020^{B}	10.95 ± 0.030^{A}	68.94 ± 2.520^{A}	Sandy Loam
Rock outcrop plot	19.68 ± 0.030^{B}	8.37 ± 0.040^{A}	71.95 ± 3.090^{A}	Sandy Loam
Cultivated farmland plot	23.40 ± 0.030^{B}	3.61 ± 0.040^{B}	72.99 ± 3.570^{A}	Sandy Clay Loam
Depths (cm)				
0-15	13.37 ± 0.020^{C}	22.24 ± 0.020	64.39 ± 2.060	Sandy Loam
15-30	26.56 ± 0.020^{B}	18.20 ± 0.020	55.24 ± 2.060	Sandy Clay Loam
30-45	32.95 ± 0.030^{A}	19.48 ± 0.040	47.58 ± 3.090	Sandy Clay Loam

Means with the same superscripts along the vertical columns are not significantly different at 0.05% level.

of the windward, leeward and the rock outcrop but, did not differ significantly (P > 0.05) as soil depth increased. The soil pH (H_2o) had values of between 5.4 and 6.0, while pH ($CaCl_2$) ranged between 4.8 and 5.1.

The organic carbon content was generally very low (<10 gkg^{-1}) in the windward, rock outcrop and the cultivated farmland plots but was moderate (10.5 gkg^{-1}) in the leeward plot. These differences in organic matter content between the plots were not significant (P > 0.05). The organic carbon decreased with increase in depth, 0 to 15 cm having a moderate organic content while 15 to 45 cm had lower organic carbon. The decrease in organic matter with depth was significant (P < 0.05) between plots.

Soil Electrical Conductivity did not differ with location. Electrical Conductivity of the four plots sampled indicated low salinity (<4 dsm^{-1}) and a similar trend was observed along the depths (Table 3). Exchangeable calcium content of the soil was high (>5 cmol 10 kg^{-1}) in the windward plot, but medium (2.94 to 3.32 cmol 10 kg^{-1}) in the other plots sampled, though the differences were not statistically significant (P > 0.05). The exchangeable calcium was generally not high at all the three soil depths. However, at depth 0 to 15 cm and 30 to 45 cm Ca values (4.57 and 4.23 cmol 10 kg^{-1}) were higher than at depth 15 to 30 cm (2.76 cmol 10 kg^{-1}), though not significant (P > 0.05).

Exchangeable Magnesium (Mg) was seen to be generally high (>1 cmol 10 kg^{-1}) in all the four sample plots. Exchangeable Mg was also generally high at all three depths categories, and significantly increased with increase in depth (P < 0.05).

Exchangeable Potassium (K) was generally moderate in all the four plots and the three depth categories sampled. Exchangeable K values appeared higher in the windward plot when compared to other locations, but this was not statistically significant (P>0.05).

Exchangeable Sodium (Na) in the soils ranged between 0.36 and 0.46 cmol 10 kg^{-1} in the four plots sampled. This is within the range of high Na availability in soils. The Exchangeable Na was high at all the depth categories of the soil (>0.3 cmol 10 kg^{-1}). The detail of exchange cations is shown in Table 4.

Sodium Absorption Ratio (SAR), Exchangeable Sodium Percentage (ESP) and Exchangeable Acidity between the plots and within the soil depth did not differ significantly (P > 0.05). The ESP was seen to increase in depth as can be seen in Table 5.

DISCUSSION

Soil chemical and physical composition

Soil reaction

The comparatively higher acidic reaction of cultivated soil (plot 3) of the Dumbi inselberg compared to soil of leeward, windward and outcrops could have resulted from added amendments to provide nutrients for arable crops. A cultivated area usually receives soil amendments like inorganic and organic fertilizers during crop farming. Accumulation of these soil amendments may be the probable reason for low pH value. Iwuafor et al. (2006) reported that application of nitrogenous forms of inorganic fertilizer will lower pH and accelerate acidity in soils. The higher acidity in the cultivated plot suggests that the soils need to be amended to restore the pH values to a range between 5.6 and 7.3. Low pH in the cultivated plot may be due to low organic matter content. Organic matter helps to keep the pH higher (Fagawalawa et al., 2014). Smart (2012) also observed lower pH and Organic carbon in cultivated plot.

Soil pH values were generally moderately acidic throughout the profile (0 to 45 cm). Such pH values were recommended by Odunze et al. (2004) as being conducive for plant growth especially in the northern Guinea savanna.

Table 3. Chemical characteristics of soils in the Dumbi Inselbergs and their environs.

Treatments	Soil pH H_2O Mean ± SE	Soil pH $CaCl_2$ Mean ±SE	Organic carbon (g kg^{-1}) Mean ±SE	Electrical conductivity (dsm^{-1}) Mean ±SE
Bulk soil				
Plot on windward side	5.98 ± 0.003^{A}	4.98 ± 0.005	8.9 ± 0.006	0.05 ± 0.001
Plot on leeward side	5.96 ± 0.004^{A}	5.08 ± 0.006	10.5 ± 0.007	0.10 ± 0.001
Plot on the rock outcrop	6.02 ± 0.005^{A}	5.10 ± 0.07	7.7 ± 0.009	0.06 ± 0.001
Plot in a farmland	5.37 ± 0.005^{B}	4.76 ± 0.008	6.8 ± 0.010	0.03 ± 0.002
Depths (cm)				
0-15	5.88 ± 0.003	5.05 ± 0.005	13.2 ± 0.006^{A}	0.10 ± 0.001
15-30	6.02 ± 0.003	5.04 ± 0.005	6.2 ± 0.006^{B}	0.04 ± 0.009
30-45	5.67 ± 0.005	4.79 ± 0.007	5.1 ± 0.009^{B}	0.04 ± 0.001

Means with the same superscripts along the vertical columns are not significantly different at 0.05% level.

Table 4. Exchangeable cations of the soils of the Inselbergs and their environs (cmol 10 kg^{-1}).

Treatments	Calcium Mean ± SE	Magnesium Mean ± SE	Potassium Mean ± SE	Sodium Mean ± SE
Bulk soil				
Plot on windward side	5.03 ± 0.030	3.10 ± 0.010	0.25 ± 0.001	0.46 ±0.001
Plot on leeward side	3.32 ± 0.030	2.39 ± 0.010	0.23 ± 0.001	0.38 ± 0.001
Plot on the main rock outcrop	2.29 ± 0.040	2.32 ± 0.020	0.21 ± 0.002	0.41 ± 0.002
Plot in a cultivated farmland	2.294 ± 0.050	2.30 ± 0.020	0.19 ± 0.002	0.36 ± 0.002
Depths (cm)				
0-15	4.57 ± 0.030	2.55 ± 0.010^{AB}	0.25 ± 0.001	0.42 ± 0.001
15-30	2.76 ± 0.030	2.33 ± 0.010^{B}	0.20 ± 0.001	0.42 ± 0.001
30-45	4.23 ± 0.040	3.65 ± 0.020^{A}	0.24 ± 0.002	0.39 ± 0.002

Means with the same superscripts along the vertical columns are not significantly different at 0.05% level.

Table 5. Sodium absorption ratio, exchangeable sodium percentage and exchange acidity of the soil.

Treatments	Sodium absorption ratio (SAR) Mean ±SE	Exchangeable sodium percentage (ESP) (%) Mean ±SE	Exchange acidity Al^{3+} + H^{+} ($cmolkg^{-1}$) Mean ±SE
Bulk soil			
Windward side (plot 1)	0.25 ± 0.001	11.33 ± 0.090	0.06 ±0.000
Leeward side (plot 2)	0.24 ± 0.001	6.81 ± 0.110	0.07 ± 0.001
Rock outcrop (plot 3)	0.27 ± 0.002	7.93 ± 0.140	0.08 ± 0.001
Cultivated land (plot 4)	0.02 ± 0.002	6.33 ± 0.160	0.06 ± 0.001
Depths (cm)			
0-15	0.25 ± 0.001	6.25 ± 0.009	0.06 ± 0.000
15-30	0.27 ± 0.001	7.59 ± 0.009	0.08 ± 0.000
30-45	0.21 ± 0.002	9.21 ± 0.140	0.05 ± 0.001

Soil organic carbon contents and cation exchange capacity

The distribution of the soil organic matter shows that location of sampling has no significant effect on its distribution. However, the soil organic matter content was medium in status at the leeward side while, in all the other location, the soil organic matter was low. Medium soil organic content recorded at the top (0 to 15 cm) soil was expected because organic debris accumulates at the top of the soil before they are decomposed '*in-situ*'. Hence top soils usually have a high soil organic matter content. This could also be associated with land use type (Fagawalawa et al., 2014).

Calcium and Magnesium ions were high in plot 1 but medium in the other three plots. Magnesium was seen to increase significantly with depths; this was probably due to leaching, since the study site is usually water log at the peak of the rainy season. High Sodium in all the four plots and in all the depths may be due to chemical fertilizers used on the cultivated plot and nearby farms which is washed off and deposited on the study site. High Sodium can result in soil dispersion, exposing them to erosion. Odunze et al. (2004) reported that the soils of the Northern Guinea savanna have low total nitrogen, organic carbon, available phosphorus and cation exchange capacity. Soil with these characteristics are said to have poor fertility status and very low buffering capacity.

Soil sodicity/alkalinity

Sodium Absorption Ratio and the Exchangeable Sodium Percentage (ESP) values which are measures of soil sodicity showed that soils at the sampling site were non-sodic/alkaline (<15%). The same observation was made for the soil in all the depths. Exchangeable Sodium percentage >15% will lead to soil dispersion which will in turn result in poor water infiltration rate and sodium toxicity to plants. Soil sodicity occurs naturally and can be increased by human activities such as irrigation. It is caused by the presence of sodium attached to clay in the soil. It only becomes a problem when there is sufficient sodium attached to the clay to affects soil structure. This low sodicity recorded at the Dumbi inselbergs and its surrounding may probably be due to absence of farming in plots 1, 2 and 3 which implies that chemical fertilizer which is one of the causes of alkalinity in soil was low in these three plots when compare with the cultivated plot. The waterlogged nature of the soil could also result in leaching of the inorganic fertilizers, leading to low sodicity.

Soil particle size and soil textural class

Clay contents in the windward plot differed significantly with the leeward, rock outcrop and the cultivated plot. Surface run-off and wind probably must have deposited clay particles at the windward site. The increased of clay contents with depth at the windward could cause infiltration and percolation problems, hence waterlogging at the peak of the rains. Odunze et al. (1996) also observed increased of clay contents with depth and concluded that increase in subsoil clays could cause impaired drainage at such shallow depths, especially at the peak of the rainy seasons.

Silt contents in plots 1, 2 and 3 were significantly higher than that of plot 4 (farmed area). The main rock outcrop slopes towards the windward plot. During the process of soil formation, disintegrated rock particles from the rock are first deposited as sand which later will disintegrate to silt and finally to clay. The weathered rock particles are washed down to plots 1, 2 and 3. The clay particles are leached in to the sub-soil followed by the silt and sand particles accumulate at the top soil. The sand particles are easily washed by rain water depositing them at the farmed area hence, the possible reason for high sand contents at the farm plot and higher silt in plots 1 and 2. The high silt values observed in plots 1, 2 and 3 may account for soil crusting observed in these three plots.

The surface soils were dominantly sandy and had sandy loam in texture. Odunze (2003) who studied the soils of Northern Guinea savanna obtained a similar result and said that such a soil has low soil moisture retention capacity and encourage leaching of nutrients away from the rooting depth of most crops as the root zone of most crops penetrates to a little less than 50 cm. The soils become degraded probably due to effects of soil erosion, overgrazing, nutrients mining and poor soil management strategies adopted by farmers.

The study has revealed some important aspects of the ecology of inselbergs to another level. The major factor identified was anthropogenic activities, such as farming and overgrazing. The soil characteristics of the study site revealed the nutrients level to be lower than what is expected of forest outlier often associated with inselbergs' habitat, rather it corresponds with other soils of the Savanna woodland and can only support crops that grow in poor nutrients soil. This study will form a baseline for further studies on inselbergs.

With these, the following recommendations are made; Completely protected inselbergs should be set aside for in-situ conservation of their biodiversity. Rural communities should be encouraged to establish and own plantations for fuelwood and other wood products. The three tiers of government and NGO's can design a way of assessing and compensating communities or individuals that embark on such projects to encourage participation.

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