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Characterization of Soils of Ogbese River Floodplain in Southwestern Nigeria

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Abstract
Soils of Ogbese river floodplain in Southwestern Nigeria were characterized and assessed with a view to identifying their agronomic potentials for crop production. The soils were generally acidic and the pH values decreased with soil depth and along the reach. Exchangeable bases were generally low (Ca^{2+} = 0.074 to 0.2 cmol/kg; Mg^{2+} = 0.018 to 0.067 cmol/kg; K^{+} = 0.017 to 0.067 cmol/kg and Na^{+} = 0.001 to 0.013 cmol/kg). Soil organic carbon, total nitrogen and available P contents were moderately high (0.47 to 3.11%, 0.03 to 0.28% and 27.49 to 49.01 mg/kg respectively) at the soil surface, the values decreased with soil depth and increased down the reach. Extractable micronutrients were medium to high in the soils, their values increased with decreasing pH and increasing organic matter content. Low nutrient reserve, high leaching potential, soil erosion and poor drainage were identified as agronomic limitations in the soils of the area. Management practices such as planting of cover crops and the use of organic residues such as charred rice husk which is abundant in the area are highly recommended as solution to the soil constraints. Poorly drained soils of the study area were classified as Aeric Endoaquepts (Jago series), imperfectly well-drained soils as Typic Plinthustalf (Gambari series) and the well-drained soils as Typic Paleustalf (Oba series).

Keywords: Amendment, Floodplain, Soil productivity and Sustainable soil resources.

Introduction
The role of agriculture in Nigeria's economy cannot be overemphasized given that 70% of the populations derive their livelihood and other related activities from it. According to World Bank (1998), it is a major source of raw materials for agro-allied industries and a potent source of the much-needed foreign exchange. Agricultural production in most Sub-saharan countries is under threat due to declining soil fertility (Tabi *et al*., 2013). Apart from the scarcity of upland soils for agriculture, the few available cultivated soils which used to be fertile, have become severely degraded by continuous cropping (Onyekwere *et al*., 2001). This is due to the fact that agriculture in Africa is largely carried out on upland soils, at the expense of the enormous available resources of wetland soils. Wetlands are those soils which have their water tables at, near or above the soil surface and are saturated for a long period of time within the year as indicated by hydric soils and hydrophytic vegetations (Mitsch and Gosselink, 2007; Adigbo *et al*., 2011 and Ogban *et al*., 2011). The wetlands in Sub-saharan Africa include coastal plains (deltas, estuaries and tidal flats), inland basins (comprising extensive drainage depressions), river floodplains (consisting of recent alluvial deposits bordering rivers) and inland valleys (Ogban and Babalola, 2009).

Floodplain soils are considered the soils found along the plains of rivers, lakes and lagoons, where they develop in sediments from various sources under various drainage classes often with hydromorphic conditions (Luís Silva Neto, 2015). Floodplains in river basins of many parts of the world have been used for agriculture i.e. for growing crops and grazing animals because of their natural fertility (Van Wambeke, 1962). Despite the enormous resources of wetlands, several workers have reported that their potentials have remained relatively untapped and under-utilized in Nigeria (Effiong and Ibia, 2009; Ogban, and Babalola, 2009; Adigbo *et al*., 2011). This could be due to poor physical properties following drainage, cost of development and difficulty of management (Guthrie, 1985). Their characteristics and potentials are little understood. Therefore, the large expanse of land in Ogbese river floodplain, the growing population coupled with its attendant needs for food and fibre, necessitated the investigation of the characteristics of the floodplain soils to enhance its maximum productivity. The objectives of this study were to provide taxonomic classification and assess the potentials of the soils for sustainable crop production.

Materials and Methods

Description of the study area

The study was carried out at Ogbese Area (Latitudes 7° 17.053 N & 7° 17.059 N and Longitudes 5° 12.558 E & 5° 12.564 E) in Akure North Local Government Area of Ondo State about 15 kilometers from Akure town (the Administrative Headquarters of the State in southwestern Nigeria) along Akure-Owo-Benin Express road (Figure 1). The climate is humid tropical, subjected to marked wet and dry seasons with a bimodal rainfall pattern, which peaks in June/July and September/October. The study area was characterized by rainy season from April to October, and dry season from November to March. The rainy season is interrupted annually by a short period of moisture deficit from late July to early August, traditionally known as "August break," which varies in duration from year to year. This is followed by another period of heavy rainfall from September to October (Ewulo *et al*., 2008; Akinbola *et al*., 2012). The mean annual rainfall of the area is about 1800 mm. The atmospheric temperature ranges between 27℃ and 31℃ with a mean annual relative humidity of about 80%. Soils of the study area are underlain by Precambrian rocks which are parts of the basement complex of Southwestern Nigeria. The rocks are made up of the migmatite-gneiss complex, the schist belts and the granitoids (Adekoya *et al*., 2003; Olusiji, 2013). Crystalline acid rocks constitute the main parent rock of the soil.

Vegetation and landuse of the study area

The soils of the floodplain are mainly formed from alluvial deposits. There is a riparian forest which forms a boundary between the floodplain and Ogbese River. The area is intensively cultivated to varieties of crops such as Rice (*Oryza sativa*), Sugarcane (*Saccharum officinarum*), Maize (*Zea mays*), Cowpea (*Vigna unguiculata*), Cassava (*Manihot esculenta*), Oil palm (*Elaeis guineensis*) and Vegetables which include Okra (*Abelmuscus esculenta*), Water leaf (*Talinum triangulare*), Amaranth (*Amaranthus virides*), Fluted pumpkin (*Telfairia occidentalis*) and Field pumpkin (*Curcubita pepo*). Grasses such as Elephant grass (*Pennisetum purpureum,*), Giant star grass (*Cynodon plectostachyus*), Siam weed (*Chromolaena odorata*), Goat weed (*Ageratum conyzoides*), clusters of bamboo

(*Bambusa vulgaris*) and shrubs are common plants in the study area. The upper reach is mainly cultivated to cassava and the mid-reach cultivated to okra while the lower reach is primarily cultivated to swamp rice.

Field study

Nine profile pits were dug along three transects (about 300 metres apart). The soil profile pits were described following FAO (2006) guidelines for soil profile description and horizon designation of the USDA Soil Survey Staff Manual (Soil Survey Staff, 1996). Bulk soil samples were collected from the identified genetic horizons for laboratory analyses.

Laboratory analyses

The samples obtained were air-dried, gently crushed and sieved using a 2 mm sieve for laboratory analyses. Particle size distribution analysis was carried out using the hydrometer method described by Boyoucos (1962) as modified by Gee and Or (2002), bulk density was by the core method. Soil pH was determined using glass electrode pH meter in duplicates in water and also in 1 N KCl solution, using 1:1 soil-water and 1:1 soil-1 N KCl solution ratios (Thomas, 1982). Soil organic carbon was determined using the Walkley-Black (1934) method as reviewed by Allison (1965). The Bray-1 method, as described by Bray and Kurtz (1945), modified by Kuo (1996) was used for the determination of the soil available phosphorus. Exchangeable cations were extracted with 1.0 N NH_4OAc solution at pH 7 according to Soil Survey Staff (2003). Magnesium and Ca concentrations were determined by the Atomic Absorption Spectrophotometer Model AA500 while K and Na were determined by the flame photometer. Exchangeable acidity was determined by titration method (McLean, 1965). Effective

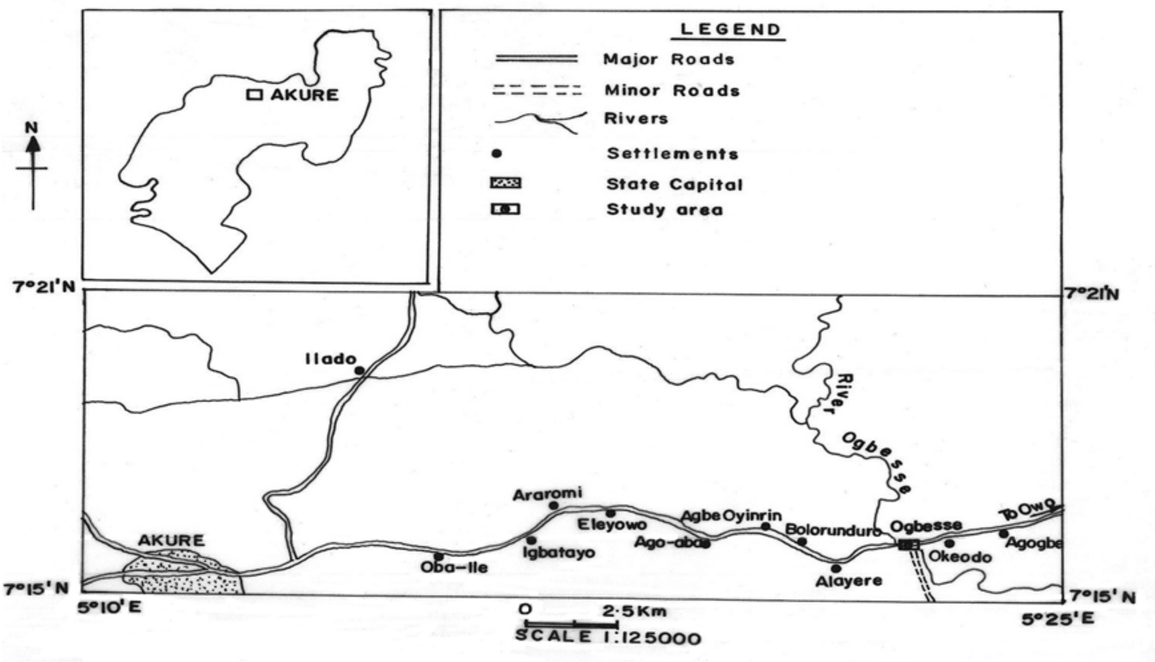

Figure 1: Location map of the study area

Cation Exchange Capacity (ECEC) was calculated (Chapman, 1965). Extractable micronutrients (Fe, Mn, Zn and Cu) were extracted with 0.1 N HCl, and determined by the use of Atomic Absorption Spectrophotometer.

Results and Discussion

Morphological characteristics of the soils

The soils studied occupy gently sloping sites at intermediate levels in the topography. The morphological properties considered in characterizing the soils include soil depth, colour, texture, structure and horizon boundary as presented in Table 1. The colour of the soils varied from hues of 10YR through 7.5YR to 2.5YR with variation of colours such as dark brown, dark greyish brown, light brown, reddish yellow, yellowish brown to light grey. The soil has chroma of varied values. The dark colour of the surface horizons could be as a result of higher content of organic materials on the soil surface according to Adamu *et al*. (2014), while the greyish colouration of the soils at the lower reach area could be as a result of the poor drainage condition as observed by Lawal *et al*. (2013). The yellowish colouration might be attributed to the presence of sesquioxides in hydrated form, especially goethite according to Lawal *et al.* (2012 and 2013). The texture of the soils ranged from fine loamy sand in the surface horizons to sandy loam in the subsoil horizons within the upper and mid-reach areas. It ranged from sandy loam in the surface horizons to clay in the subsoil horizons within the lower reach of the floodplain. The soils of the area were generally weak, fine to moderate sub-angular blocky to angular blocky structure on the surface horizons. The upper reach soils were well drained, the mid-reach soils ranged between somewhat poorly drained to poorly drained while the lower reach area was poorly drained.

Table 1: Morphological characteristics of the soils

Horizon	Depth	Colour	Mottles	Texture	Structure	Consistence	Boundary	Remarks
Pedon 1 (07? 17' 053? N – 005? 12' 559? E) Upper Reach – Oba series								
A	0 - 17	10YR 3/3	nm	ls	2fsbk	wsssp	cw	Many fine and medium roots
AB	17- 35	10YR 4/3	nm	ls	1fsbk	wsp	cs	Few roots and scattered slickensides
Bt	35- 91	7.5YR 5/4	nm	c	2fsbk	wvsvp	cw	Very few roots with many small and big pores
Bv	91-129	7.5YR 5/4	nm	c	2msbk	wsp	cw	Soft plinthic layer
Pedon 2 (07? 17' 053? N – 005? 12' 558? E) Mid Reach/Break of reach – Gambari series								
Ap	0 - 21	10YR 4/2	nm	sl	2fgr	wsnp	gw	Many fine and medium roots
AB	21- 59	10YR 4/4	nm	ls	2fgr	wnsnp	gw	Few fine roots
B	59- 93	10YR 5/6	nm	sl	2fgr	wsssp	aw	Few scattered roots, spots of Fe/Mn concretions
Bv	93-117	10YR 5/8	nm	sl	3mgr	wssnp	gw	Petroplinthite,black spots of Fe/Mn concretions
Pedon 3 (07? 17' 054 N – 005? 12' 558? E) Lower reach – Jago series								
Ap	0 - 20	10YR 3/3	m	fsl	2fgr	wsssp	gw	Many fine roots
AB	20 - 73	10YR 5/6	m	fsl	2fgr	wvsvp	gw	Few roots with many fine tubular imped pores
B1	73-141	10YR 7/1	10YR5/6	vc	2fgr	wvsvp	gw	Tubular imped pores and yellow brown mottles.
B2	141-200	10YR 7/1	m	vc	3fgr	wvsvp	gw	No roots. It is clayey and covered with water.
Pedon 4 (07? 17' 057? N – 005? 12' 560? E) Upper Reach – Oba series								
A	0 - 20	7.5YR 4/4	nm	ls	3fsbk	wsssp	cs	Many fine roots, slickensides and interstitial pores
AB	20 - 36	10YR 4/4	nm	cosl	3msbk	wsp	cw	Many roots, coarse and gravelly.
B	36 - 52	7.5YR 5/6	nm	vc	2fsbk	wvsvp	cw	Few roots, gravelly
Bt1	52 - 78	7.5YR 5/6	m	vc	2fsbk	wvsvp	cw	Few roots, pores, slickensides.
Bt2	78 - 200	7.5YR 5/6	m	vc	2fsbk	wvsvp	cw	Black spots of Fe/Mn concretions.
Pedon 5 (07? 17' 059? N – 005? 12' 560? E) Mid Reach/Break of reach – Gambari series								
A	0-15	10YR3/3	m	cs	1mabk	wnsnp	cw	Many roots, tubular pores
AB	15-52	10YR 5/3	m	cs	1mabk	wssnp	cs	Few roots
B1	52-74	10YR 5/3	m	sl	3mabk	wsssp	cw	Very many black spots of Fe/Mn concretions
B2	74-108	10YR 5/8	m	sl	1mabk	wsp	cs	Few black spots of Fe/Mn concretions
Bv	108-154	10YR 5/8	m	sl	3mabk	wnsnp	cw	Very hard plinthite layer. It is stony.

Table 1 (Cont'd): Morphological characteristics of the soils

Horizon	Depth	Colour	Mottles	Texture	Structure	Consistence	Boundary	Remarks
Pedon 6 (07? 17' 057? N - 005? 12' 561? E) Lower Reach – Adio series								
A	0 - 20	10YR 4/2	m	ls	3fsbk	wvsvp	aw	Many roots, scattered slickensides and imped pores
AB	20-55	10YR 4/2	m	c	1fsbk	wvsvp	aw	Many roots
B	55 - 101	10YR 5/8	m	c	1fsbk	wvsvp	aw	Few scattered roots
Bt1	101-150	10YR 5/6	m	c	2fsbk	wvsvp	aw	Many imped pores
Bt2	150-200	10YR 5/4	m	c	2fsbk	wvsvp	aw	Many scattered black spots of Fe/Mn concretions
Pedon 7 (07? 17' 059? N – 005? 12' 562? E) Upper Reach – Oba series								
Ap	0 -20	10YR 4/2	nm	cosl	2mgr	wnsnp	cw	Many fine roots
AB	20 - 69	10YR 5/4	nm	sl	2mgr	wsp	cw	Few roots
B	69 - 87	10YR 5/4	nm	scl	1mgr	wsp	gw	Gravelly clayey, quartz gravel and Fe/Mn concretions
Btv1	87 - 116	7.5YR 5/6	nm	sc	3mgr	wsssp	gw	Hard plinthic layer
Btv2	116-200	2.5YR 6/2	10R 3/6	vc	3mgr	wvsvp	gw	Clayey with mottles of different colours and pronounced scattered dark red spots (10 R 3/6)
Pedon 8 (07? 17' 058? – 005? 12' 562? E) Lower Reach – Jago series								
A	0 - 18	10YR3/1	m	sl	1fsbk	wsssp	dw	Very many fine roots
AB	18 - 66	10YR3/1	m	sl	1fsbk	wsp	dw	Few roots
B1	66-124	10YR 4/1	m	vc	1fsbk	wvsvp	dw	Fine clayey. No root.
B2	124-174	10YR 4/1	10YR 5/6	vc	1fsbk	wvsvp	dw	Very fine clay with many yellowish brown spots. No roots. The B-horizon is covered with water.
Pedon 9 (07? 17' 059? – 005? 12' 564? E) Lower Reach – Adio series								
Ap	0 - 17	10YR 3/3	m	scl	1fabk	wsp	cw	Many roots
B1	17 - 34	10YR4/2	m	vc	1fabk	wvsvp	gw	Weakly developed black spots of Fe/Mn concretions
B2	34 - 60	10YR6/3	m	vc	2mabk	wvsvp	cw	Clayey with many black spots of Fe/Mn concretions
B3	60 - 185	10YR 5/1	m	vc	1fabk	wvsvp	gw	Broken cutans on peds.

Mottles: m – mottled, nm – no mottles;
Texture: f – fine, v – very, co – coarse, c – clay, s – sandy or sand, l – loamy or loam;
Structure: 1 – Weak, 2 – Moderate, 3 – Strong, f – fine, m – medium, gr – granular, sbk – subangular blocky, abk angular blocky;
Consistence: wnsp – wet, nonsticky, plastic; wsp – wet, sticky, plastic; wssp – wet, slightly sticky, plastic; wnsnp – wet, nonsticky, nonplastic, wvsvp – wet,very sticky,
very plastic, wsssp – wet, slightly sticky, slightly plastic; wssnp – wet, slightly sticky, nonplastic; wsnp – wet, sticky, nonplastic;
Boundary: aw – abrupt wavy, cw – clear wavy, dw – diffuse wavy, gw – gradual wavy, cs – clear smooth

There were other important features such as tubular pores, spots of Fe/Mn concretions, petroplinthites, broken cutans and scattered slickensides in the soil as reported by Akpan-Idiok *et al.* (2013).

Physical characteristics of the soils

The physical characteristics of soils of Ogbese river floodplain are summarized in Table 2. Generally, the particle size distribution data indicated the dominance of sand fraction with a range of 8 to 80%, followed by clay with a range of 1 to 61% while silt content was the least with a range of 2 to 53%. It was observed that soils of the upper reach had coarse texture at the surface horizons while surface horizons of the lower reach soils were fine-textured. The soil texture varied widely from fine loamy sand in the surface horizons to sandy loam in the subsoil horizons within the upper and mid-reach (upland) areas of the floodplain. It ranged from sandy loam in the surface horizons to clay in the subsoil horizons within the lower reach of the floodplain. The upland soils had higher values of sand fraction than the flooded areas, whereas the floodplain had higher values of silt and clay fractions compared to the upland. The relative abundance of sand particles observed at the surface horizons could be as a result of preferential removal of clay and silt materials by run off and their subsequent transportation and deposition in the lower reach positions during heavy rainfall and translocation of colloidal clay particles deep into the profile by percolating water (Babalola *et al.*, 2011).

According to Ogbodo (2011), the different land uses between cultivated upland reach soils and the fallowed lower reach soils could be responsible for the transportation of eroded lighter soil particles (silt and clay) to the lower plains where they accumulated on the topsoil.

The upper reach soils were well drained and aerated as evidenced by their bright colour which may be attributed to the upper reach position of the soils. The mid-reach soils ranged from somewhat poorly drained

Table 2: Physical characteristics of the soils

Horizon	Depth (cm)	Sand ←	Silt (%)	Clay →	Textural class	Silt/Clay	BD (g/cm^3)
Pedon 1 (07? 17' 053? N – 005? 12' 559? E) Upper Reach							
A	0 - 17	67	15	18	SL	0.83	1.15
AB	17 - 35	66	10	24	SCL	0.42	1.39
Bt	35 - 91	47	7	46	SC	0.15	1.43
Bv	91 - 129	55	11	34	SCL	0.32	1.61
Pedon 2 (07? 17' 053? N – 005? 12' 558? E) Mid-Reach/Break of Reach							
Ap	0 - 21	77	11	12	SL	0.92	1.16
AB	21 - 59	77	19	4	LS	4.75	1.21
B	59 - 93	79	13	8	LS	1.63	1.34
Bv	93 - 117	75	7	18	SL	0.39	1.56
Pedon 3 (07? 17' 054 N – 005? 12' 558? E) Lower Reach							
Ap	0 - 20	60	21	19	SL	1.11	1.07
AB	20 - 73	57	12	31	SCL	0.39	1.14
B1	73 - 141	58	17	25	SCL	0.68	1.26
B2	141-200	58	13	29	SCL	0.45	1.22
Pedon 4 (07? 17' 057? N – 005? 12' 560? E) Upper Reach							
A	0 - 20	68	11	21	SCL	0.52	0.92
AB	20 - 56	78	5	17	SL	0.29	1.26
B	56 - 92	70	9	21	SCL	0.43	1.38
Bt1	92 - 150	58	7	35	SC	0.20	1.45
Bt2	150 - 200	54	9	37	SC	0.24	1.47
Pedon 5 (07? 17' 059? N – 005? 12' 560? E) Mid Reach/Break of reach							
A	0 - 15	79	2	19	SL	0.11	1.12
AB	15 - 52	79	6	15	SL	0.40	1.15
B1	52 - 74	80	15	5	LS	3.00	1.37
B2	74 - 108	74	19	7	SL	2.71	1.35
Bv	108 - 154	70	11	19	SL	0.58	1.47
Pedon 6 (07? 17' 057? N - 005? 12' 561? E) Lower Reach							
A	0 - 20	28	39	33	CL	1.18	0.95
AB	20 - 55	32	33	35	CL	0.94	1.01
B	55 - 101	12	53	35	SiCL	1.51	1.08
Bt1	101 - 150	8	31	61	C	0.51	1.06
Bt2	150 - 200	26	33	41	C	0.80	0.88

BD – Bulk density
SL = Sandy Loam, Sandy Clay = SC, SCL = Sandy Clay Loam, Loamy Sand = LS,
SiCL = Silty Clay Loam, CL = Clay Loam, C = Clay

Table 2: (Cont'd): Physical characteristics of the soils

Horizon	Depth (cm)	Sand ←	Silt (%)	Clay →	Textural class	Silt/Clay	BD (g/cm^3)
Pedon 7 (07? 17' 059? N – 005? 12' 562? E) Upper Reach							
Ap	0 -20	79	12	9	LS	1.33	1.25
AB	20 - 69	76	23	1	LS	23.00	1.43
B	69 - 87	75	22	3	LS	7.33	1.50
Btv1	87 - 116	59	16	25	SCL	0.64	1.61
Btv2	116 - 200	32	33	35	CL	0.94	1.48
Pedon 8 (07? 17' 058? – 005? 12' 562? E) Lower Reach							
A	0 - 18	56	27	17	SL	1.59	1.08
AB	18 - 66	59	23	18	SL	1.28	1.20
B1	66 - 124	64	11	25	SCL	0.44	1.23
B2	124 - 174	57	14	29	SCL	0.48	1.25
Pedon 9 (07? 17' 059? – 005? 12' 564? E) Lower Reach							
Ap	0 - 17	28	39	33	CL	1.18	0.99
B1	17 - 64	26	39	35	CL	1.11	1.16
B2	64 - 110	20	45	35	CL	1.29	1.16
B3	110 - 185	24	37	39	CL	0.95	1.15

BD – Bulk density
SL = Sandy Loam, Sandy Clay = SC, SCL = Sandy Clay Loam, Loamy Sand = LS,
SiCL = Silty Clay Loam, CL = Clay Loam, C = Clay

to poorly drained, as a result of the break of reach position of the soils in the area. The lower reach area was moderately drained to poorly drained as evidenced by mottles which was as a result of the near valley floor position that receives runoff water and sediment from the upper reach areas. The surface horizons of all the pedons were mottle-free, an indication of good surface drainage according to Lawal *et al*. (2013).

Silt/clay ratios were relatively higher in the surface horizons and decreased with increasing soil depth except in pedons 2, 5 and 7 at the break of reach which were exposed to high erosion activity. This indicated that the soils were relatively young according to Van Wambeke (1962), who reported that soils from old parent materials usually have silt/clay ratios below 0.15 while silt/clay ratio above 0.15 were indicative of young soils. The bulk density values for the soils at the lower reach were lower than those of the upper reach. This could be as a result of the low moisture retention capacity of the upper reach soils and higher content of organic matter which reduce soil bulk density and accumulation of layers of unconsolidated alluvial materials at the lower reach (Ogbodo, 2011; Akhtaruzzaman *et al*., 2014). Bulk density increased with depths in all the profiles examined as also reported by Christopher and William (2000). This was probably because of the presence of higher organic matter content at the soil surface compared to the subsoil. Organic matter has low bulk density and so can impart the property to the top soil (Logan and Harrison, 1995). The moderate values of bulk densities as observed in the study area showed that bulk density will not be a limiting factor for crop cultivation in the area (Esu, 2005; Umeugochukwu, 2009).

Chemical characteristics of the soils

The chemical characteristics of soils of Ogbese river floodplain are summarized in Table 3. The surface pH values of the soils vary from 4.5 to 5.9 (mean = 5.1 ± 0.72) in the upper reach (upland) area and 3.8 to 6.0 (mean = 4.7 ± 1.0) at the lower reach area depicting that the soil reaction varies from strongly acid to very strongly acid. It was observed that acidity increased from the upper reach to the lower reach of the floodplain. The higher pH at the upper reach was probably due to the drainage pattern and the effect of topography which encouraged surface run off along the transect (Uzoho and Okechukwu, 2014; Jimoh, 2015). High annual precipitation which causes leaching, absorption of nutrients by plants and crop removal could also be responsible for the acidic nature of the soils. Surface soils showed slightly lower pH values in comparison to subsoils at the upland areas, which might be due to huge dose of fertilizer application by the farmers in the area as observed by Bera *et al*. (2014).

Organic carbon was observed to decrease with depth; this according to Babalola *et al*. (2011) was an indication of continuous deposition of organic material. The organic carbon content of the soil was low especially in the subsoils while it was relatively higher at the soil surface horizons in most of the soil profiles studied in the floodplain. This could be as a result of the accumulation of leaf litters at the soil surface which subsequently decayed and mineralized to yield soil organic matter (Olayinka, 2009). High organic carbon at the surface horizons of wetland soil is an indication of poor natural drainage which probably slowed the rate of decomposition according to Babalola *et al*. (2011). It was observed that total nitrogen (TN) was higher at the lower reach and at the surface soil than in the subsoil across the reaches as also reported by Christopher and William (2000) and Ukut *et al*. (2014). This could be attributed to addition of plant residue during the farming season, higher rate of organic matter decomposition, rapid mineralisation and absorption of nitrogen due to continuous farming (Abah and Petja, 2016). Furthermore, the low level of TN observed in pedons 2, 5 and 7 may be associated with leaching coupled with intermittent flooding and drying which is known to favour N loss through nitrification-denitrification process (Wong *et al*., 1991). Total nitrogen was observed to follow the same trend with organic carbon distribution in the studied soils probably because soil organic matter (SOM) is the basic source of total nitrogen

Table 3: Chemical characteristics of the soils

Horizon	Depth (cm)	pH H_2O	pH KCl	OC (%)	TN (%)	Exchangeable Bases Ca^{2+}	Mg^{2+}	K^{+}	Na^{+} $cmol_{(+)}kg^{-1}$	EA Al^{3+}	H^{+}	TEA	ECEC	BS (%)	Avail P	Extractable micronutrients Fe^{2+}	Mn^{2+} (mg/kg)	Zn^{2+}	Cu^{2+}
Pedon 1 (07? 17' 053? N – 005? 12' 559? E) Upper Reach																			
A	0 - 17	5.0	4.9	2.32	0.21	0.200	0.045	0.039	0.003	0.06	0.13	0.19	0.347	82.71	27.49	1.40	7.47	1.63	0.32
AB	17 - 35	5.8	4.9	1.09	0.09	0.178	0.043	0.030	0.002	0.03	0.07	0.10	0.283	89.40	40.49	1.33	5.05	0.84	0.30
Bt	35 - 91	5.7	4.8	0.97	0.08	0.200	0.050	0.037	0.002	0.04	0.19	0.23	0.329	87.84	37.51	1.08	1.05	0.95	0.28
Bv	91 - 129	5.9	5.1	0.31	0.02	0.241	0.050	0.045	0.003	0.06	0.02	0.08	0.399	84.96	40.92	1.58	2.27	1.12	0.28
Pedon 2 (07? 17' 053? N – 005? 12' 558? E) Mid Reach/Break of reach																			
Ap	0 - 21	5.5	5.1	1.25	0.12	0.156	0.042	0.034	0.003	0.04	0.10	0.14	0.275	85.45	29.41	1.26	6.60	2.02	0.41
AB	21 - 59	5.8	4.9	0.08	0.01	0.108	0.039	0.028	0.003	0.04	0.09	0.13	0.218	81.65	40.70	1.26	1.38	1.29	0.26
B	59 - 93	6.2	5.0	0.15	0.01	0.095	0.027	0.019	0.001	0.05	0.16	0.21	0.192	73.96	34.74	0.91	2.48	1.06	0.19
Bv	93 - 117	6.2	5.5	0.08	0.01	0.159	0.046	0.028	0.006	0.04	0.15	0.19	0.279	85.66	37.93	2.18	5.31	1.23	0.39
Pedon 3 (07? 17' 054 N – 005? 12' 558? E) Lower Reach																			
Ap	0 - 20	6.8	6.0	2.11	0.19	0.334	0.068	0.054	0.006	0.04	0.07	0.11	0.502	92.03	39.85	2.67	10.16	3.78	0.45
AB	20 - 73	6.1	4.8	0.58	0.06	0.295	0.069	0.049	0.007	0.05	0.06	0.11	0.470	89.36	52.00	2.95	3.25	1.12	0.41
B1	73 - 141	5.8	4.3	0.18	0.02	0.194	0.056	0.058	0.002	0.04	0.09	0.13	0.350	88.57	29.62	5.90	0.40	0.48	0.20
B2	141 - 200	5.8	4.5	0.15	0.01	0.126	0.050	0.036	0.001	0.03	0.08	0.11	0.243	87.65	21.43	6.10	0.08	0.28	0.13
Pedon 4 (07? 17' 057? N – 005? 12' 560? E) Upper Reach																			
A	0 - 20	6.6	5.9	3.04	0.25	0.367	0.050	0.062	0.013	0.08	0.17	0.25	0.572	86.01	44.54	0.72	11.55	2.40	0.53
AB	20 - 56	6.9	5.7	0.93	0.08	0.178	0.035	0.036	0.008	0.03	0.12	0.15	0.287	89.55	27.92	0.68	3.82	0.59	0.45
B	56 - 92	6.3	5.5	0.86	0.07	0.200	0.038	0.039	0.011	0.03	0.24	0.27	0.318	90.57	44.54	1.12	2.99	0.62	0.30
Bt1	92 - 150	6.4	5.3	0.47	0.03	0.286	0.046	0.050	0.012	0.04	0.03	0.07	0.434	90.78	43.05	1.30	1.90	0.39	0.28
Bt2	150 - 200	6.3	5.3	0.31	0.02	0.277	0.051	0.049	0.010	0.05	0.16	0.21	0.437	88.56	47.10	2.53	2.45	0.48	0.26
Pedon 5 (07? 17' 059? N – 005? 12' 560? E) Mid Reach/Break of reach																			
A	0 - 15	5.8	4.7	1.40	0.15	0.119	0.034	0.021	0.002	0.03	0.14	0.17	0.206	85.44	32.39	11.16	7.84	0.76	0.30
AB	15 - 52	5.6	4.8	0.93	0.08	0.081	0.021	0.017	0.001	0.03	0.14	0.17	0.150	80.00	40.70	6.16	2.55	3.73	0.89
B1	52 - 74	6.8	5.5	0.16	0.01	0.121	0.027	0.026	0.002	0.04	0.10	0.14	0.216	81.48	33.24	2.28	1.53	0.28	0.45
B2	74 - 108	6.9	5.3	0.23	0.02	0.053	0.026	0.022	0.002	0.04	0.11	0.15	0.143	72.03	38.36	1.99	0.10	0.36	0.41
Bv	108 - 154	6.4	5.3	0.23	0.02	0.124	0.049	0.037	0.004	0.06	0.17	0.23	0.274	78.10	30.90	4.23	3.23	0.36	0.14

Table 3 (Cont'd): Chemical characteristics of the soils

Horizon	Depth (cm)	pH H_2O	pH KCl	OC (%)	TN (%)	Exchangeable Bases Ca^{2+}	Mg^{2-}	K^+	Na^+ ($cmol_{(+)}kg^{-1}$)	EA Al^{3+}	H^+	TEA	ECEC	BS (%)	Avail P	Extractable micronutrients Fe^{2+}	Mn^{2+} (mg/kg)	Zn^{2+}	Cu^{2+}
Pedon 6 (07° 17' 057° N - 005° 12' 561° E) Lower Reach																			
A	0 - 20	4.9	4.0	3.11	0.28	0.244	0.055	0.045	0.012	0.04	0.10	0.14	0.396	89.90	46.88	4.74	17.07	1.07	0.29
AB	20 - 55	4.3	3.2	0.67	0.05	0.164	0.049	0.021	0.005	0.03	0.13	0.16	0.269	88.85	45.91	2.86	3.63	0.49	0.22
B	55 - 101	3.9	3.3	0.55	0.05	0.084	0.046	0.032	0.005	0.05	0.14	0.19	0.216	76.85	45.39	3.29	3.40	0.34	0.31
Bt1	101 - 150	4.1	3.2	0.47	0.03	0.070	0.053	0.024	0.004	0.02	0.08	0.10	0.171	88.30	48.59	4.16	2.50	0.58	0.24
Bt2	150 - 200	4.5	3.5	0.39	0.03	0.058	0.050	0.036	0.010	0.03	0.10	0.13	0.184	83.70	37.08	5.87	3.21	0.48	0.29
Pedon 7 (07° 17' 059° N – 005° 12' 562° E) Upper Reach																			
Ap	0 -20	5.8	4.5	0.47	0.03	0.081	0.022	0.017	0.001	0.03	0.07	0.10	0.150	80.00	49.01	1.81	4.02	0.53	0.24
AB	20 - 69	6.4	4.8	0.23	0.01	0.056	0.018	0.019	0.001	0.05	0.15	0.20	0.144	65.28	37.08	3.00	0.36	0.29	0.40
B	69 - 87	6.4	4.8	0.08	0.02	0.074	0.019	0.019	0.002	0.04	0.13	0.17	0.153	73.86	43.69	1.62	0.27	0.41	0.22
Btv1	87 - 116	5.5	5.1	0.31	0.02	0.157	0.052	0.032	0.006	0.03	0.09	0.12	0.276	89.13	45.60	2.20	1.88	0.46	0.31
Btv2	116 - 200	5.7	4.6	0.23	0.02	0.319	0.062	0.067	0.008	0.09	0.13	0.22	0.546	83.52	76.50	0.57	0.01	0.34	0.33
Pedon 8 (07° 17' 058° – 005° 12' 562° E) Lower Reach																			
A	0 - 18	5.9	5.0	2.67	0.22	0.311	0.056	0.045	0.006	0.04	0.10	0.14	0.457	91.25	46.24	16.51	11.21	1.40	0.38
AB	18 - 66	6.1	4.9	0.63	0.04	0.284	0.057	0.042	0.006	0.03	0.09	0.12	0.419	92.84	41.53	5.20	2.40	0.91	0.40
B1	66 - 124	6.4	4.7	0.23	0.02	0.251	0.059	0.036	0.005	0.03	0.07	0.10	0.381	92.13	56.05	4.84	0.89	0.58	0.27
B2	124 - 174	6.2	4.8	0.21	0.02	0.157	0.059	0.047	0.005	0.02	0.03	0.05	0.287	93.03	39.75	4.48	0.58	0.29	0.21
Pedon 9 (07° 17' 059° – 005° 12' 564° E) Lower Reach																			
Ap	0 - 17	4.8	3.8	2.57	0.21	0.236	0.056	0.049	0.006	0.03	0.06	0.09	0.376	92.02	42.41	19.52	17.33	1.70	0.33
B1	17 - 64	5.1	3.7	0.93	0.08	0.193	0.052	0.049	0.003	0.05	0.11	0.16	0.347	85.60	56.47	5.41	7.19	0.87	0.38
B2	64 - 110	4.9	3.4	0.39	0.03	0.098	0.054	0.064	0.003	0.02	0.06	0.08	0.238	91.60	49.65	8.07	5.24	0.58	0.34
B3	110 - 185	4.4	3.0	0.16	0.01	0.074	0.068	0.064	0.004	0.02	0.06	0.08	0.229	91.27	44.32	9.25	1.04	1.03	0.34

OC – organic carbon, TN – Total nitrogen, EA – Exchangeable acidity, TEA – Total exchangeable acidity in soils as reported by Olayinka (2009) and Lawal *et al*. (2012). This was confirmed by the positive significant correlation ($P = 0.05$) between SOM and TN in the floodplain.

Available phosphorus in the surface soils of the upper reach in the study site ranged from 27.49 to 49.01 mg/kg (mean = 40.35± 11.36 mg/kg) and 39.85 to 46.88 mg/kg (mean = 43.85 ± 3.3 mg/kg) at the lower reach. The high available P content could be due to the higher organic matter in the Ap horizons, higher microbial and phosphatase activities, soil moisture and low pH in the flooded area (Boyoucos, 1962; Christopher and William, 2000; Ogban *et al*., 2011; Ogbodo, 2011; Jimoh, 2015; Abah and Petja, 2016). Available P was rated high in the soils of the area according to Malgwi (2007). According to Abah and Petja (2016), available phosphorus level below 20 mg kg^{-1} is a limitation to successful crop production.

Exchangeable bases (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) were generally low in the study area. Calcium and Mg^{2+} were the dominant cations, while K^{+} and Na^{+} had low concentrations. All the basic cations were higher at the surface soil than in the subsoil across the reaches and had higher values in the lower reach than the upper reach probably because they could have likely been contributed by organic matter (OM) at the soil surface according to Olayinka (2009) and Tsheboeng *et al*. (2014) who reported that OM was the store house of plant nutrients. This was also confirmed as OM and basic cations had positive correlation especially Mg^{2+} which was significant ($P = 0.05$) at the upper reach. The K^{+} values for surface soils were higher than the underlying subsoil horizon values as also observed by Shobayo (2010). Exchangeable K^{+} had a weak but positive correlation with organic matter content. Fagbemi *et al*. (1985) attributed this to small concentration of K^{+} in organic matter and flood water. Generally, the exchangeable cations were low in the floodplain soils probably as a result of the rate of decomposition of organic matter, acidifying properties of organic matter (causing low pH), leaching and dilution because flooding increases the solubility of mineral nutrients (Gallardo, 2003; Mitsch and Gosselink, 2007; Ukut *et al*., 2014).

According to Babalola *et al*. (2011), the low content of exchangeable cations may be due to intense leaching, weathering and ferrolysis, hence low inherent fertility status with regards to the major and micro-nutrients. Exchangeable acidity was higher at the surface soil than in the subsoil at the upper reach area while it was higher in the subsoil than at the surface soil of the lower reach soils. It was further observed that the exchangeable acidity values decreased down the reach. Similar results were observed by Jimoh (2015). This trend could be as a result of the drainage pattern in the area and the effect of erosion which washed down the basic cations to the lower reach of the floodplain. This is in line with Amberger (2006), who observed that flooding affects the exchangeable acidity of soil. Exchangeable acidity values in the soils of the study area were classified as generally low (< 1.0 $cmol^{(+)}kg^{-1}$) according to Malgwi (2007). This indicated that acidity would not be a threat to crop production in the studied soils as reported by Lawal *et al*. (2012).

The low level of exchangeable cations was also reflected in the low levels of the effective cation exchange capacity (ECEC) of the soils studied. This indicated that the soils had low ability for retaining plant nutrients against leaching; therefore soils of the floodplain require adequate soil management practices for higher and sustainable productivity. Exchangeable cations had positive correlations with ECEC at both the surface soil and subsoil except K^+ which had negative correlation at the soil surface and in the subsoil of the lower reach. This indicated that Ca^{2+}, Mg^{2+} and Na^+ contributed largely to ECEC while K^+ contributed very little to it at the upper and lower reaches of the plain. According to Ernest and Onweremadu (2016), high annual precipitation, the low buffering capacity to retain basic cations against leaching and removal by erosion probably explained the low ECEC in the floodplain soils. Extractable micronutrients were observed to be concentrated at the surface soils than the subsoils and decreased with soil depth in the floodplain probably as a result of higher organic matter and low pH (Brady and Weil, 2002; Kefas *et al.*, 2016). Extractable Fe^{2+} and Mn^{2+} were higher in the floodplain soil (i.e. lower reach) with values well above the critical limits (4.5 mg/kg and 1 mg/kg), respectively while Zn^{2+} and Cu^{2+} had low to medium values according to Malgwi (2007). The sequence of micronutrients in order of concentration on the surface soil of the floodplain was $Mn^{2+} > Fe^{2+} > Zn^{2+} > Cu^{2+}$.

Classification of the soils

The soil morphological, physical and chemical properties were used to classify the soil according to USDA Soil Taxonomy and local system of Smyth and Montgomery (1962). The mean annual soil temperature of the study area was higher than 22° C while the mean summer and mean winter soil temperatures differ by less than 6° C at the control section, thus the temperature regime is isohyperthermic, having aquic moisture regime at the lower reach and ustic moisture regime at the upper reach with ochric epipedon and argillic sub-surface horizons in the soil profiles.

Based on USDA Soil Taxonomy (Soil Survey Staff, 2014), the poorly drained soils of the study area (pedons 3, 6, 8 and 9) have ochric epipedons over cambic B-horizon, with minimal soil development. The pedons were classified as Inceptisol and suborder Aquepts (since the soils are under the influence of high ground water table indicating the presence of an aquic soil moisture regime), great group Endoaquepts (because they can be saturated for more than 90 consecutive days) and sub-group Aeric Endoaquepts as these soils have 50% or more matrix colour chroma > 2 within 75 cm depth. At the family level, pedons were classified as loamy isohyperthermic Aeric Endoaquepts and correlate at the local classification as Jago series.

Soils in the imperfectly well-drained areas (Pedons 2 and 5 at the break of the reach) have ochric epipedon and argillic B-horizon with high base saturation more than 50% are classified as Alfisols (Soil Survey Staff, 2014). The pedons qualified as Ustalfs at suborder level because of the ustic moisture regime. They are Plinthustalfs at great group level due to the presence of plinthic layer. At the subgroup level, pedons qualify as Typic Plinthustalfs. At the family level, they are classified as loamy-skeletal isohyperthermic Typic Plinthustalfs and correlate at the local classification as Gambari series.

Soils in the well-drained areas (Pedons 1, 4 and 7) have ochric epipedons and argillic B-horizon with high base saturation and are classified as Alfisols (Soil Survey Staff, 2014). The pedons are characterized by presence of argillic horizon and base saturation of more than 50%. These soils were classified as Alfisols and sub-order Ustalfs, great group Paleustalfs and subgroup Typic Paleustalfs. At family level, it is classified as a loamy isohyperthermic Typic Paleustalfs and Oba at series level.

Conclusion

In conclusion, soil acidity, low nutrient reserve, high leaching potential, soil erosion and poor drainage were identified as agronomic constraints for sustainable crop production in soils of the floodplain. These constraints could be managed by the adoption of management practices such as the use of organic residue like charred rice husk which is abundant in the area to ensure sustainable use of the soil resources. Poorly drained soils of the study area are classified as Aeric Endoaquepts (Jago series), imperfectly well-drained soils as Typic Plinthustalf (Gambari series) and the well-drained soils as Typic Paleustalf (Oba series).

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