Journal of Scientific Research & Reports

20(4): 1-10, 2018; Article no.JSRR.42888
ISSN: 2320-0227

Properties and Conservation Needs of Wetland Soils along Kaduna River, Northern Guinea Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author PNE designed the study, performed the field work, wrote the protocol, and wrote the first draft of the manuscript. Authors PNE and PIE managed the analyses of the study. Author FCO managed the literature searches, contributed data and analysis tools. Author FCO wrote the final manuscript. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JSRR/2018/42888
Editor(s):
(1) Dr. Luigi Rodino, Professor of Mathematical Analysis, Dipartimento di Matematica, Università di Torino, Italy.
Reviewers:
(1) Ana Leônia de Araújo, Universidade Federal do Ceará, Brazil.
(2) Rebecca Yegon, University of Embu, Kenya.
(3) Diony Alves Reis, Federal University of Western Bahia, Brazil.
Complete Peer review History: http://www.sciencedomain.org/review-history/26653

Original Research Article

Received 23 June 2018
Accepted 15 September 2018
Published 15 October 2018

ABSTRACT

The purpose of the study was to evaluate properties of wetland soils along River Kaduna and suggest management needs for environmental sustainability. Two sites were identified based on their use for arable agriculture and two profile pits were excavated in each. Soil samples were collected from the identified pedogenetic horizons. A total of 16 samples were bagged and subjected to physical and chemical analysis. The results showed that the soils were influenced by hydromorphic conditions which resulted in mottled colour features. The soils were predominantly sandy clay loam with silt and clay contents increasing at the lower horizons and otherwise for sand contents. Soil reaction ranged from strongly to slightly acidic at both sites (4.4-6.3). Organic carbon values were generally higher at the topsoils but do not follow any particular

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trend down the profiles. Total nitrogen was generally low while available phosphorus values ranged from low to moderate. Exchangeable bases were generally low except the magnesium contents which had high values. The cation exchange capacity was moderate to high while percentage base saturation ranged from low to moderate. For sustainable crop production in the study area, the application of organic matter complimented by split application of inorganic fertilizers is recommended.

Keywords: Crop production; environmental sustainability; land use; soil properties.

1. INTRODUCTION

The need to provide food of crop and animal origin to meet ever growing human demands necessitates opening up of lands hitherto uncultivated including marginal lands. In many cases, especially where high population densities have led to overcrowding of existing farm lands, agricultural intensification has inevitably resulted [1]. This also resulted in changing patterns of agricultural production from the traditional subsistence farming to mechanized farming occasioned by population and/or market driven intensification. Improved systems of agriculture are increasingly gaining national and international support in many parts of Africa including Nigeria. The potential of Nigeria wetlands (f*adamas*) has been observed as an alternative and competitive usage for crop farming, grazing and fishing [2,1]. Wetland soils constitute vast under-exploited and sometimes undiscovered ecologies in Nigeria. It is estimated that Nigeria's floodplain areas cover 65.785 km^2 translating to 7.2% of the total land area of the country [3]. Some of the soils are indeed waterlogged, low in pH values; low in phosphorus values with insipient problems of salinity and sodicity [4]. Other studies observed that wetland soils are mainly composed of organic matter which may vary in the horizons due to its transport and storage within and across the soil profile [5]. Both horizontal and vertical variability of soil properties have been studied in temperate soils [6] with other works and literature available on the variability of Nigeria soils [7,8]. In all the studies estimating the nutrients in the complex heterogeneous system of wetlands, a pedological and ecological significance have been observed. The distributions of nutrients in soils are influenced by a number of factors comprising parent material, topography, soil management practices, biota, climate and precipitation.

The characterization of wetland soils relating to elemental distribution in soil profiles will provide useful information for assessment and monitoring of the behaviour and fertility status and help to predict the suitability of soils for agricultural uses [9]. Hence, the aim of this study is to evaluate some physicochemical properties of selected soils along River Kaduna, Nigeria as a pre-requisite to their sustainable utilization and to ascertain its conservation needs.

2. MATERIALS AND METHODS

2.1 Study Site

The study sites were the riverine alluvial floodplains along the Kaduna River, Kaduna, Nigeria which lies within latitudes 10^o 26' and 10^o 30' N and longitudes 7^o 25' E and 7^o 30' E (Fig. 1). Achi et al. [10] reported that the mean annual rainfall of the area ranged from 924.3 to 1,543.6 mm while annual temperature varies between 29^{0C} to 38^{0C}. The spatial and temporal distribution of the rain varies, decreasing from an average of about 1530 mm in Kafanchan-Kagoro areas in the Southeast to about 1015 mm in Ikara Makarfi districts in the northeast. High storm intensities (ranging from 60 mm/hr to 99 mm/hr) due to the A_w tropical continental climate according to Koppens classification (1928) plus the nature of surface run off build up the good network of medium sized river systems. High evaporation during the dry season, however, creates water shortage problems. The soils are rich in kaolinitic clay and organic matter, very heavy and poorly drained, characteristics of Vertisols [11]. Land clearing for agricultural purposes is by slash-and-burn technique while soil fertility regeneration is mainly by bush fallowing whose length has decreased due to anthropogenic activities. Agricultural land use is mainly: rainfed; for arable cropping, plantations, and pasture while irrigated agriculture pertains to sugarcane, rice, plantain etc.

2.2 Field Work

A reconnaissance survey of the area was carried out with the aid of a topographic map of Kaduna South Local Government Area of Kaduna State,

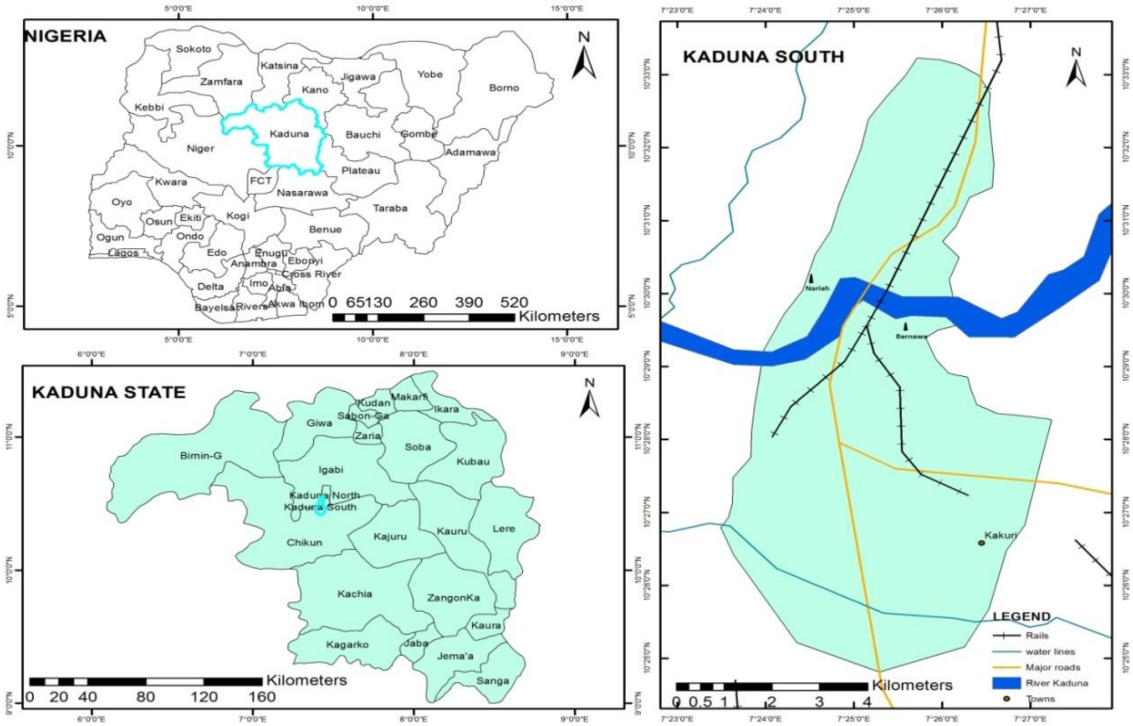

Fig. 1. Location of study area

Nigeria. Two locations were selected for the study namely Nariah and Barnawa (Fig. 1) and two pits were dug in each of the location. A total of four profile pits were therefore obtained. All sampled points were geo-referenced with the Garmin Geographic Positioning Systems (GPS) and designated NA_1, NA_2, BA_1, and BA_2. A total of 16 genetic horizons were identified and described with the aid of FAO [12] guidelines. The morphological characteristics of each profile pit such as soil depth, drainage, colour, mottle, structure, consistency, concretions, cutans, pores, roots and horizon boundary were described in the field. Bulk samples for physico-chemical analyses were collected from the identified genetic horizon. The samples were later air-dried, crushed and sieved through a 2 mm sieve. The fine earth fraction was subjected to standard laboratory procedures at the Soil Science Laboratory, University of Nigeria Nsukka.

2.3 Laboratory Procedures

Particle size distribution was determined by hydrometer method as described by Gee and Bauder [13] using sodium hexametaphosphate as a dispersant. The pH was determined in distilled water using soil/liquid ratio of 1: 2.5. Organic carbon was determined by the Walkley and Black oxidation method as modified by Allison [14]. Total nitrogen was determined by the Kjeldahl method [15], while the exchangeable bases were determined by the complexometric titration method as described by Chapman [16]. The CEC was determined by the ammonium acetate method of Jackson [17]. Available P was extracted by Bray-1 method [18] and determined colorimetrically with a spectrophotometer.

3. RESULTS AND DISCUSSIONS

3.1 Morphological and Physical Properties

Morphological and physical properties of the pedons are presented in Table 1. The pedons were deep and slightly well drained but did not exceed 180 cm before hard pans were encountered. In all the profiles, hydromorphic features were observed (mottling and gleying), associated with periodic fluctuations in ground water positions during wet periods of the year (Aquic conditions). According to the Munsell notation, the predominant hue was 10YR (yellowish) associated with the presence of sesquioxides in hydrated form, especially the geothite. The colours (dull yellowish brown, dull grayish brown, light brown gray, orange and brown) are associated with oxidized soils resulting from flooded fields with water table below 1m soil depth at most parts of the year [19]. The surface colour (moist) was characterized by a dull yellowish brown colour (10YR 4/3) in NA_1 and brownish grey colours (10YR 5/4) in NA_2. The profile surface colours were light brown gray (7.5YR 7/2) and dull yellow brown (10YR 5/4) for BA_1 and BA_2 respectively. The subsurface layers however, graded into shades of brown, orange, gray and yellowish brown colours irregularly that are associated with oxidized conditions of soils rich in red clay and then brown colours were mainly due to high magnetite content in the soils.

The soil textures were loamy ranging from sandy clay loam, followed by sandy loam, clay loam and loam. Fine sand fractions dominated the total sand content across the locations (Table 1). This implies lesser problems in germination of seed, use of mechanical implements in the field and water movements. The percentage contents of clay and silt generally increased down the profiles' depths. This could be as a result of weathering of sand and argilluviation [20]. The clay bulge (argillic horizons) developed in all the profiles may be attributed to its high amount of rainfall and movement of pedogenic clay. Similarly, erosion of fine particle by surface run off down the slope from the crestal position has been observed to be predominant factor information of soils in the area [21]. The relationship between rainfall, drainage and dispersible clay movements has been observed [22,23].

3.2 Chemical Properties

The chemical properties of the pedons are shown in Table 2. The results of the chemical properties obtained were compared against the rating scales given by Chude et al. [24] and Enwezor et al. [25] (Table 3). Soil pH values ranged between 4.4 and 6.3, indicating the soils were very strongly to slightly acidic in reaction. The pH value of NA ranged from 4.4 to 5.6 (very strongly to moderately acidic), while the pH values of BA soils ranged from 5.0 to 6.3 (strongly acidic to slightly acidic). The strong acidity might have been caused by a high level of leaching of non-acid cations and application of acidifying fertilizers in crop cultivation. Continual increase in acidity will affect plant availability of most soil nutrients especially phosphorus, nitrogen, sulphur and other micronutrients by increasing their mobility [26]. The pH values obtained in this study are similar to earlier findings by Mohammed and Jimoh [27] in soils of the area. The top soils, however, had higher pH values compared to the subsoils. At NA_1, the top soils were strongly acidic (5.2) and very strongly acidic at the subsoil (4.7) while at NA_2, the top soils and subsoils were very strongly acidic at 4.8 and 4.4 respectively. Similarly, at BA_1 the top soils ranged from moderately acidic (5.6) at the top soil to very strongly acidic (5.0) at the subsoils whereas; at BA_2 top soils were slightly acidic (6.3) and moderately acidic (6.0) at the subsoil. The higher non-acidity on the some profile top soils may be as a result of deposition of bases through litter fall and flood deposits [23].

The soil organic carbon values ranged from 1.01 to 5.70 gkg^{-1} and are rated very low to low based on Chude *et al.* [24]. At NA_1, SOC values ranged from 1.02 to 4.69 gkg^{-1} whereas at NA_2, the values ranged from I.68 to 5.70 gkg^{-1}. At BA_1, SOC values ranged from 1.02 to 4.69 gkg^{-1} while at BA_2, the values ranged from 4.02 to 4.36 gkg^{-1}. The low organic matter contents of the soils are indicative of very high biological degradation of organic matter in the soils. This may be as a result of high temperatures that rapidly breakdown organic matter, inhibiting nitrogen fixation by rhizo-bacteria in savanna ecologies [28]. The organic carbon contents were generally higher at the top soils and decreased irregularly with depth at the subsoils. This may be linked to the deposition of parent materials, residue and organic materials periodically [29,30]. The total nitrogen contents was rated low to medium and ranged from 0.42 to 0.1.68 gkg^{-1}. At NA_1, the values were rated low to moderately low (0.42 to 1.54 gkg^{-1}). At NA_2, the concentrations of total nitrogen were rated low to medium (0.42 to 1.68 gkg^{-1}). Generally, the BA soils had higher values of total soil nitrogen compared to NA, ranging from 1.26 to 1.68 gkg^{-1} (BA_1) and 0.98 to 1.40 gkg^{-1} (BA_2). The low status of nitrogen could be due to leaching, volatilization and other forms of nitrogen losses as a consequence of its high mobility [28]. The irregular decrease of total nitrogen values with depth is consistent with previous reports on wetlands [31,23]. They further observed a correlation between total nitrogen and soil organic matter. Available phosphorus ranged from 3.7 to 13.99 $mgkg^{-1}$ and was rated low to moderate. At NA_1, the values ranged from 4.66 to 11.19 $mgkg^{-1}$ (low to moderate), while at NA_2, the values ranged from 5.6 $mgkg^{-1}$ (low) to 7.46 $mgkg^{-1}$ (moderate).

Table 1. Soil morphological and physical properties of the profile pits in Nariah (NA) and Barnawa (BA)

Description	Horizon	Depth (cm)	Colour	%Clay	%Silt	%Fine sand	%Coarse sand	T.C
NA_1	Ap	0 – 45	10 YR 4/3 Dull Yellow Brown	22	15	44	19	SCL
	B	45 – 72	10 YR 4/2 Dull Yellow Brown	32	21	33	14	SCL
	BC	72 – 121	10 YR 7/3 Dull Yellow Orange	32	33	21	14	SCL
	Bt1	121 – 168	7.5 YR 6/5 Orange	34	35	19	12	CL
	C	168 – 180	7.5 YR 6/6 Orange	34	21	35	10	SCL
NA_2	Ap	0 – 18	10 YR 5/1 Brownish Gray	18	9	66	7	SL
	Bt1	18 – 57	10 YR 7/2 Dull Yellow Orange	26	9	56	9	SCL
	B	57 – 116	10YR 5/3 Dull Yellow Brown	32	33	15	20	SCL
	C	116-155	2.5 YR 5/2 Dull Grayish Yellow	32	29	23	16	SCL
BA_1	Ap	0-24	7.5 YR 7/2 Light Brown Gray	18	27	36	19	SL
	Bt1	24 – 65	10 YR 5/3 Dull Yellow Brown	32	29	27	12	CL
	BC	65 –113	10 YR 5/3 Dull Yellow Brown	30	35	24	11	SCL
	C	113 – 162	7.5 YR 7/2 Light Brown Gray	16	9	56	19	SL
BA_2	Ap	0 – 32	10 YR 5/4 Dull Yellow Brown	30	35	17	18	SCL
	Bt1	32 – 80	10 YR 4/4 Brown	30	25	28	17	SCL
	Bt2	80-148	10 YR 4/4 Brown	26	39	21	14	L

Table 2. Soil chemical properties of profile pits in Nariah (NA) and Barnawa (BA) locations

Profile	Horizon	Depth(cm)	pH H2O	pH KCl	OC (%)	TN(%)	Exchangeable Bases				CEC (cmol kg^{-1})	B. S. (%)	H^+ (cmol/kg^{-1})	AP (mg kg^{-1})
							Na	K	Ca	Mg				
							← (cmol kg^{-1}) →							
NA_1	Ap	0 – 45	5.2	4.0	4.69	1.12	0.02	0.13	2.2	0.6	12.4	23.76	1.4	11.19
	B	45 – 72	4.7	3.6	3.35	0.70	0.02	0.10	2.4	1.6	18.8	21.93	4.8	6.53
	BC	72 – 121	5.0	4.0	2.01	0.60	0.02	0.08	2.8	1.4	16.0	26.86	4.8	5.6
	Bt1	121 – 168	5.5	4.2	1.02	0.42	0.02	0.08	3.4	1.6	24.4	20.92	2.2	4.66
	C	168 - 180	4.7	3.7	2.01	1.54	0.3	0.07	3.4	2.4	19.6	30.17	4.4	5.6
NA_2	Ap	0 – 18	4.8	3.7	5.70	0.84	0.04	0.11	2.6	2.6	32.4	20.52	4.4	6.53
	AB	18 – 57	4.4	3.5	4.02	1.68	0.04	0.07	2.4	3.4	22.0	26.28	4.0	7.46
	Bt	57 – 116	4.9	3.8	1.68	0.42	0.03	0.10	5.2	4.4	25.2	38.61	3.6	5.6
BA_1	C	116 – 155	5.6	4.5	1.68	0.70	0.01	0.09	6.8	4.6	26.0	44.23	2.0	5.6
	Ap	0 – 24	5.6	4.5	4.69	1.26	0.04	0.12	3.2	1.4	14.8	32.12	1.8	13.99
	Bt1	24 – 65	5.0	4.1	4.02	1.54	0.02	0.11	4.6	1.6	19.0	33.06	4.0	7.46
	B	65 –113	5.2	4.0	2.68	1.68	0.04	0.09	3.8	2.4	21.2	29.94	3.2	5.6
	C	113 – 162	5.5	4.2	1.01	1.68	0.02	0.10	4.2	2.2	26.0	25.08	1.6	5.6
BA_2	Ap	0 – 32	6.3	4.7	4.02	1.26	0.04	0.09	3.2	2.8	23.0	26.65	1.6	3.73
	Bt1	32 – 80	6.0	5.0	4.02	0.98	0.04	0.11	4.8	1.8	22.0	30.67	1.6	3.7
	Bt2	80 – 148	5.2	4.3	4.36	1.40	0.03	0.05	4.2	2.4	20.8	32.11	1.2	4.66

pH(H_20)- pH in water, pH(KCl) – pH in Potassium Chloride, OC - Organic carbon, TN- Total nitrogen, Na- Sodium, K- Potassium, Ca- Calcium, Mg- Magnesium, CEC- CEC-Cation exchange capacity, BS- Base saturation EA- Exchangeable acidity, Av.P- Available phosphorus.

Table 3. Critical limits for interpreting fertility levels of soil analytical parameters

Parameter	Very low	Low	Moderate	High	Very high
Ca^{2+} (cmol kg-^{1})	<2.0	2.0-5.0	5.0-10.0	10.0-20.0	>20.0
Mg^{2+} (cmol kg-^{1})	<0.3	0.3-1.0	1.0-3.0	3.0-8.0	>8.0
K^{+} (cmol kg^{-1})	<0.2	0.2-0.3	0.3-0.6	0.6-1.2	1.2-2.0
Na+ (cmol kg^{-1})	<0.1	0.1-0.3	0.3-0.7	0.7-2.0	>2.0
CEC (cmol kg^{-1})	<6.0	6.0-12.0	12.0-25.0	25.0-40.0	>40.0
Org. C (g kg^{-1})	<4.0	4.0-10	10.0-14.0	14.0-20.0	>20.0
Avail. P (mg kg^{-1})	<3.0	3.0-7.0	7.0-20.0	>20.0	
BS (%)	<20.0	20.0-40.0	40.0-60.0	60.0-80.0	80.0-100.0
ESP (%)	<0.1	0.1-2.0	2.0-8.0	8.0-15.0	>15
TN (g kg^{-1})	0.3-0.5	0.6-1.0	1.1-1.5	1.6-2.0	2.1-2.4

pH	Extremely acidic	Very strongly acidic	Strongly acidic	Moderately acidic	Slightly acidic	Neutral	Slightly alkaline	Moderately alkaline	Strongly alkaline	Very strongly alkaline
	<4.5	4.5-5.0	5.1-5.5	5.6-6.0	6.1-6.5	6.6-7.3	7.4-7.8	7.9-8.4	8.5-9.0	>9.0

Source: [26, 27]

At BA_1, the values ranged from 5.6 to 13.99 $mgkg^{-1}$ (low to moderate) while at BA_2, the values ranged from 3.7 $mgkg^{-1}$ to 4.66 $mgkg^{-1}$, indicating low concentrations. Associated with the low contents of available phosphorus may be organic carbon mineralization, sparse vegetation, low litter incorporation and short fallow period practiced in the area. Available phosphorus in the Ap horizons were 11.19 $mgkg^{-1}$ (NA_1), 6.3 $mgkg^{-1}$ (NA_2), 13.99 $mgkg^{-1}$ (BA_1) and 3.73 $mgkg^{-1}$ (BA_2), decreasing irregularly down the profiles. Higher values of AP in the top soils may be attributed to fertilizer application and organic matter deposition especially on cultivated soils. Raji [32], Hassan [33] and Maniyunda [21] reported similar findings in soils of savanna ecologies of Nigeria.

Calcium and magnesium dominated the exchange sites ranging from 2.2 to 6.8 $cmolkg^{-1}$ (low to medium) and 0.6 to 4.6 $cmolkg^{-1}$ (low to high) for Ca and Mg respectively. The dominance of Ca on the exchange sites was reported by other works in floodplains of Nigerian savanna [32,34,35]. Ca values were observed to increase with depth within the subsoil. This may be attributed to the influence of land use and leaching. Similarly, exchangeable Mg increased with increase in soil depth and was high at the uncultivated surface soils of NA_2 (2.6 $cmolkg^{-1}$) and BA_2 (2.8 $cmolkg^{-1}$) than the cultivated NA_1 (0.6 $cmolkg^{-1}$) and BA_1 (1.4 $cmolkg^{-1}$) a further suggestion that leaching and crop removal may have caused the lower quantity of Mg content in the cultivated soil.

Exchangeable sodium (Na) ranged between 0.01 and 0.04 $cmolkg^{-1}$ and was rated very low [25]. The values decreased irregularly with depth in the profiles. The irregular distribution may be related to the nature of deposited parent material and its low contents may imply low vulnerability of the soils to salinity problems.

Exchangeable K ranged between 0.048 and 0.126 $cmolkg^{-1}$ (Table 2) and rated very low based on Enwezor et al. [25]. The values were higher in Ap horizon and decreased inconsistently in the underlying horizons in soils as a result of differential depositions of flood materials [23]. Exchangeable bases were observed to occur in the order Ca > Mg > Na > K. At both locations, the CEC values were higher at the top soils. This suggests that organic matter added from litter deposition on the soil is the main contributor to the CEC of the soil. In the profiles, the concentration of cation exchange capacity was from 12.4 and 32.4 $cmolkg^{-1}$ (Table 2). According to Enwezor et al. [25], this shows a moderate to high concentration of CEC in the soil profiles studied. This observation corresponds with the findings of Akamigbo et al. [2] in fadama soils of Bauchi State which were attributed to the influence of organic matter contents at the surface and slight increases in clay content with depth.

The exchangeable acidity for the profiles ranged from 1.2 to 4.8 $cmolkg^{-1}$ (Table 2). The values increased in an irregular pattern down the profile depths. This is also attributed to different properties of deposited soil materials [23]. The EA was also observed to generally increase with a decrease in pH in the profiles. The variations in the exchangeable acidity in the horizons may be attributed to aluminosilicate clay minerals releasing Al^{3+} and H^+ into the soil solution through isomorphous substitution and leaching [36,37]. It may also be linked to the effect of nutrient bio-cycling [38].

The percentage base saturation of the soil profiles ranged from 20.52 to 44.23% (Table 2). The values according to Enwezor et al. [25] ranged from low to moderate and this may be due to differences in weathering rates, leaching rates, lateral translocation of cations with depth, previous land use as well as erosion [39].

4. CONCLUSION

Fadama soils along Kaduna River are deep and slightly well drained. The properties of the soils are mainly influenced by periodic deposition of sediments, clay movements, tillage practices, leaching and erosion. The processes resulted in depletion of organic matter and some soil nutrients required for crop yield in the area. To ensure productivity of the soils, occasional liming, incorporation of organic manure, fertilizer application and adequate tillage practices are recommended for sustainable soil management.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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