

CLASSIFICATION AND ASSESSMENT OF AGRICULTURAL POTENTIAL OF THE LOWER NIGER FLOODPLAIN SOILS OF ATANI, SOUTHEASTERN NIGERIA

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ABSTRACT

The soils of Atani floodplain in Anambra State of Nigeria contribute significantly to the food production of the State, hence the need to understand their behavior in order to enhance their management and productivity. Profile pits were sited along three physiographic units viz: levee crest, levee slope and flood basin. Soil samples were collected from the profile horizons and subjected to standard laboratory procedures. Characterization of the soils was based on their morphological, physical and chemical properties. Soil classification was carried out using the USDA Soil Taxonomy and correlated with FAO/IUSS World Reference Base. Its agricultural potential was assessed using the fertility capability classification. The soils were deep. Topsoil colour was dominantly blackish black (10YR 3/2). Mottles were pervasive; an indication of impeded drainage conditions. The soils were predominantly fine textured. Soil pH values ranged from 4.8 to 6.2. Exchangeable Calcium was low to moderate (2.6-8.2 cmol kg⁻¹); Magnesium was moderate to high (1.6-6.8 cmol kg⁻¹); Sodium was high to very high (1.0-2.5 cmol kg⁻¹), while potassium was high (1.2-4.2 cmol kg⁻¹). Cation exchange capacity values ranged from 11.6 to 42.6 cmol kg⁻¹. Total nitrogen was very low to low (0.14-1.12 g kg⁻¹), while organic carbon was low to moderate (0.4-15.2 g kg⁻¹). Available phosphorus was very low to high ranging from 0.93 to 31.71 mg kg⁻¹ while base saturation ranged from 64 to 93%. The soils were classified as Typic Fluvaquents (Typic Fluvisols), Fluvaquentic Endoaquents (Endostagnic Cambisols) and Fluventic Endoaquents (Endostagnic Cambisols) according to the USDA and FAO/IUSS. The fertility capability evaluation of the soils revealed that the pedons were Lgn in classification due to limitations in drainage.

Key words: alluvium, cambic horizon, Inceptisols, lithologic discontinuity

INTRODUCTION

The slow pace of agricultural growth and development in Nigeria has been attributed to lack of adequate resource information (Fagbami, 1986; Medugu, 2006). A sound resource judgment is a prerequisite for adequate land use planning. Recently emphasis has shifted from uplands to floodplains due to characteristics such as fine-scale slopes, stability of moisture conditions, climate and nutrient supplies through fluvial processes (Akamigbo *et al.*, 2001; Idoga and Azakagu, 2008, Moustakidis, 2016). Rivers at some time during the year overflows its banks, leading to differential deposition of parent material. The deposition pattern is influenced by fine-scale topographic variation and distance from the river channel which results in large differences in patterns of silt and clay

distribution (Stoeckel and Miller-Goodman, 2001; Ajiboye *et al.*, 2012). Hence, the complex natures of alluvial soils have given rise to large variations in properties over short distances; a major determinant of soil productivity (Udo *et al.*, 2006, Dengiz, 2010). The diverse characteristics of depositional lowlands perhaps had triggered the interest of scientists to embark on studies related to toposequence (Lima *et al.*, 2002; Umeugochukwu, 2009; Layzell and Eppes, 2012).

The Lower Niger floodplain at Atani is drained mainly by the River Niger and its tributaries and is highly cultivated. Due to annual flooding, soils formed along the slope often vary greatly in pedological, chemical and mineralogical characteristics as well as land use. Some attempts made to characterize and classify the soils have

highlighted such variations in properties (Asadu, 1989, Buri *et al.*, 1999, Igwe *et al.*, 2006) and identified Ultisols and Inceptisols in Atani floodplains following the U.S. Soil Taxonomy.

However, no study has considered the fine-scale topography and distance from river channel which often influences land use in the region. Such systematic classification and characterization will inform land users and managers on how best to use and protect such areas. Thus, the objective of this study was to evaluate the properties of the soils, classify, establish fertility capability classes and suggest management options in relation to land positions for their sustainable productivity.

MATERIALS AND METHODS

Study Site

The study site was the bank of the River Niger at Atani in Ogbaru LGA of Anambra State. It lies within latitudes 5° 58' and 6° 06' N and longitudes 6° 41' E and 6° 51' E along the Lower River Niger Basin south of Onitsha town, 18.5 km west of Nnewi town and is part of a floodplain which extends more than 1000 km² (Figure 1). The annual rainfall of the area ranges from 1500 mm to 3000 mm and annual temperature from 20.8°C to 35°C (Nigeria Meteorological Agency, 2013). The seasonal wet (April to October) and dry (November to March) tropical climates subject the site to flooding during the rainy season and complete drying during the dry season (Okeke *et al.*, 2011). Hence the soil moisture regime is aquic while the soil temperature regime is isohyperthermic. The parent material is Alluvium from the Niger River sediments. The dominant clay mineral is kaolinite while smectite, illite, quartz and aluminium-smectite have also been identified (Asadu, 1989, Igwe *et al.*, 2006). Ogbaru is predominantly an agrarian community. The major arable crops grown include yam (*Dioscorea* spp.), cassava (*Manihot esculenta*), rice (*Oryza sativa*), cocoyam (*Colocasia esculenta*), maize (*Zea mays*), melon (*Citrullus vulgaris*) and vegetables. Tree crops include oil palm (*Elaeis guineensis*), raphia palm (*Raphia* spp.), coconut (*Cocos nucifera*), citrus (*Citrus* spp.), etc.

Field Work

A reconnaissance survey of the area was carried out with the aid of a topographic map of scales 1:100,000, soil maps and soil reports. The topographic map was obtained from the Department of Geology, University of Nigeria, Nsukka. Representative soil geomorphic units were identified. Due to sedimentation, the floodplain has a slightly convex cross-section and the identification of the different physiographic units followed this landform shape, alongside its

accessibility and land use (Figure 2 and Table 1). All sampled points were geo-referenced with the Garmin Geographic Positioning Systems (GPS) and designated OGB₁, OGB₂, OGB₃ for levee crest, levee slope and flood basin respectively. Each of the pits representing the units was dug to a depth of 2 m. The morphological characteristics of each profile pit such as soil depth, drainage, colour, mottle, structure, consistence, concretions, cutans, pores, roots and horizon boundary were described in the field, according to FAO's (2006) guideline. Bulk samples for physico-chemical analyses were collected from the identified genetic horizons. The bulk samples were later air-dried, crushed and sieved through a 2 mm mesh sieve. The fine earth fraction was subjected to standard laboratory procedures.

Laboratory Procedures

Particle size distribution was determined by hydrometer method as described by Gee and Bauder (1986) using sodium hexametaphosphate as a dispersant. The pH was determined in distilled water using soil/liquid ratio of 1: 2.5 (Gee and Bauder (1986). Organic carbon was determined by the Walkley and Black method described by Nelson and Sommers (1982). Total nitrogen (TN) was determined by the Kjeldahl method (Bremner and Mulvaney, 1982). Available phosphorus (P) was measured by Bray II extraction method (Page *et al.*, 1982). The exchangeable bases were determined by the complexometric titration method as described by Chapman (1982). Exchangeable acidity was determined by the titrimetric method after extraction with 1N KCl (McClean, 1982). Exchangeable hydrogen (H⁺) was obtained using 5 drops of phenolphthalein indicator titrated with 0.05N NaOH and 0.05N HCl to obtain end point. Aluminium (Al³⁺) was obtained using 10 mls of 4% NaF and titrated with 0.05 HCl while the sum of exchangeable bases and exchange acidity was taken as the effective cation exchange capacity (ECEC). The CEC was determined by the ammonium acetate method of Jackson (1958). Percentage aluminium saturation was calculated using the formula:

$$\%Al \text{ saturation} = \frac{\text{Exchangeable Al}}{\text{ECEC}} \times \frac{100}{1}$$

Percentage base saturation (BS) was calculated by obtaining the sum of the exchangeable bases and dividing by the ECEC, and then multiplying the quotient by 100, thus:

$$BS = \frac{\text{TEB}}{\text{ECEC}} \times \frac{100}{1}$$

where TEB is total exchangeable bases (cmol kg⁻¹) and ECEC is effective cation exchange capacity (cmol kg⁻¹) of the soil.

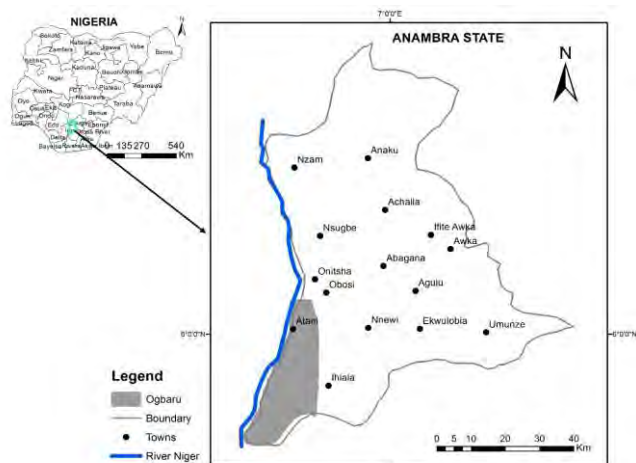


Figure 1: Study site in Atani, Anambra State, Nigeria

where is ESP is exchangeable sodium percentage, (%), Na is measured exchangeable Na (cmol kg⁻¹), and CEC is cation exchange capacity (cmol kg⁻¹).

The Carbon/Nitrogen ratio was calculated from the contents of carbon and nitrogen in the samples. The soils were classified according to the USDA Keys to Soil Taxonomy (Soil Survey Staff, 2014) and correlated with the FAO/IUSS World Reference Base (WRB) for Soil Resources (FAO/IUSS Working Group, 2015). Fertility capability classifications of the soils was done following the procedure documented by Sanchez *et al.* (1982).

RESULTS AND DISCUSSION

The results of the study and important discussions are summarized below.

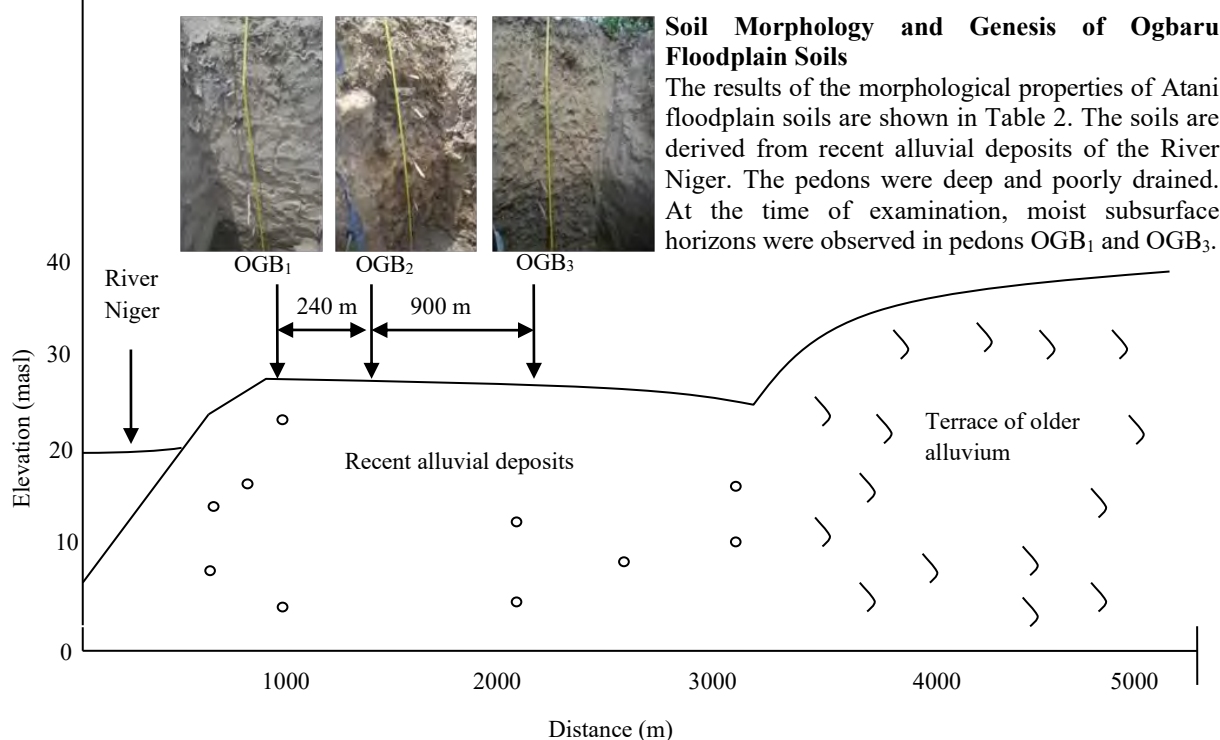


Figure 2: Schematic representation of the area showing topographic sequence and the distance from the river channel

Table 1: Identification and land use of the studied profiles

Profile	Position/Coordinate/ slope	Elevation (m)	Land use
OGB ₁	Natural levee (Latitude 6°00'23.4N, Longitude 6°44'26.0"E)/ 1.5%	27	Grassland; mainly elephant grass (<i>Pennisetum purpureum</i>). Surrounding area is used for vegetable cultivation.
OGB ₂	Levee slope (Latitude 6°00'23.3N, Longitude 6°44'33.6"E)/ 3%	26	Under yam and cassava cultivation. Other uses include: oil palm, bananas and plantain cultivation.
OGB ₃	Flood basin (Latitude 5°59'55.7"N, Longitude 6°44'40.2"E)/ 6%	23	Fallow as at the time of examination but evidence of previous yam cultivation. Other vegetation include: oil palm, bamboo, snake weed (<i>Euphorbia hirta</i>), elephant grass (<i>Pennisetum purpureum</i>), <i>Calapogonium mucunoides</i> , <i>Ageratum</i> spp., etc.

Exchangeable sodium percentage was obtained by dividing the respective amount of sodium of soil by the ECEC and multiplying the quotient by 100:

$$ESP = \frac{Na^+}{ECEC} \times \frac{100}{1}$$

This is an indication of ground water fluctuations within the upper 2 m depth of the pedons. Additionally, the presence of stagnic or gleyic properties in all the profiles, as designated by 'g' is caused by prolonged period of water stagnation due

to river flooding and previously stated ground water fluctuations. Under the aquic condition, Fe and Mn become reduced to form redoximorphic features (Esu, 2010; Okenmuo, 2015). Such feature was only absent between 25-50 cm depth of OGB₂ and suggests that soluble Fe was lost in the layer. The stratification of the profiles with depth presented a sequence of various thin layers which bore the characteristics of the predominant environmental conditions during deposition. According to the munsell notation, the predominant hue was 10YR (yellowish) which was associated with the hydromorphic conditions and the presence of oxidized ferric iron oxides or some organic matter. In OGB₁, the surface colour (moist) was characterized by brownish black (10YR 3/2), dull yellowish brown (10YR 4/3) in OGB₂ and dark brown (10YR 3/4) in OGB₃. The dark brown and blackish-coloured soil surface colour suggests that organic matter decomposition was dominant at OGB₁ and OGB₂ under the prevailing environmental condition. This is in line with Ahukaemere *et al.* (2016), Abagyeh *et al.* (2017) and D’Elia *et al.* (2017) who observed that dark soil colours in sedimentary soils signaled increased SOC contents associated with annual flooding. The subsurface layers however graded into shades of brown, dark brown and yellowish brown colours showing various patterns of sedimentation and occurrence of pigmentary materials of hydrated iron oxide and water-soluble organic matter. These results are buttressed by similar works in flooded environments (Sakar *et al.*, 2001; Schiavo *et al.*, 2012; D’Elia *et al.*, 2017). Platy structure admixture with subangular blocky structure was observed at topsoil of OGB₁ while subangular blocky structures and single grained structures were common down the profile. The platy structure may be related to parent material or compaction caused by prolonged submergence

period and the influence of deposited organic material (NRCS, 2011; Abagyeh *et al.*, 2017). Pedons OGB₂ and OGB₃ had subangular blocky structures at the surface and subsurface except in OGB₂ with a massive structure at 25-50 cm depth. The massive structure was designated a cambic horizon. Underneath the layer, at 50-60 cm depth, large stones of bricks reflected human activities with machinery or hand tool and was designated Bwg. These conditions will restrict water movement and workability of the soils in this position.

Apart from the levee soil (OGB₁) which was loose within 54-150 cm, the other profiles have a friable to firm consistence; indicating moderate water retention in the soils. Other features such as fine to coarse roots were observed in all the horizons of the three profiles except below 54 cm depth of OGB₁. Artefacts such as pottery, bricks and charcoal were observed at the levee (OGB₁) and the levee-slope (OGB₂), which was attributed to flood deposition and past human activities in the area. OGB₁ is characterized by a simple A and C horizons without diagnostic horizons due to their early stage of development. A little more development was observed at OGB₂ and OGB₃ with the development of cambic B-horizons, suggesting their older age. There was no diagnostic epipedon in surface soils of all the soil profiles, except in OGB₂, which had an ochric epipedon. Ochric epipedon has a Munsell color value of 4 or more when moist, and 6 or more when dry; or chroma of 4 or more; or includes an A or Ap horizon that has both a low color value and low chroma (Soil Survey Staff, 2014). Horizon designations of OGB₁ placed depths 14-39 cm as a buried soil horizon because they are underneath a deposit of a new material. However, the mantle does not reach the minimum requirement of 50 cm to qualify as a buried soil (Soil Survey Staff, 2014).

Table 2: Morphological properties of Ogbaru floodplain soils

Pedon	Horizon	Depth (cm)	Colour*	Mottle	Structure	Consistency*	Other features
OGB ₁	Ag	0-14	10YR 3/2	2.5YR 4/6	1p/msbk	fr	1fr, A
	Abg	14-39	10YR 4/2	2.5YR 4/2	3csbk	fi	2mcr, A
	Cg1	39-54	10YR 4/3	2.5YR 4/8	3csbk	fr	2mcr
	2Cg2	54-110	10YR 4/6	2.5YR 4/6	sg	lo	-
	2Cg3	110-150	10YR 6/6	2.5YR 3/6	sg	lo	A
	3Cg4	150-200	10YR 4/3	2.5YR 5/8	2msbk	fr	A
OGB ₂	Apg	0-25	10YR 4/3	5YR 4/6	2csbk	fr	3cr
	Bw	25-50	10YR 4/4	-	m	vfi	1fr, A
	^Bwg	50-65	10YR 3/3	5YR 4/8	3csbk	vfi	1fr, A
	Bwg	65-101	10YR 3/3	5YR 4/8	2msbk	fr	1fr
	Cg	101-140	10YR 5/4	2.5YR 2/4	2msbk	fr	
	2Cg	140-200	10YR 6/3	7.5YR 3/4	2msbk	fi	A
OGB ₃	Apg	0-14	10YR 3/4	5YR 5/8	2msbk	fr	3cr
	ABg	14-30	10YR 3/4	5YR 5/8	2msbk	fi	1cr
	Bg1	30-84	10YR 6/4	5YR 5/6	2msbk	vfr	1fr
	Bg2	84-116	10YR 6/4	5YR 5/6	2msbk	vfr	1fr
	CBg	116-135	10YR 5/4	5YR 2/4	1msbk	fr	1fr
	Cg	135-200	10YR 5/4	5YR 3/4	2msbk	fr	1fr

*Determined at wet condition, Note: symbols or codes according to FAO (2006). **Structure:** 0, structureless; 1, weak; 2, moderate; 3, strong; Sg, single grained; csbk, coarse subangular blocky; msbk, medium subangular blocky; fsbk, fine subangular blocky; p, platy; m, massive. **Consistence:** lo, loose; fr, friable; vfr, very friable; fi, firm; vfi, very firm. **Roots:** 1, few; 2, moderate; 3, many; fr, fine roots; cr, coarse roots. **Pores:** mp, many pores; fp, few pores; A, Artefacts

Physical Properties of Ogaru Floodplain Soils

The particle size distribution of the soils is shown (Table 3). All three pedons show sequences of fluvial sands, silts and clay depositions. Textural classes were clay loam to sand (OGB₁), clay loam to sandy clay loam (OGB₂) and clay loam to sandy loam (OGB₃). The varied textures of lowland soils have been related to parent material and topographic position (Akamigbo, 2001; Nwite *et al.*, 2012; Obalum *et al.*, 2014; Kefas *et al.*, 2016; Obalum and Chibuike, 2017). At OGB₁, parent materials were dominantly total sand which was higher in the pedon with average values of 57% and clay fractions were lowest. Silt contents were higher at the OGB₂ by average values of 37% while at OGB₃, the total sand fraction was higher in the pedon by 46%. The distinct dominance of textural compositions is indicative of the differential deposition of particles during floods, from coarser particles at the levee and finer particles further away from the river channel. This finding agrees with Ukaegbu and Akamigbo (2004) and Obalum *et al.* (2011) that the natural levees (upper land positions) are dominated by sand and silt, while silt and clay dominated down-slope, due to the lateral movement of the sediment-laden water down-slope. In this study, the burial of soils surface by a recent deposit of 14 cm thickness at the levee position and erosion of clay particles at the epipedon of the floodplain basin may be responsible for decline of clay and high sand-sized particles at the positions. The dominance of fine sand over coarse sand and the higher silt contents in the soil compared to adjacent soils within the region have been reported (Igwe *et al.*, 2006). While clay was slightly depleted in the A-horizon of all the profiles, it gradually increased at the subsurface horizons. This may be associated with sediment deposition process, removal of clay and silt through runoff during intense rainfall as common in the area, as well as illuviation of clay due to percolation of flood waters (Igwe *et al.*, 2006). However, the increase in clay within the respective depths of 25-65 cm of pedon OGB₂ and 14-30 cm of pedon OGB₃ was not designated an argillic horizon because the clay maxima was reached within 30 cm of surface, and the clay content decreased downward from the clay maxima. In addition, the increases appear to be related to deposition rather than pedogenic processes which require enough time to alter the original sediment distribution. This finding corroborates observations of Markewich *et al.* (1988) in soils developed in Holocene-age alluvium in east-central Alabama, classified as Hapludults instead of as Fluventic Dystrochrepts. At OGB₁, lithological discontinuity was placed at depth 54-150 cm, where there is a significant change in relative compositions of sand, silt, and clay. Such layers are caused by abrupt changes in parent material, agent and energy of transportation and deposition.

Soil Chemical Properties

Table 4 shows the chemical properties of the soils. The pH values ranged from 4.8 to 6.2 and 3.7 to 5.9 in distilled water and 1 M KCl respectively. They were very strongly to slightly acidic in reaction (in H₂O) (Enwezor *et al.*, 1989). Topsoil of OGB₁ and OGB₂ were strongly acidic and very strongly acidic with values 5.1 and 4.9 respectively while the subsurface horizons of both pedons irregularly increased to slight acidity. In contrast to this, topsoil reaction was moderately acidic (6.0) at OGB₃ while the subsurface ranged from strongly acidic to moderately acidic (5.4-5.9). Low pH and its gradual increases with depth have been observed in floodplains of West Africa (Buri *et al.*, 1999). Considering the pH values at the topsoil of each unit, the order of nutrient loss of cations from the pedons will be OGB₂ > OGB₁ > OGB₃. The low pH and its slight tendency towards neutrality down the profiles may be associated with horizons textural compositions, their cation retention abilities and leaching consequent on the high rainfall cum water table activities in this region. Notwithstanding, at this pH range, most crops can still thrive because the H⁺ concentration does not inhibit cation absorption. When the pH values in water are compared to the pH values in KCl, they were observed to be higher (Table 4). This indicates the dominance of a net negative charge in the soils and the lowering of soil pH due to increased neutrality of salt concentration to 0.1 or 1M (Bohn *et al.*, 2001; Silva Neto *et al.*, 2015). At OGB₁, exchangeable Ca and Mg ranged from 2.6 to 6.2 and 1.6 to 6.8 cmol_c kg⁻¹ respectively, whereas exchangeable Na and K varied from 1.5 to 1.8 and 1.6 to 2.2 cmol kg⁻¹ respectively. Based on the ratings of Enwezor *et al.* (1989), the soils are categorized as low to moderate with respect to Ca and moderate to high with respect to Mg. In terms of Na, the soil was categorized as high while K was very high. At OGB₂, the value of exchangeable Ca and Mg ranged from 4.8 to 8.2 and 2.2 to 4.2 cmol kg⁻¹ respectively, whereas Na and K ranged from 1.0 to 2.5 and 1.7 to 3.8 cmol kg⁻¹ respectively. Hence the soils were categorized in accordance to Enwezor *et al.* (1989) as low to moderate for Ca, moderate to high for Mg, high in terms of Na and very high in terms of K. At OGB₃, the value of exchangeable Ca and Mg ranged from 2.8 to 5.0 and 2.0 to 5.4 cmol kg⁻¹ respectively, whereas Na and K ranged from 1.4 to 3.0 and 1.2 to 4.2 cmol kg⁻¹ respectively. Hence the soils were categorized in accordance to Enwezor *et al.* (1989) as low for Ca, moderate to high for Mg, high to very high in terms of Na and very high in terms of K. The dominant cations on the exchange complex were Ca²⁺ and Mg²⁺ whereas K⁺ and sodium Na⁺ were observed to be less dominant on the exchange complex but were higher

Table 3: Particle size distribution (g kg^{-1}) of Ogbaru floodplain soils

Position of profile	Horizon	Depth (cm)	Clay	Silt	Fine sand	Coarse sand	Total sand	Textural class
OGB ₁	Ag	0 - 14	260	290	330	120	450	Loam
	Abg	14 - 39	360	390	200	40	250	Clay loam
	Cg1	39 - 54	180	290	510	20	530	Sandy loam
	2Cg2	54 - 110	80	10	850	60	910	Sand
	2Cg3	110 - 150	60	10	600	330	930	Sand
OGB ₂	3Cg4	150 - 200	300	350	300	50	350	Clay loam
	Apg	0 - 25	280	370	280	60	350	Clay loam
	Bw	25 - 50	300	370	260	60	320	Clay loam
	Bwg	50 - 65	340	350	270	40	310	Clay loam
	BCg	65 - 101	220	270	470	30	500	Sandy clay loam
OGB ₃	Cg1	101 - 140	260	390	340	10	350	Loam
	Cg2	140 - 200	340	450	180	30	210	Clay loam
	Apg	0 - 14	120	350	520	10	530	Sandy loam
	ABg	14 - 30	300	290	380	30	410	Clay loam
	Bg1	30 - 84	220	430	330	10	340	Loam
	Bg2	84 - 116	100	270	620	10	630	Sandy loam
	CBg	116 - 135	180	370	430	20	450	Loam
	Cg	135 - 200	320	290	370	20	390	Clay loam

Table 4: Chemical properties of Ogbaru floodplain soils

Horizon	Depth (cm)	Soil pH		Ca	Mg	Na	K	ECEC	TEB	TN	CEC	OC	Av.P	EA		Al Sat.	BS	ESP	C/N ratio
		H ₂ O	KCl											H ⁺	Al ³⁺				
				(cmol _c kg ⁻¹)				(g kg ⁻¹)	(cmol _c kg ⁻¹)	(g kg ⁻¹)	(mg kg ⁻¹)	(cmol _c kg ⁻¹)		(%)					
Profile 1 (OGB ₁)																			
Ag	0-14	5.1	4.3	6.0	6.8	1.8	2.2	19	16.8	1.12	29.2	14.3	15.86	1.4	0.8	4.2	88	9	13
Abg	14-39	5.1	3.9	6.2	3.4	1.8	1.8	15.6	13.2	0.98	39.6	11.5	7.46	0.8	1.6	10.3	84	12	33
Cg1	39-54	5.3	4.0	4.4	2.8	1.6	1.6	12.6	10.4	0.42	30.8	3.4	9.33	1.4	0.8	6.3	83	13	8
2Cg2	54-150	6.1	4.7	2.6	1.6	1.5	1.6	9.5	7.3	0.14	11.6	2.6	4.66	1.8	0.4	4.2	76	16	19
3Cg3	150-200	4.8	3.7	4.8	2.6	1.8	1.8	17	11.0	0.14	32.4	2.9	12.12	2.4	3.6	21.2	65	11	20
Profile 2 (OGB ₂)																			
Apg	0-25	4.9	4.0	5.8	2.2	2.5	3.0	14.5	13.5	0.84	36.8	15.2	13.99	0.4	0.6	4.1	93	17	18
Bw	25-50	5.2	4.1	5.0	4.2	1.0	3.0	15.0	13.2	0.28	40.4	9.2	12.12	0.8	1.0	6.7	88	7	33
Bwg	50-65	5.4	4.9	8.2	3.2	2.0	3.6	19.0	17.0	0.70	42.4	8.3	13.99	1.6	0.4	2.1	89	11	12
Bwg	65-101	6.2	4.1	7.4	3.0	1.9	3.8	17.5	16.1	0.56	30.4	12.4	31.71	0.8	0.6	3.4	92	11	22
C'g	101-140	6.2	4.1	6.4	3.2	2.0	2.1	14.7	13.7	0.42	25.2	8.0	2.80	0.6	0.4	2.7	93	14	2
2Cg	140-200	6.2	4.9	4.8	3.0	2.0	1.7	12.5	11.5	0.40	42.6	3.6	7.47	0.8	0.2	1.7	92	16	9
Profile 3 (OGB ₃)																			
Apg	0-14	6.0	4.7	4.4	2.0	1.7	1.2	10.8	9.3	0.42	16.8	6.7	5.60	0.3	1.2	11.1	86	16	16
ABg	14-30	5.4	3.9	4.0	2.6	3.0	4.2	15.8	13.8	0.42	28.8	4.2	0.93	0.8	1.2	7.6	87	19	10
Bg1	30-84	5.5	3.9	4.0	5.4	1.4	1.9	15.9	12.7	0.56	29.2	1.8	3.73	0.8	0.4	2.9	91	9	3
Bg2	84-116	5.7	4.1	3.0	3.2	1.9	1.7	11.5	9.8	0.28	14.8	2.8	5.60	0.3	1.4	12.2	85	17	10
CBg	116-135	5.4	3.9	5.0	3.0	1.5	1.8	13.5	11.3	0.56	28.8	0.4	1.87	0.8	1.4	10.4	84	11	1
Cg	135-200	5.9	4.0	2.8	2.8	1.7	1.7	11.0	9.0	0.56	33.6	4.6	7.46	0.0	2.0	18.2	82	15	8

Ca, Calcium; Mg, Magnesium; Na, Sodium; K, Potassium; ECEC, effective cation exchange capacity; TEB, total exchangeable bases; TN, total nitrogen; CEC, apparent cation exchange capacity; OC, organic carbon, OM, organic matter; Av.P, available phosphorus; EA, exchangeable acidity; Al Sat, aluminium saturation; BS, base saturation; ESP, exchangeable sodium percentage; C/N, Carbon/Nitrogen ratio

in concent based on rating by Enwezor *et al.* (1989). The dominance of Ca and Mg in flooded lowland soils have been reported (Idoga and Azagaku, 2008; Ogbodo, 2011; Obalum *et al.*, 2012, Nwite *et al.*, 2012, 2017). All profiles were rated similar in exchangeable bases supply except in OGB₃ where Ca was consistently low in all horizons and Na was very high in the AB horizon. This indicates similarity in parent material and further influence of erosion at the depressions (Buri *et al.*, 1999). OGB₁ had low ECEC at the horizon with a lithological discontinuity within 54-150 cm depth where coarse sand dominated and at the surface of OGB₃ where erosion leads to loss of clay. The irregular distribution of ECEC reflected contribution of exchangeable acidity and the type of clay mineral in each horizon from kaolinite (lower values) to smectite (higher values). The influence exchangeable acidity and clay minerals on the ECEC of floodplain soils have been reported (Asadu, 1989; Buri *et al.*, 1999). Total exchangeable bases were slightly higher at the soil

surface except in OGB₃. TEB decreased down slope from OGB₁ (16.8), OGB₂ (13.5) to OGB₃ (9.3) and is associated with deposition of basic cations at the levee and levee slope while erosion and leaching may be the reason for the depletion of bases at the flood basin. The irregular distribution of TEB in the subsurface horizons of the soil is clay contents related. An increase in clay entailed higher exchangeable cation levels. This is in line with previous reports of Buri *et al.* (1999).

The TN for OGB₁ was 1.12 g kg^{-1} at the topsoil, decreasing gradually down the profile. A similar trend of decrease was observed for OGB₂ from 0.84 to 0.40 g kg^{-1} . The only exception to this was a sharp decrease between depths of 25- 50 cm of OGB₂. In contrast, TN values at OGB₃ increased gradually from the topsoil (0.42 g kg^{-1}), decreased within 84-110 cm depth and increased sharply beneath. The TN irregular decrease down the profile has been previously reported in floodplain soils (Akamigbo *et al.*, 2001). The higher values at the topsoil of OGB₁ and OGB₂ compared to OGB₃

followed the organic carbon contents. Its inconsistent occurrence at the subsurface may be attributed to leaching. The effective CEC and TEB followed a similar trend to the distribution of the various cations, declining from the levee to the lower positions as associated with varying deposits of cations during flooding and clay distribution pattern. TN contents of the soils were generally very low to moderately low (Enwezor *et al.*, 1989). The low values of TN of soils in the area may be attributed inadequate application of nitrate fertilizers by farmers in the region and other forms of TN losses associated with floods.

The value for the CEC due to the clay fraction (clay CEC) value was highest at OGB₂, ranging from 25.2 to 42.6 cmol kg⁻¹, followed by OGB₃ which ranged from 14.8 to 33.6 cmol kg⁻¹ and OGB₁ which ranged from 11.6 to 39.6 cmol kg⁻¹. They were rated high to very high, moderate to high and low to high respectively (Enwezor *et al.*, 1989). At the topsoil region, the values were higher at OGB₂ (36.8 cmol kg⁻¹) and lowest at the OGB₃ (16.8 cmol kg⁻¹) due to erosion of clay at the depression. The near absence of clay at the lithological discontinuous layer of OGB₁ is responsible for the low CEC observed at depth 54-150 cm. The CEC values followed the order OGB₂ > OGB₃ > OGB₁. This indicates that the soils in the middle-slope were more fertile as influenced by high clay and organic matter contents (Akamigbo *et al.*, 2001; Gregory and Nortcliff, 2012). The value of CEC seems to fairly follow the clay content changes (Table 3) in all the pedons.

Based on Chude *et al.* (2011), very low to high OC values were observed at OGB₁ (2.6-14.3 g kg⁻¹) and OGB₂ (3.6-15.2 g kg⁻¹), whereas the values at OGB₃ (0.4-6.7 g kg⁻¹) were consistently very low to low. Organic carbon contents were highest at the topsoil of OGB₂ (15.2 g kg⁻¹) compared to OGB₁ (14.3 g kg⁻¹) and OGB₃ (6.7 g kg⁻¹) with the lowest values. The high OC at the levee and levee slope may due to greater deposition of parent material rich in organic matter at the upper zones of the floodplain compared to the flood basin during the recent flood. Also, the values of OC decreased in an irregular pattern from topsoil to subsoil in all the profiles. This irregular decrease in the distribution of OC with depth in floodplain soils have been reported (Buri *et al.*, 1999; Dengiz, 2010; Eleke *et al.*, 2018). Available P content at was highest at the topsoil of OGB₁ (15.86), followed by sharp decrease and irregular increment down the profile. In contrast, available P values at OGB₂ (13.99) and OGB₃ (5.6) decreased gradually from the topsoil and peaked at the subsoil. Based on the rating by Chude *et al.* (2011) the values 4.66 to 15.86 mg kg⁻¹ at OGB₁, 2.8 to 31.71 mg kg⁻¹ at OGB₂ and 0.93 to 7.46 mg kg⁻¹ at OGB₃ were rated low to moderate, very low

to high and very low to moderate respectively. The low values of available P in certain profiles may be related to the low native phosphorus in the parent material, P-fixation, low organic matter and the inability of farmers to apply inorganic fertilizers (Buri *et al.*, 1999; Eleke *et al.*, 2018). These factors may also account for the low available P at the flood basin compared to the levee and levee slope. The differentia in P-fixation would be explained by the relative wetness of the soils occurring at these topo-positions (Obalum and Chibuikwe, 2017).

The values of titratable exchangeable acidity (Al³⁺ + H⁺) increased as pH reduced in most horizons (Table 4). The Al³⁺ and H⁺ equally constituted the exchangeable acidity except in OGB₃ where Al³⁺ constituted most. The variations may be linked to the nature of parent material. This result agrees with Abreu Jr *et al.* (2003) on the presence of Al³⁺ in soils of high acidity as a function of parent material and soil mineralogy. The resultant variability in the values of exchangeable acidity is attributable to aluminosilicate clay minerals releasing Al³⁺ and H⁺ into the soil solution via isomorphous substitution, leaching and nutrient biocycling (Akamigbo and Nnaji, 2011; Ogunwale *et al.*, 2002) under repeated wetting and drying conditions. Exchange acidity and Al saturation are also useful indices of horizon development of some tropical soils; because exchangeable Al is relatively less mobile in soil and differential accumulation of may be attributed to in situ clay destruction (Okunsami *et al.*, 1987). Lower aluminum saturation (4.2 %) at horizon Ag and 2Cg2 of pedon OGB₁ indicates minimal weathering compared to the other horizons in the pedon. Also, moist subsurface horizons (poor internal drainage) observed in OGB₁ (3Cg3) and OGB₃ seems to be related to greater aluminum saturation in the profiles compared to OGB₂. This is similar to findings of Okunsami *et al.* (1987) in alluvial landforms of Central Nigeria. The higher values of aluminium saturation on the levee and flood basin positions implies low cation retention and buffering capacity due to its high leaching potentials. The exchangeable aluminium levels were still within tolerant limits of reserved acidity but must be countered with subsoil liming to ensure adequate crop performance at the two positions.

Higher values of base saturation were obtained at OGB₂ and OGB₃ compared to OGB₁, reflecting the occurrence of basic nutrients in available forms in the solution despite the soil low cation reserves. The base saturation is above 50% in all positions, an indication of the high fertility of the soils. The ESP values were high to very high in all the profiles based on Enwezor *et al.* (1989). Sodicity problems are associated with soils with ESP > 15%. Hence the soils may possibly be dispersive and poor in physical and water movement characteristics.

The C/N values were higher at OGB₁ (8-33) and OGB₂ (2-33) compared to OGB₃ (1-16). In this regard, recent flood deposits may have contributed biomass rich in less decomposed carbon. The C/N ratios show a marked difference in the rate of decomposition and humification processes of the horizons. Generally, the high C/N values at the topsoil indicate recent deposition of organic matter, while the variable values down the profiles may indicate its loss over time and retarded decomposition at some horizons. Organic matter is usually lost in soils over time (Ping *et al.*, 1997). The decline in values of C/N ratio at the subsoils of OGB₂ and OGB₃ indicates advanced stage of humification.

Classification of the Soils

The soil profiles of the floodplain at Ogbaru are classified according to the USDA Soil Taxonomy and the FAO/IUSS WRB as follows:

Pedon OGB₁: The soils classify as Entisols at the order level of the USDA Soil Taxonomy because the mineral soils lacked developed soil horizons. At the suborder level, the soils were categorized as Aquents because the soils are seasonally wet for some time. At the great group level, soils were grouped into Fluvaquents due to the important role played by fluvial depositions in its formation. Due to the hydric conditions in all the layers, the soils classified as Typic Fluvaquents at the subgroup level. The soils were correlated with Stagnic Fluvisols in FAO/IUSS WRB (2015).

Pedon OGB₂: The soils classify as Inceptisols due to the presence of an incipient cambic B-horizon. The soils were grouped under the suborder Aquepts because their aquic moisture regime, gleyic properties and ESP > 15% characteristics do not match other groups in the category. At the great group level, the soils were grouped into Endoaquepts, and further into Fluvaquentic Endoaquepts at the subgroup level following its slope, thickness, presence of transported materials at the surface and irregular decreases in organic carbon. The soils were correlated with Pantofluvic Endostagnic Cambisols in FAO/IUSS WRB (2015).

Pedon OGB₃: The profile classifies as Inceptisols due to weak structural development within 30-116 cm depth. At the suborder level, the soils were grouped under Aquepts. At the great group level, the soil belongs to the Endoaquepts. Due to an irregular decrease in organic-carbon content between depth of 125 cm with no lithic characteristics and aquic conditions, the soil classify as Fluventic Endoaquepts at subgroup level. The soils correlated with Stagnic Endogleyic Cambisols in FAO/IUSS WRB (2015).

Table 5: Fertility capability classification of Ogbaru floodplain soils

PU	FCC	Interpretation/Description	Limitations	Options
OGB ₁	Lgn	Loamy to clay loamy topsoils, good water holding capacity, moisture will not be a challenge during the short dry spell that occur during the growing season, CEC is moderate to high and there is no need for k-fertilizers for crops that demand for high levels of potassium. Soil is potentially sodic.	Limitations in drainage so that tillage operations and some crops may be adversely affected unless drainage is improved by tiles or other procedures, strong to medium soil acidity.	Liming is required for some crops, the soils can support rice cultivation, some vegetable like Amaranth (<i>Amaranthus spp</i>) can be planted during the short dry spell, the soil can support irrigation agriculture.
OGB ₂	Lgn	Topsoils are characterized by clay loam textural class with good water holding capacity, moisture will not be a challenge during the short dry spell that occur during the growing season. > 15% Na saturation of ECEC within 50 cm depth indicates alkalinity problems.	Limitations in drainage so that tillage operations and some crops may be adversely affected unless drainage is improved by tiles or other procedures, strong to medium soil acidity.	Liming is required for some crops, the soils can support rice cultivation, some vegetable like Eggplant (<i>Solanum melongena</i>) can be planted during the short dry spell, the soil can support irrigation agriculture.
OGB ₃	Lgn	Topsoils are characterized by textural classes of sandy loam and clay loam, average water holding capacity, moisture will not be a challenge during the short dry spell that occur during the growing season, there is no need for K-fertilizers for crops that demand for high levels of potassium (K) since the soil has moderate to high ability to supply K (exchangeable K is higher than 0.20 cmol kg ⁻¹). > 15% Na saturation of ECEC within 50 cm depth indicates alkalinity problems.	Limitations in drainage so that tillage operations and some crops may be adversely affected unless drainage is improved by tiles or other procedures, strong to medium soil acidity.	Liming is required for some crops, the soils can support rice cultivation, some vegetable like pumpkin (<i>Telfiera indica</i>) can be planted during the short dry spell, the soil can support fadama agricultural activities.

PU: Physiographic Unit; FCC: Fertility Capability Class; CEC: Cation Exchange Capacity

Fertility Classification of Ogbaru Floodplain Soils

The fertility classification of Ogbaru floodplain soils are shown in Table 5. The three soil physiographic units (OGB₁, OGB₂ and OGB₃) are classified as Lgh. The soil type L indicates the loamy nature of the soil texture while the modifiers, g and h indicate the hydromorphic nature and the strongly acidic state of the soils. The recommendations for the best use of the soils are clearly stated in Table 5.

CONCLUSIONS

It is evident that fine-scale topographic landscape variations and the distance from river channel accounts for differences in properties of floodplain soils as well as the use to which the land is put to. More so, the aftermath of major floods results in more pronounced variations associated with fluvial depositions, erosion hazards and aquic conditions. Under these conditions, the studied soils are deep, layered and mottled. Along with the reduced iron content associated with repeated wetting and drying, nature of parent material and organic matter contents contribute to the colour of the soils. At distances closer to the river channel (levees), energy of the deposition media (flood) is greater and becomes weaker down slope. Hence total sand dominated the levee while silts and clay dominated the lower slopes except at the flood basin surfaces where erosion hazard caused by runoff leads to the loss of clay and increased sandiness. Due to frequent depositional disturbances and erosion hazards during floods, the soil development is hampered with closeness to the river channel. Further away from the channel, some layers were compact due to increased clay contents but the increases are mainly related to the nature of deposited parent material rather than pedogenesis. Generally, the soils have low to high base status, organic carbon contents and cation exchange capacity (CEC); reflecting the influence of organic matter and clay content. Soils on the levee slope were most fertile while soils on the levee position were less fertile due to rapid loss of basic cations. On the soil surfaces, higher values of cations reflect flood deposits which were rich in basic cations. There is need for further studies in order to understand the mechanism behind soil salinization in this river floodplain, their mobilization through the soil profile and its impact on crops. More so, the boundary between physiographic zones of the floodplain, as it is with many other floodplains is less understood and will require more detailed study for precision agriculture. Management of the soil requires drainage during cropping season, subsoil liming in order to replace negative charges in the exchange complex with Ca²⁺ which is low in the studied soils, adequate tillage in order to break clods at the lower slopes. Irrigation agriculture will ensure all round production of vegetables and other crops in the area.

ACKNOWLEDGMENTS

The paper forms part of the MSc research project of the first author (OFC) at the University of Nigeria Nsukka, Nigeria. The authors wish to gratefully acknowledge the invaluable support and input to the research by members of academic staff of the Department of Soil Science of this University while the first author (OFC) was on the MSc degree programme. Deserving special mention is Dr. S.E. Obalum who, through the corresponding author, provided extra support with useful comments/suggestions on the initial and the final drafts of the paper.

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