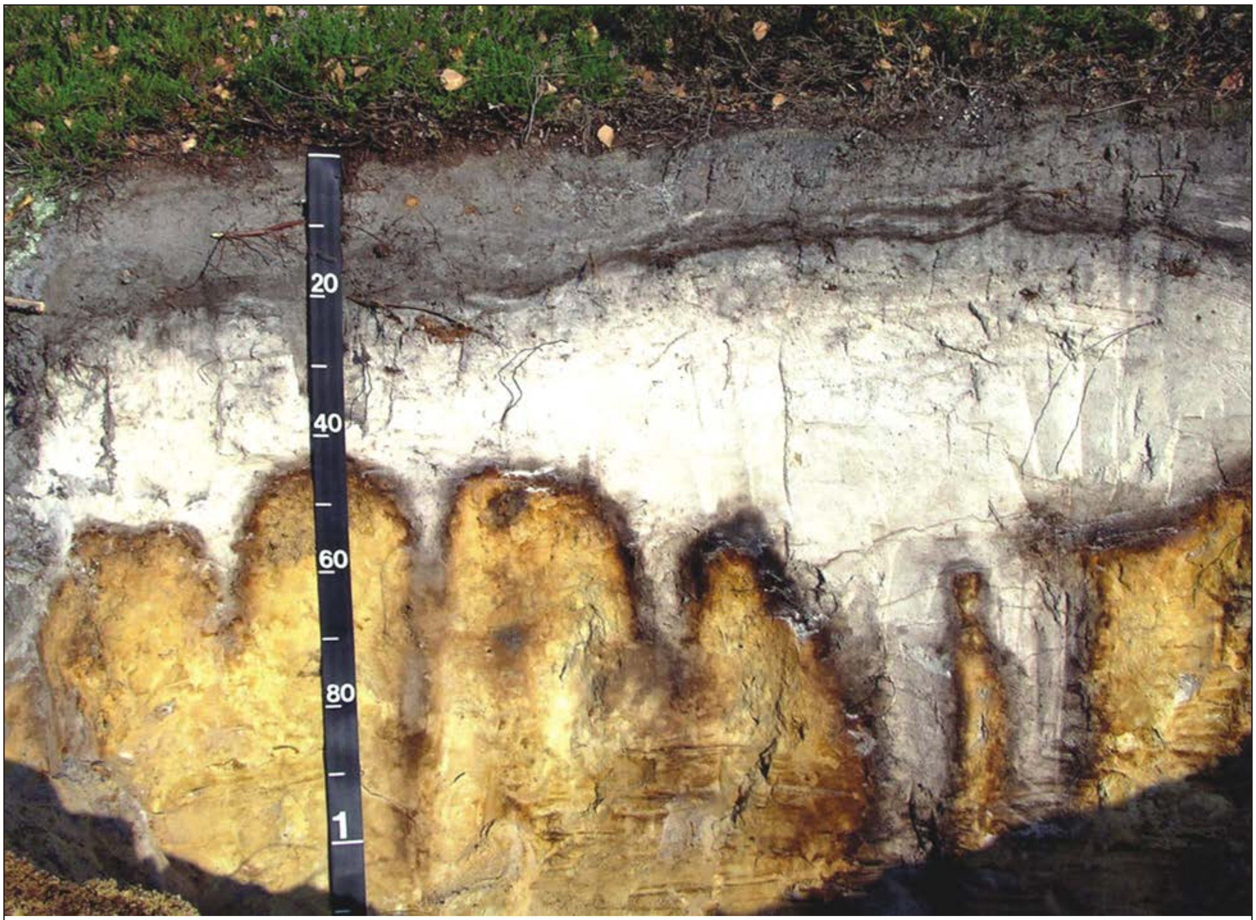

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Characterization and Classification of River Benue Floodplain Soils in Bassa Local Government Area of Kogi State, Nigeria

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ABSTRACT

The floodplain soils occupy about 1,179,400 ha along the river Benue and are useful for agricultural production, but their agricultural potentials have not been scientifically evaluated. Soil characterization was carried out to determine the morphological, physicochemical and mineralogical characteristics of river Benue floodplain soils in Bassa, Kogi State, Nigeria. Three physiographic units were identified and designated as Bassa Loamy Soils (BLS), Bassa Cleyey Soils (BCS) and Bassa Sandy Soils (BSS). Seven profiles were excavated with three in BCS, two each in BLS and BSS units. The soils were characterized as follows: Hues of 10YR-2.5YR, low chroma (≤2), high value mottles (≥4), high contents of clay (>400 g kg^{-1}) in BCS, sand (>900.0 g kg^{-1}) in BSS, strongly to slightly soil reaction (pH 5.5-6.3), low organic carbon (0.3-14.3 g kg^{-1}), low available P (3-8 mg kg^{-1}), high effective cation exchange capacity (ECEC) (6.54-22.2 cmol kg^{-1}), base saturation (90-99%) and low mineral contents (<40%) for quartz, kaolinite and illite in silt-clay fraction of BLS and BCS soil units. The pedogenic process was "gleization" in the soils. The USDA Soil Taxonomy classified the BLS and BCS units as Fluventic Ustropepts, Loamy, Mixed, Isohyperthermic and Vertic-Fluventic Ustropepts, Clayey, Mixed Isohyperthermic, respectively while BSS fitted Oxyaquic Quartzipsamment at the subgroup level. Equivalent FAO-UNESCO units were Eutric Fluvisols for BLS, Vertic Cambisols for BCS and Arenic Fluvisols for BSS. The BCS unit was rated high in fertility status and fine-textured materials than the BLS and BSS units.

Key words: Characterization, classification, floodplain soils, river Benue

INTRODUCTION

The river Benue floodplain at Shintaku in Bassa Local Government Area of Kogi State is gently undulating from the upland to nearly flat in the floodplain with small in-filled channels that empty into the river Benue valley. The extensive floodplain is drained by small river channels and is seasonally flooded for about two to three months when river Benue overflows its bank. The fine and coarse materials (sediments) carried by floodwater are deposited in the floodplains. The soils formed on this floodplain differ in their morphological, physical and chemical characteristics probably due to its age of sedimentation, micro-relief, drainage and mineralogy (Hossain *et al.*, 2011). Three physiographic units such as Bassa Loamy Soils (BLS), Bassa Clayey Soils (BCS) and Bassa Sandy Soils (BSS) have been identified in the vast floodplain (Ukabiala, 2012). The soils have been characterized by dark greyish brown, greyish brown, yellow surface overlying pinkish, grey olive yellow subsurface; medium or strong medium/coarse subangular blocky structure with very sticky consistence in the subsurface and strongly acid to slightly acid/neutral when dried (Ogbaji, 2010; Ukabiala, 2012).

Floodplain soils are distributed along major active rivers in West Africa, about 47% of the soils have been utilized for rice cultivation (Wakatsuki, 2004). In Nigeria, about 65,783 ha of floodplains constituting about 7.2% of the total land area have been identified (Ojanuga *et al.*, 2003). The river Benue floodplains cover approximately 1,179,400 hectares or 1.3% of the total land area of Nigeria (Mutter, 1972; Ojanuga *et al.*, 2003; Ukabiala, 2012). Studies also state that seasonal submergence and drying are the most active factors in developing redoximorphic features such as mottles, iron and manganese concretions, chroma diagnosis of 2 or less, gleyed soil matrix (Ogban and Babalola, 2009; Egbuchua and Ojobor, 2011; Hossain *et al.*, 2011). The mineralogical characteristics such as quartz, kaolinite, illite, smectite, vermiculite and interstratified types are common in silt-clay fraction of floodplain soils (Ogban and Babalola, 2009; Egbuchua and Ojobor, 2011; Hossain *et al.*, 2011; Ukabiala, 2012). Floodplain soils have been classified as Vertic Tropaquepts, Typic Ustruepts (USDA) or Luvisols (FAO) and Humaquepts (USDA) or Gleyic/Vertic Cambisols (FAO) for soils of the Central and Northern Cross River State of Nigeria (Akamigbo, 2009; Ogbaji, 2010).

Characterizing the floodplain soils for agricultural purposes does not only establish relationship between soil properties and the landscape parameters, but also provides preliminary information on the nutrient status, limitations and ensure sound judgement on the behaviour or response of the soils to specific uses (Esu, 2004; Egbuchua and Ojobor, 2011). Therefore, the objectives of this study were to determine the morphological, physicochemical, mineralogical properties and classify the soils on the three physiographic units from river Benue floodplain in Bassa Local Government Area, Kogi State, Nigeria.

MATERIALS AND METHODS

Study area: The river Benue floodplain (07°44' 10" and 07°44' 07" N; 06°46' 46" and 06°46' 59" E) is located at Shintaku in Bassa Local Government Area of Kogi State, Nigeria (Fig. 1). The relief of the area is gently undulating to nearly level in the floodplain. The climate is characterized by a mean annual rainfall of 1016-1524 mm, average maximum temperature of 29.1°C and average minimum of 27.6°C (Ifatimehin *et al.*, 2010; Ukabiala, 2012). Vegetation of the area is typical of Southern Guinea Savannah (Keay, 1959), but the floodplain is vegetated by grasses with scattered trees/shrubs. The geologic materials are made up of Awgu shale group in the floodplain and false-bedded Keana sandstones in the upland of the area (Fagbami and Akamigbo, 1986; Ukabiala, 2012).

Soil sampling and analytical procedure: A total of seven representative soil profile pits of depths, 0-200 and 0-45 cm for deep and shallow profiles, respectively were dug in the soil units namely: Bassa Loamy Soils (BLS), Bassa Clayey Soils (BCS) and Bassa Sandy Soils (BSS). The coordinates were obtained using GARMIN etrex GPS meter. Field characterization of the profiles was carried out and the soil samples obtained from the pedogenic horizons from the base of the profiles to avoid contamination. The samples were preserved in polyethylene bags and were taken to the laboratory for physicochemical and mineralogical analyses.

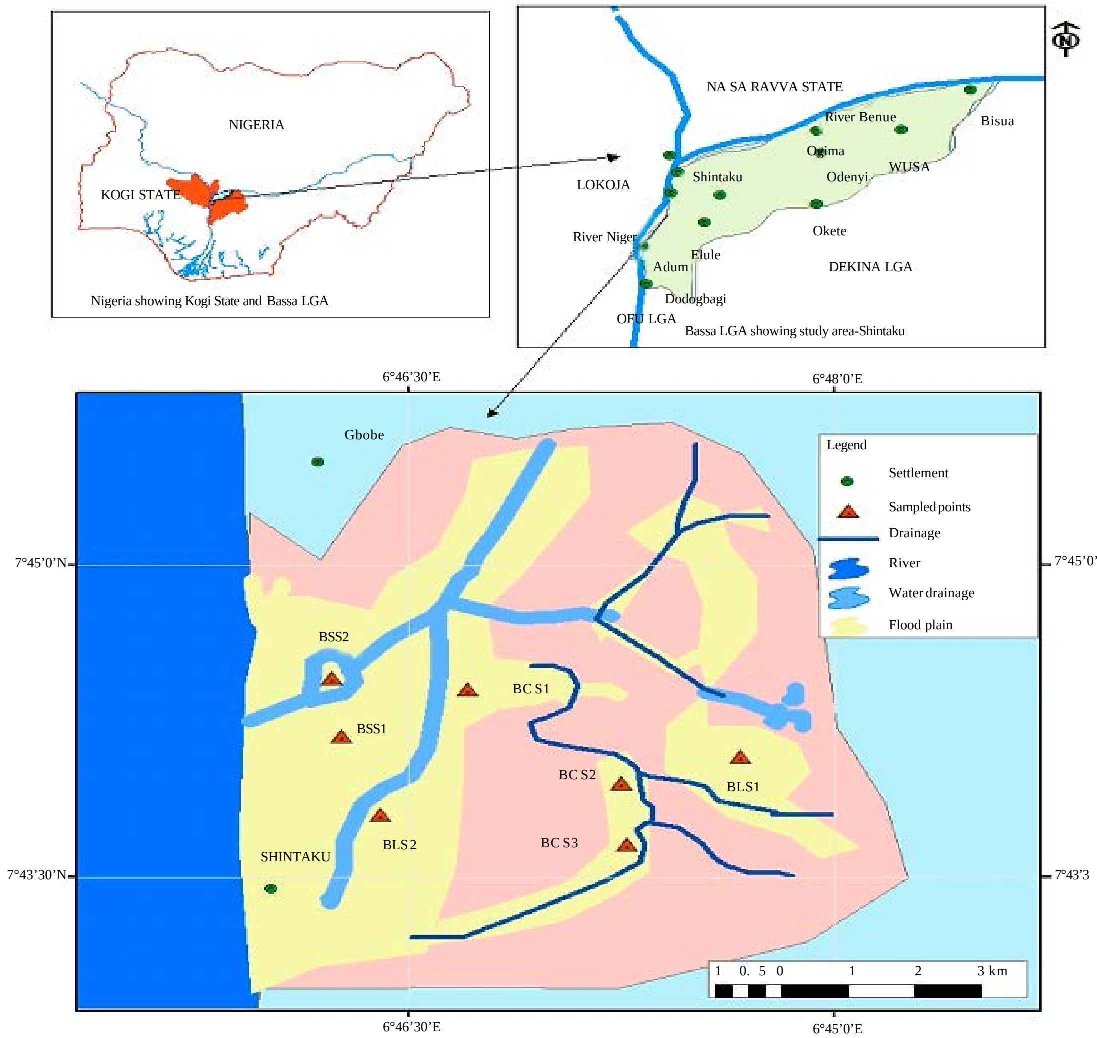

Fig. 1: Map of river Benue floodplain showing sampling points at Shintaku, Bassa, Kogi state, Nigeria

Laboratory analysis: Soil samples were air-dried and sieved through a 2 mm mesh. Particle size analysis was carried out by hydrometer method (Juo, 1979) using sodium hexametaphosphate (calgon) as the dispersant. Soil pH was determined in soil water ratio of 1:2.5 using a glass electrode pH meter. Organic carbon was determined by the Walkley and Black method (Juo, 1979) while total nitrogen was by the Micro-Kjeldahl digestion method (Juo, 1979). Available phosphorus was determined by Bray and Kurtz (1945) No. 1 method. Exchangeable bases (Ca, Mg, K and Na) were extracted with 1N NH_4OA_c at pH 7. Exchangeable potassium and sodium were determined with a flame photometer while Ca and Mg were determined by the EDTA titration method (Black *et al.*, 1965). Exchangeable acidity was determined by titration method using 1N KCl extract (McLean, 1965). Effective cation exchange capacity was estimated by summing the exchangeable bases (Ca, Mg, K and Na) and exchangeable acidity. Percent base saturation was obtained by dividing the total exchangeable bases (Ca, Mg, K, Na) by the effective cation exchange capacity. The powder samples (silt-clay fraction-<0.05 mm) obtained by sieving through 53 μm mesh were subjected to x-ray diffraction (XRD) analysis (Chen *et al*., 2001) with a Bruker AXS Diffractometer, Model D 8 using monochromatic CuKα radiation at the Beijing Centre for Physical and Chemical Analysis, People's Republic of China.

Statistical analysis: The data collected were analysed using descriptive statistics (the mean, range and standard deviation) with the help of SPSS software.

RESULTS AND DISCUSSION

Soil morphology: The morphological properties of the seven profiles representing soils in the three physiographic/geomorphic units namely: Bassa Loamy Soils (BLS), Bassa Clayey Soils (BCS) and Bassa Sandy Soils (BSS) are presented in Table 1 and 2. The morphological features show a range of hues of 10 YR through 7.5 YR to 2.5 Y which typifies the soils with variation of colour such as dark greyish brown, greyish brown, brown, olive brown, yellow and olive yellow. Also, the soil matrix has low chroma ($\leq$2) and high value mottles. Implications of redoximorphic features are that the soils (BLS and BCS) have the alternate wetting and drying conditions that results in the reduction and subsequent release of iron oxides, which give rise to reddish yellow, yellowish red/brown, strong brown and red mottles; generally, the soils are classified as imperfectly drained (BLS 1) and poorly drained (BLS 2, BCS) and very poorly drained (BSS). Redoximorphic features associated with flooding/wetness resulted from alternating periods of reduction and oxidation of iron and manganese compounds in the soils (Ogbaji, 2010; Hossain *et al*., 2011; Ukabiala, 2012). Structurally, the soils have either moderate or strong medium or coarse subangular or angular blocky (BLS and BCS) or structureless (single grained) for BSS. In terms of consistency, they are either non-sticky, slightly sticky or very sticky. Horizon delineation varies from clear smooth, abrupt irregular, gradual smooth to diffuse smooth in most of the profiles. Other pedological significant inclusions such as roots, ants, manganese concretions, mica flakes, among others are identified in the soils. The same observations have been reported by Egbuchua (2007), Hossain *et al*. (2011) and Akpan-Idiok (2012) in their studies on floodplain/wetland soils.

Particle size: Table 2 presents the results of particle size analysis of the soils. Bassa loamy soils (BSL) are characterized by sandy nature (>600.0 g kg^{-1}) in BLS 1 and silt (>300.0 g kg^{-1}) in BLS 2 with low clay content (<300.0 g kg^{-1}) in the profiles. Clay fraction varies from 330.0-740.0 g kg^{-1} with a mean of 443.0 g kg^{-1} in BCS profiles, hence, the classification "Bassa Clayey Soils (BCS)". Similarly, Bassa Sandy Soils (BSS) have a mean value of 980.0, 200.0 g kg^{-1} silt and 0.0 g kg^{-1} of clay throughout the shallow profiles in the valley bottom of river Benue (Table 2). The study reveals that the soils have characteristic properties of floodplains in which the vertical and horizontal variation in texture is due to sedimentation and micro-topography (Ogban and Babalola, 2009; Hossain *et al*., 2011; Ukabiala, 2012). The sequence of dominance of soil materials is as follows: BLS-medium-coarse textured materials, BCS-fine-textured materials and BSS-coarse-textured materials. Similar textural classes with high clay and silt contents were obtained in the Ganges river floodplain of Bangladesh and Onwu river floodplain in Cross River State, Nigeria (Hossain *et al*., 2011; Akpan-Idiok *et al*., 2012).

Sand/silt ratio refers to the relative amount of sand and silt in soils. Using sand/silt ratio of 0.2 (Anand *et al*., 1977), the high sand/silt ratios of 0.25-6.27 for BLS, 0.35-1.34 for BCS and 49 for BSS (Table 2) indicate the parent material of the floodplain as alluvium and that the poorly drained profiles are under low degree of weathering.

Table 1: Morphology of river Benue floodplain soils in Bassa, Kogi State, Nigeria

Profile	Horizon	Depth (cm)	Munsell	Mottles	Texture	Structure	Consistence	Boundary	Others
Cordinates = 07° 44' 10" N, 06° 46' 68" E, elevation 56 m									
BLS 1	Ap	0-19	10YR 4/2 (dark grayish brown)	-	ls	2fgr	nsnp	cs	Many fine pores, many fine roots, many ants
	AB	19-32	7.5YR 5/2 (brown)	-	s	2fmsbk	nsnp	gs	Common fine pores, common fine roots, common ants.
	B	32 - 69	7.5YR 7/2 (pinkish grey)	-	ls	sg	nsnp	ai	Many medium pores, few fine roots
	Bwg	69-126	10YR 6/1 (grey)	7.5YR 6/8 (reddish yellow)	scl	3mabk	sssp	ds	Few very fine pores, few fine roots, many black Mn concretions
	Cg	126-200	10YR 7/2 (light gray)	7.5YR 6/8 (reddish yellow)	scl	3mabk	sssp	-	Few very fine pores, few very fine roots
Cordinates = 07° 43' 22" N, 06° 45' 62" E, elevation 34 m									
BLS 2	Apg	0-12	7.5 YR 5/2 (brown)	7.5YR 5/6 (Strong brown)	stl	2mcsbk	sssp	cw	Medium fine pores, many fine mica flakes, mane ants
	Bwg1	12-82	7.5 YR 5/2 (brown)	10YR 5/8 (red)	cl	2mcsbk	sp	ds	Common fine pores, common moderate roots, many mica flakes, many ants
	Bwg2	82-115	10YR 5/2 (greyish brown)	5YR 5/6 (yellowish red)	l	2mcsbk	sp	gw	Common fine pores, common medium roots, many mica flakes
	Bwg3	115-144	10YR 5/2 (greyish brown)	7.5YR 5/8 (strong brown)	stl	2mcsbk	sssp	cw	Common fine pores, common fine roots, many mica flakes
	Cg	144-200	10YR 5/2 (greyish brown)	5YR 6/8 (reddish yellow)	stl		sssp	-	Common fine pores, common fine roots, few mica flakes
Cordinates = 07° 42' 63" N, 06° 46' 26" E, elevation 47 m									
BCS 1	Apg	0-20	10YR 4/2 (dark greyish brown)	10YR 5/6 (yellowish brown)	cl	3mcsbk	sp	cs	Many medium pores, many coarse medium roots, many cracks, many ants
	Bwg1	20-69	10YR 5/2 (greyish brown)	-	c	3mcsbk	vsvp	gs	Common medium pores, common fine roots, common medium cracks, common ants
	Bwg2	69-119	10YR 5/3 (brown greyish)	10YR 5/6 (yellowish brown)	c	2msbk	sp	ds	Common very fine pores, few fine roots, common Mn concretions
	Cg	119 - 200	10YR 5/2 (greyish brown)	10YR 5/8 (yellowish red)	cl	2mcsbk	sssp	-	Common fine pores, few very fine roots
Cordinates = 07° 43' 51" N, 06° 45' 99" E, elevation 46 m									
BCS 2	Apg	0-19	10YR 5/2 (greyish brown)	5YR 5/8 (yellowish red)	cl	3msbk	sp	gs	Many fine pores, common fine roots, many ants
	Bwg1	19-42	10YR 6/1 (gray)	7.5YR 4/6 (strong brown)	c	3mcsbk	vsvp	gs	Common fine pores, many medium roots, many black Mn concretions
	Bwg2	42-105	10YR 5/2 (greyish brown)	7.5 YR 4/4 (brown)	c	3msbk	vsvp	ds	Many fine pores, few very fine roots, few black Mn concretions
	Cg	105 - 200	10YR 5/2 (greyish brown)	7.5 YR 4/4 (brown)	c	3mcsbk	vsvp	-	Few very fine pores, few very fine roots

Table 1: Continue

Profile	Horizon	Depth (cm)	Munsell	Mottles	Texture	Structure	consistence	Boundary	Others
Cordinates = 07° 43' 30" N, 06° 45' 99" E, elevation 46 m									
BCS 3	Apg	0-18	10YR 3/1 (very dark grey)	10YR 5/8 (yellowish red)	cl	2mcsbk	sp	Cw	Many fine moderate pores, many fine medium roots, few medium Mn concretions, few ants
	Bwg1	18-47	10YR 6/1 (grey)	2.5 YR 4/8 (red)	c	2mcsbk	sp	cs	Common coarse pores, common fine roots
	Bwg2	47-104	10YR 5/2 (greyish brown)	10YR 4/8 (red)	c	3mcsbk	vsvp	gs	Common fine pores, few fine roots, few fine Mn concretions
	Bwg3	104-130	10YR 6/2 (gray)	2.5 YR 4/6 (red)	c	2m sbk	sp	cs	Common very fine pores, few fine roots, common black Mn concretions
	Cg	130-200	10YR 6/2 (light brownish grey)	2.5 YR 7/8 (yellow)	c	2mcsbk	sp	-	Common many very fine pores, few fine roots
Cordinates = 07° 43' 91" N, 06° 45' 64" E, elevation 38 m									
BSS 1	Ap	0-19	10Y 7/8 (yellow)	-	s	sg	ns;np	cs	Many medium pores
	C	19-35	2.5Y 5/6 (light olive brown)	-	s	sg	ns;np	-	Common many pores
Cordinates = 07° 44' 07" N, 06° 45' 59" E, elevation 38 m									
BSS 2	Ap	0-29	10YR 7/6 (yellow)	-	s	sg	ns;np	cs	Many medium pores
	C	29 - 45	2.5Y 6/6 (olive yellow)	-	s	sg	ns;np	-	Many medium pores

Structure-1: Weak, 2 = , nsnp: Non-sticky and non-plastic, Boundary-c: Clear, d: Diffuse, g: Gradual, s: Smooth, d: Diffuse, w: Wavy, Texture-c: Clay, cl: Clay loam, scl: Sandy clay loam, stl: Silty loam, stcl: Silty clay loam, s: Sand, ls: Loamy sand, l: Loam

Table 2: Physical characteristics of river Benue floodplain soils in Bassa, Kogi State, Nigeria

Profile location	Horizon depth (cm)	Particle size distribution Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})	Textural class	Sand/silt ratio
BLS 1 (Bassal loamy soils)	0-19	833.0	117.0	50.0	ls	7.12
(07°44' 10" N, 06°46' 68" E)	19-32	906.0	54.0	40.0	s	16.77
	32-69	853.0	127.0	20.0	ls	6.72
	69-126	603.0	137.0	260.0	scl	4.40
	126-200	653.0	117.0	230.0	scl	5.58
BLS 2 (Bassa Loamy soils)	0-12	166.0	614.0	220.0	stl	0.27
(07°43' 22" N, 06°45' 62" E)	12-82	146.0	574.0	280.0	stcl	0.25
	82-115	266.0	494.0	240.0	stl	0.54
	115-144	526.0	334.0	140.0	sl	1.57
	144-200	506.0	270.0	220.0	scl	1.87
Surface soil range		166.0-833.0	117.0-614.0	500.0-220.0		0.27-7.12
Surface soil mean		500.0	366.0	135.0	sl	3.70
Subsurface soil range		14.6-90.6	5.4-57.4	20.0-280.0		0.25-16.77
Subsurface soil mean		557.0	263.0	179.0	sl	4.71
BCS 1 (bassa clayey soils)	0-20	363.0	307.0	330.0	cl	0.11
(07°42' 63" N, 06°46' 26" E)	20-69	166.0	234.0	600.0	c	0.70
	69-119	146.0	234.0	620.0	c	0.62
	119-200	286.0	214.0	500.0	c	1.34
BCS 2 (bassa clayey soils)	0-19	186.0	21.4	600.0	c	0.84
(07°43' 51" N, 06°45' 99" E)	19-42	146.0	13.4	720.0	c	1.08
	42-105	166.0	15.4	680.0	c	1.07
	105-200	106.0	17.4	720.0	c	0.60
BCS 3 (bassa clayey soils)	0-18	246.0	354.0	400.0	c	0.69
(07°43' 30" N, 06°45' 99" E)	18-47	86.0	194.0	720.0	c	0.44
	47-104	86.0	174.0	740.0	c	0.49
	104-130	326.0	254.0	420.0	c	1.28
	130-200	126.0	354.0	520.0	c	0.35
Surface soil range		186.0-363.0	21.4-35.4	33.0-60.0		0.11-0.84
Surface soil mean		264.0	292.0	443.0	c	0.55
Subsurface soil range		860.0-326.0	134.0-354.0	420.0-740.0		0.35-1.34
Subsurface soil mean		164.0	212.0	624.0	c	0.80
BSS 1 (bassa sandy soils)	0-19	980.0	20.0	0.0	s	49.0
(07°43' 91" N, 06°45' 64" E)	19-35	980.0	20.0	0.0	s	49.0
BSS 2 (bassa sandy soils)	0-29	980.0	2.0	0.0	s	49.0
(07°44' 07" N, 06°45' 59" E)	29-45	980.0	2.0	0.0	s	49.0
Surface soil range		980.0-980.0	20.0-20.0	0.0-0.0		-
Surface soil mean		980.0	20.0	0.0	s	49.0
Subsurface soil range		980.0-980.0	20.0-200.0	0.0-0.0		-
Subsurface soil mean		980.0	20.0	0.0	s	49.0

ls: Loamy sand, s: Sandy, scl: Sandy clay loam, stl: Silty loam, stcl: Sandy clay loam, sl: Sandy loam, cl: Clay loam, c: Clay

Chemical characteristics: The surface mean pH values vary from 5.5 in BCS to 6.2 in both BLS and BSS profiles suggesting that the soil reaction varies from strongly acid to slightly acid in the floodplain (Table 3). The exchangeable acidity values of the soils are low to moderate with surface mean values of 0.20, 2.23 and 0.24 cmol kg^{-1} for BLS, BCS and BSS, respectively, depicting the strongly and slightly acidic nature of the soils. The soils (BLS and BSS) are low in content of organic carbon and total nitrogen except for a moderate surface mean value of 1.43% in BCS. The generally low organic carbon may be the result of poor vegetative growth and fast rate of

Table 3: Chemical characteristics of river Benue floodplain soils in Bassa Local Government Area, Kogi State, Nigeria

	Horizon	pH	Org. C	Total N	Avail. P	Exchangeable Bases (cmol(+)(kgG¹)				EA	ECEC	
Profile location	depth (cm)	H_2O	(g kgG¹)	(g kgG¹)	(mg kg⁻¹)	Ca	Mg	K	Na	(cmol kgG¹)	(cmol kgG¹)	BS (%)
BLS 1 (Bassal loamy soils)	0-19	6.5	30.0	0.20	3	9.0	0.8	0.13	0.11	0.08	10.12	99.0
(07°44= 10== N, 06°46= 68== E)	19-32	6.0	10.033	0.10	13	5.4	1.0	0.09	0.07	0.16	6.72	98.0
	32-69	5.8	0.60	0.10	13	5.8	1.4	0.09	0.08	0.40	7.77	95.0
	69-126	6.3	0.80	0.10	5	11.2	4.2	0.14	0.11	0.16	15.81	99.0
	126-200	7.3	0.40	0.00	9	12.6	4.4	0.15	0.12	0.20	8.67	98.0
BLS 2 (Bassa Loamy Soils)	0-12	5.9	15.5	1.30	13	18.0	3.2	0.17	0.11	0.32	21.80	98.0
(07°43= 22== N, 06°45= 62== E)	12-82	6.0	14.9	1.20	6	14.0	5.6	0.16	0.12	0.40	20.28	98.0
	82-115	6.0	9.90	0.80	5	15.6	2.2	0.18	0.13	0.40	18.51	98.0
	115-144	6.3	3.20	0.20	5	11.2	0.8	0.12	0.09	0.28	12.49	98.0
	144-200	6.2	6.60	0.50	5	14.2	2.8	0.13	0.10	0.28	17.51	98.0
Surface Soil Range		5.9-6.5	30.0-15.5	0.20-1.30	3.13	9.0-18.0	0.8-3.2	0.13-0.17	0.11-0.11	0.08-0.32	10.12-21.80	98.0-99.0
Surface Soil Mean		6.2	9.30	0.80	8	13.5	2.0	0.15	0.15	0.20	15.96	99
Subsurface Soil Range		5.8-7.3	0.40-.14.9	0.00-0.12	5-13	5.4-15.6	0.8-5.6	0.09-0.18	0.09-0.18	0.16-0.40	6.72-20.28	6.72-20.28
Subsurface Soil Mean		6.2	4.70	0.40	8	11.3	2.8	0.13	0.13	0.29	13.47	13.47
BCS 1 (Bassa clayey Soils)	0-20	6.3	10.9	0.90	3	15.8	3.2	0.15	0.12	0.32	19.59	98.0
(07°42= 63== N, 06°46= 26== E)	20-69	6.1	3.40	0.20	4	8.0	2.6	0.12	0.11	0.28	11.11	97.0
	69-119	7.2	1.20	0.10	5	20.6	8.6	0.18	0.13	0.00	29.51	100.0
	119-200	7.4	0.40	0.10	6	18.0	5.0	0.19	0.13	0.00	23.32	100.0
BCS 2 (Bassa clayey Soils)	0-19	5.2	10.9	10.9	3	14.2	6.6	0.16	0.11	3.12	24.19	87.0
(07°43= 51== N, 06°45= 99== E)	19-42	5.2	30.0	30.0	4	13.2	7.6	0.15	0.10	4.00	25.05	84.0
	42-105	5.2	3.20	3.20	3	15.8	2.6	0.15	0.09	3.04	21.68	86.0
	105-200	5.0	20.0	20.0	4	10.4	5.4	0.14	0.09	1.76	17.79	90.0
BCS 3 (Bassa clayey Soils)	0-18	4.9	21.1	1.80	3	13.6	5.6	0.14	0.12	3.36	22.82	85.0
(07°43= 30== N, 06°45= 99== E)	18-47	4.6	4.60	0.30	3	12.4	8.0	0.13	0.10	6.96	27.59	75.0
	47-104	4.7	3.60	0.20	4	10.6	5.8	0.13	0.09	8.00	24.62	67.0
	104-130	5.6	20.0	0.10	5	9.0	3.0	0.09	0.07	1.76	13.92	87.0
	130-200	5.3	2.60	0.10	5	13.4	6.2	0.15	0.09	0.96	20.80	95.0
Surface soil range		4.9-6.3	10.9-21.1	0.90-1.80	3-3	13.6-15.8	3.2-6.6	0.14-0.16	0.11-0.12	0.32-0.80	19.59-24.19	85.0-98.0
Surface soil mean		5.5	14.3	4.50	3	14.5	5.1	0.15	0.12	0.5	22.20	90.0
Subsurface soil range		4.6-7.4	0.40-4.60	0.10-3.20		8.0-20.6	2.6-8.6	0.09-0.19	0.07-0.13	0.0-1.6	11.11-29.51	67.0-100.0
Subsurface soil mean		5.6	2.60	0.90		13.1	5.4	0.1	0.10	0.78	21.54	81.1
BSS 1 (bassa sandy soils)	0-19	6.0	0.20	0.0	4	7.2	1.0	0.10	0.07	0.24	8.61	97.0
(07°43= 91== N, 06°45= 64== E)	19-35	6.4	0.20	0.0	5	4.2	1.2	0.08	0.06	0.16	5.70	97.0
BSS 2 (bassa sandy soils)	0-29	6.5	0.30	0.10	7	4.8	0.8	0.09	0.05	0.24	5.98	96.0
(07°44= 07== N, 06°45= 59== E)	29-45	6.6	0.40	0.10	4	6.2	0.8	0.10	0.07	0.20	7.37	97.0
Surface range		6.0-6.5	0.20-0.30	0.0-0.10	4-7	4.8-7.2	0.8-1.0	0.09-0.10	0.05-0.07	0.24-0.24	5.98-8.61	96.0-97.0
Surface soil mean		6.3	0.30	0.10	6	6.0	0.9	0.10	0.06	0.24	7.30	97.0
Subsurface soil range		6.4-6.6	0.20-0.40	0.0-0.10	4-5	42.2-6.2	0.8-1.2	0.08-0.10	0.06-0.07	0.16-0.20	5.70-7.37	97.0-97.0
Subsurface soil mean		6.5	0.10	0.10	5	5.2	1.0	0.09	0.07	0.18	6.54	97.0

decomposition under the prevailing high temperature of the ecological zone. Organic carbon is irregularly distributed with depth, reflecting alluvial deposits associated with floodplains.

The available phosphorus is low across the soil units (BLS, BCS and BSS) with surface mean values of 8, 3 and 6 mg kg^{-1}, respectively. These low values could be associated with high contents of sesquioxides, high phosphorus absorption capacity and the acidic nature of the soils. Previous researchers have reported low phosphorus contents in floodplain/wetland soils (Stoeckel and Miller-Goodman, 2001; Egbuchua, 2007; Ukabiala, 2012). Calcium and magnesium are the predominant exchangeable bases and the cation distribution is Ca>Mg>K>Na in all the soils (Table 3). Effective cation exchange capacity (ECEC) in surface soils occurs in abundance in the order BCS: (22.2 cmol k^{-1})>BLC (15.5 cmol kg^{-1})>BSS (7.30 cmol kg^{-1}), indicating that the cation dominates the clay fraction (Ogban and Babalola, 2009; Hossain *et al*., 2011; Ukabiala, 2012). The mean base saturation percentage values are high (81-99%) across the soil units, indicating the presence of soluble forms of basic cations in soil solution and that the applied fertilizers would be in available forms for crop uptake in the soil.

Mineralogical characteristics

Quartz: Quartz is an important mineral and intrinsic component of sand sized grains and silt fraction of soils (Oliveira *et al*., 2004; Akpan-Idiok and Ukwang, 2012). The x-ray powder diffraction data show that quartz constitutes about 30.5-35.1% and 20.6-25.9% in silt-clay fraction of surface and subsurface of Bassa Loamy Soil (BLS) and Bassa Clay Soil (BCS) units, respectively (Fig. 2a, b). The low percentage (<40%) suggests that the soils are in early stage of weathering. Previous researchers have obtained quartz in silt fraction of floodplain/wetland soils in Nigeria

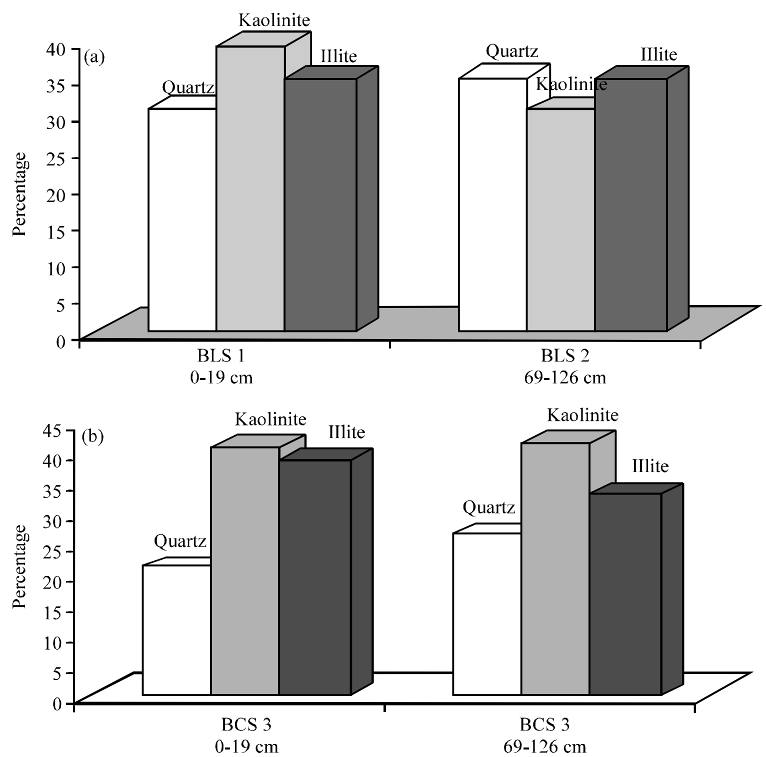

Fig. 2(a-b): Distribution of minerals in silt-clsy fraction of (a) BLS and (b) CS unit in river Benue floodplain, Kogi state, Nigeria

(Chikezie *et al*., 2010; Ogbaji, 2010; Ukabiala, 2012). Quartz is an agricultural limitation in terms of fertility, but its association with other soil elements ensures structural development, water permeability, biomass productivity, aeration and being a component of soil medium that provides nutrients for plan uptake (Devnita, 2009; Chikezie *et al*., 2010). The x-ray diffractograms of the mineral are shown in Fig. 3a-d.

Kaolinite: Kaolinite is another most abundant clay mineral in the silt-clay fraction of river Benue floodplains. It is known to be one of the most widespread clay minerals in humid tropical soils which is the product of acidic weathering (White and Dixon, 2002; Hossain *et al*., 2011). The x-ray powder diffraction data show that kaolinite accounts for 30.2-39.4 and 40.6-41.4% in BLS and BCS units, respectively (Fig. 2a,b). This percentage range of kaolinite is rated low (<40%), depicting that the soils are in the early weathering stage. Though kaolinite is a weathering product of feldspar, almost all primary silicates have been listed as precursor minerals of kaolinite (Devnita, 2009; Chikezie *et al*., 2010; Akpan-Idiok and Solomon, 2012). Kaolinite is important as it interacts with other soil elements to ensure structural stability, water permeability, biomass productivity, resistance to erosion, adsorption of basic cations/metals depending on the pH of the soil environment and being a component of soil medium that provides nutrients for plant uptake (Al-Farraj, 2008; Akpan-Idiok and Ukwang, 2012). Figure 3a-d present the x-ray diffractograms of the mineral.

Illite: Illite is a non-swelling (mica type) mineral occurring in pedogenic and sedimentary environment and is mostly inherited from parent materials (Hassannezhad *et al*., 2008). It has a chemical formular of $Ki(H_2O)Al_2Si_3Al_{10}(OH)_2$. The x-ray powder diffraction data indicate that illite constitutes about 34.6-34.7 and 32.7-38.8% in silt-clay fraction of surface and subsurface soils of BLS and BCS units, respectively (Fig. 2a, b). Illite concentration in the floodplain soils is rated low (<40%) probably because of the poor drainage conditions that favours leaching and release of K from the mineral and possible transformation to the other 2:1 clay minerals. The same low percentage was reported by Hassannezhad *et al*. (2008) for paddy soils of Mazandaran Province in Northern Iran. The alteration of illite mineral can be associated with the decrease of layer charge and the degradation of crystal structure through the pedogenesis under the seasonally reduced condition of the floodplain soil (Lee *et al*., 2003; Hassannezhad *et al*., 2008; Ukabiala, 2012). Generally, the study is consistent with the findings of Adegbite and Ogunwale (1994), who obtained kaolinite, degraded mica and quartz in clay fraction of Abugi floodplain soils in Kogi State, Nigeria. The x-ray diffractograms of the mineral are presented in Fig. 3a-d.

Classification: On the basis of morphological, physical, chemical and mineralogical characteristics, the soils are characterized according to USDA soil classification system (Table 4). The BLS and BCS

Table 4: Classification of soils from the river Benue floodplain in Bassa, Kogi State, Nigeria

Order	Suborder	Great group	Subgroup	Family	Soil unit	FAO/UNESCO equivalent
Inceptisols	Ustrepts	Ustropepts	Fluventic ustropepts	Loamy, mixed isohyperthermic	BLS	*Eutric fluvisols*
Inceptisols	Ustrepts	Ustropepts	Vertic-fluventic ustropepts	Clayey, mixed isohyperthermic	BCS	*Vertic cambisols*
Entisols	Psamments	Quartizipsamment	Oxyaquic quartzipsamments	-	BSS	*Arenic fluvisols*

BLS: Bassa loamy soils, BCS: Bassa cleyey soils, BSS: Bassa sandy soils

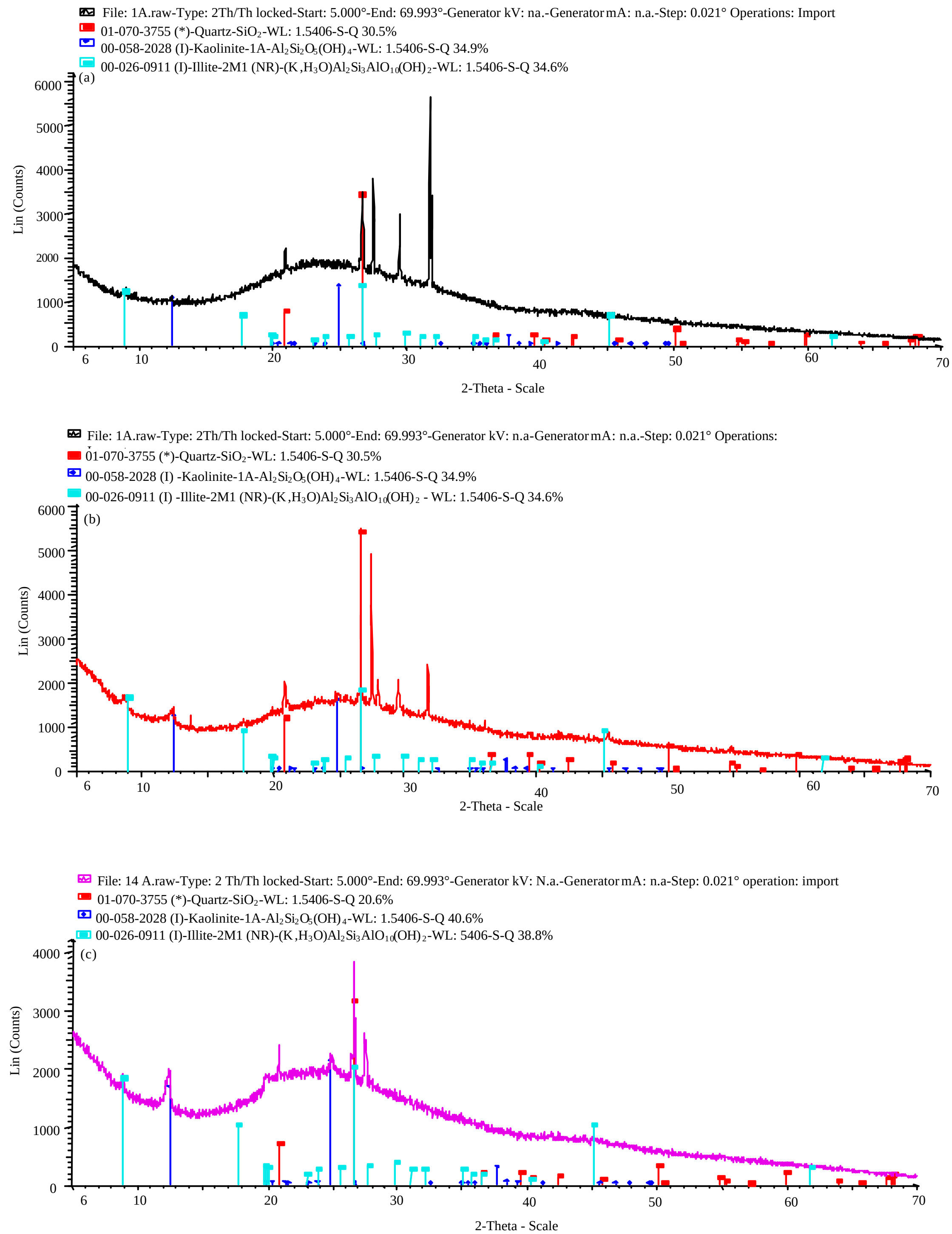

Fig. 3(a-d): Continue

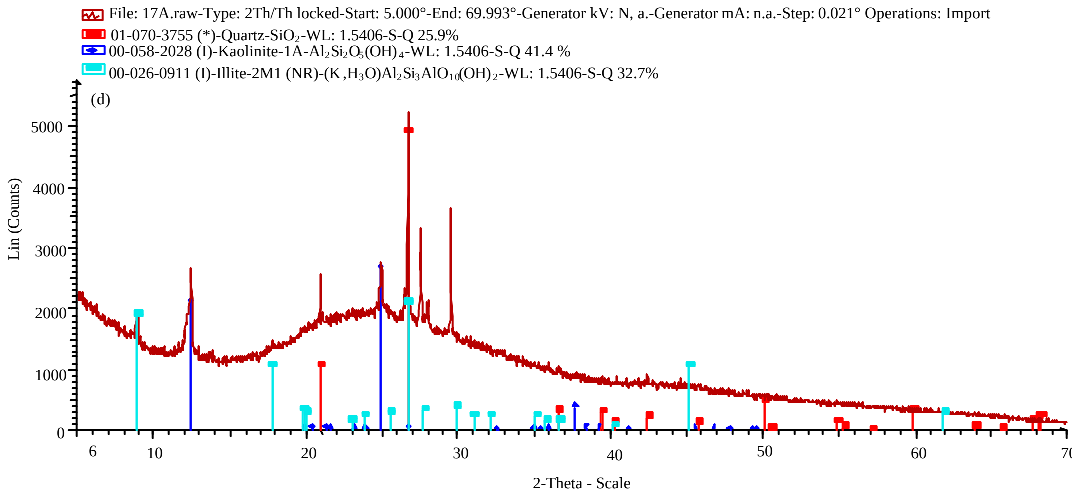

Fig. 3(a-d): X-ray diffractogram of silt clay fraction at depths 0-19 cm (BLS 1a) and 69-126 cm (BLS 1b) obtained from BLS 1 in river Benue floodplain

have cambic horizons along with an ochric epipedon with moist colour value of 4 or more, chroma of 2 or less and minimal horizon development in the seasonally flooded plain and are placed in the order of Inceptisols. With ustic soil moisture regime occurring in the study location, the soils fit Ustrept suborder and being in the tropical environment, they are further placed into Ustropepts great group. For profile BLS 1 showing characteristics of wetness/flooding, matrix colour chroma ≤2 and redox concentrations as manifested by common medium to coarse distinct reddish yellow mottles below 70 cm depth, the profile belongs to Fluventic Ustropept subgroup. At the family level, the pedon fits loamy, Mixed, Isohyperthermic.

At the subgroup level, the profiles BLS 2 and BCS 1, 2 and 3 are further characterized as Vertic Fluventic Ustropepts because of matrix colour chroma ≤2, red and strongly brown mottles and vertical cracks from the surface down the profiles. At the family levels, the soils are classified as Clayey, Mixed, Isohyperthermic. The classification of soils at family level of USDA Soil Taxonomy has great agricultural significance in terms of understanding the mineralogical impacts on soil productivity, mineral transformation and degree of soil development. Above all, this family level classification can serve as useful vehicle for crop production and agrotechnology transfer (Hossain *et al*., 2011).

The BSS 1 and 2 profiles represent soils in the valley bottom and consist of coarse sandy alluvial deposits with no evidence of development of pedogenic horizons and are placed in the order, Entisol. With high sand content (>960.0 g kg^{-1}), the soils fits the suborder, Psamments and the Great group, Quartzipsamment as the particles can pass 2.0 mm mesh and further as Oxyaquic Quartzipsamment as the soils are saturated with water within 100 cm (under aquic conditions). The FAO (2006) equivalents are Eutric Fluvisols, Vertic Cambisols and Arenic Fluvisols.

CONCLUSION

The study highlights the morphological, physical, chemical and mineralogical characteristics of river Benue floodplain in Bassa Local Government Area of Kogi State, Nigeria. The soils are derived from recent alluvial-collovial deposits, imperfectly to poorly drained with light to heavy textured materials. The soils are also characterized by strongly to slightly acid in reaction, low contents of organic carbon, total nitrogen, available P and moderate to high cation exchange capacity. The percentages of the minerals in silt-clay fraction (quartz, kaolinite and illite) are similar in surface and subsurface soils in BLC and BCS units, indicating that they are under the same geologic and climatic conditions and are undergoing the same rate of weathering. Therefore, soil fertility management practices should focus on maintaining and increasing organic carbon, nitrogen and phosphorus to balance the nutrient composition in the soils.

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