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Characterization and classification of floodplain soils of different geomorphic surfaces along onumirikwa River Ulakwo Owerri Southeastern Nigeria

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Abstract

Investigating the degree of variability of soil properties along a river slope is important for planning appropriate and sustainable agriculture. The study was conducted on soils of a floodplain formed by the Onumiriukwa river slope in Ulakwo, Southeastern Nigeria. Three (3) profile pits were dug, one on each geomorphic unit (upland, terrace and back- swamp) using a transect method. Soil samples were collected from each horizon based on soil profile differentiation. Samples collected were sent for laboratory analysis, and data collected were subjected to statistical analysis using the coefficient of variation (CV). Results showed that soil properties differed in their degree of variation among different geomorphic units. Sand content ranged from 626.0-806.6 g/kg, with low variations in upland (CV = 2.53%), back-swamp (CV = 2.56%) and terrace (CV = 6.41%). The pH varied as soils were strongly to moderately acidic which ranged from 5.37 – 5.93, with low variations in upland (CV = 0.98%), terrace (CV = 0.81%) and back swamp (CV = 3.99%). High CV was recorded in total nitrogen with upland, terrace and back swamp having 64.77%, 63.04% and 80.85% respectively. B-Sat had high CV in back-swamp (CV = 35.44%), moderately in upland (CV = 31.46%) and terrace (23.52%). Soils were classified as Arenic Kandiudults (soil taxonomy) and Dystric Acrisols (FAO/UNESCO). These soils were constrained with low nutrient holding capacities and moderate to strong acidity. In recommendation, it is vital to implement an integrated nutrient management system that will sustain and improve the productive capacity of these soils, by adopting a balanced use of liming materials, organic (biochar) and inorganic nutrient (fertilizer) sources.

Keywords: Floodplain soils, Onumiriukwa River, Geomorphic units, Acid ultisol, Arenic Kandiudult.

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1.0 Introduction

The high competition in land usage by land users and degradation of most agricultural uplands has led to a decline in food production. This trend could be attributed to ever-growing population and the high demand for land for other purposes. To increase food production, there is a need to study floodplain soils, considering their huge potentials for agricultural production. This will require a proper soil assessment for land use planning and utilizing available land resources. Floodplain soils constitute a huge reserve of available nutrients and are useful for agricultural development (Akpan-Idiok and Ogbaji, 2013). In Africa, about 12 million hectares of floodplain are used for agriculture; in West Africa, about 47 % are used for rice cultivation, while in Nigeria, 65,783 hectares (7.2 %) of the total area was identified for agricultural production (Ojanuga *et al*., 2003; Wakatsuki, 2004).

Floodplain soils are derived from alluvial deposits and are located in areas that are susceptible to flooding during the wet season and are somewhat well-drained during the dry season (Carsky, 1992). Geomorphic surfaces are influenced by landscape positions, as these affect runoff, drainage, erosion and depth of the soil, as well as formation and development of soils. Most soil properties like soil reaction (pH), organic carbon, sand and clay contents showed high correlations with landscape positions (Wang *et al*., 2000; Mulugeta and Sheleme, 2011). Soil characterization is the key to soil productivity and determines options for soil management (Onyekwere *et al*., 2011). It is useful in the classification and determination of physical and chemical properties of soils that are not observable in the field examination (Nortcliff, 2006). Soil classifications systematically arrange soils into groups or categories base on distinguishing characteristics, as well as the criteria that dictate choices in use. It serves as a basis for efficient land suitability evaluation, planning, and management (Teshome Yitbarek *et al*., 2006; Onyekwere *et al*., 2011). Characterization and classification of Onumirikwa river floodplain soils are important in the evaluation of their potentials for crop production. Detailed information on soil resources is required to assess their potentials to produce food, fibre, and fuel for present and future generations (Teshome Yitbarek *et al*., 2006).

The knowledge of these soils is important in making decisions on land use plans and crop production, understanding their characteristics, applying proper management strategies for nutrient and moisture requirements provides a guide to actualizing maximum crop production. However, reliable soil data in the study site is not adequately available, hence, the essence of this research, as the data generated will help floodplain users manage these soils for agriculture and environmental sustainability. This study was conducted to characterize and classify soils of Onumirikwa river floodplains, and provide management and conservation strategies to facilitate the transfer of knowledge.

2.0 Materials and methods

2.1 Description of the study area

The study was carried out on geomorphic surfaces (back-swamp, terrace and upland) of Onumirikwa river floodplain Ulakwo, Owerri North Imo State. Located within Latitude 05^o 00' and 05^o 30' N and Longitude 07^o 00' and 07^o 30' E, covering a total area of about 2,664 km^2 within a tropical climate characterized with high relative humidity, atmospheric temperature and rainfall. The mean annual atmospheric temperature ranges from 28^{0}C to 31^{0}C with February and April as the hottest period (Monanu, 1975; NIMET 2015). Mean annual rainfall range from 2500mm – 3000mm with the highest intensity between April to November (Inyang, 1975; Obi and Salako, 1995; NIMET, 2015). The mean elevation is about 70m above sea level. Geology and geomorphology are coastal plain sands, influenced by fluvial deposition of alluvium (Orajaka, 1975). It is with the lowland area of Southeastern Nigeria and greater portions have flat topography (Ofomata, 1975; Onweremadu *et al*., 2006). The vegetation is that of secondary forests-savannah mosaic, as anthropogenic activities have reduced the density of these forests. Some of the plants conspicuously growing wild include oil palm (*Elaeis guineensis*), raffia palm (*Raphia hokeri*), mango (*Mangifera indica*), Avocado (*Persea americana*), kola (*Kola nitida*) and various species of shrubs, herbs and grasses. Cultivated crops in the area include maize (*Zea mays*), Yam (*Dioscorea spp*), cassava (*Manihot esculenta*), fluted pumpkin (Telfairia accidentalis), pumpkin (Cucurbita spp), et cetera. The major agricultural activity practised by the people in these areas is food crop production. Crops like cassava and yam are intercropped with maize, fluted pumpkin, and sometimes African yam bean at subsistence scale.

Soil sampling and laboratory analysis

A reconnaissance survey was carried out before field operations. The site selected for this study was guided by observed variability in geomorphic features form of the terrain change with movement towards the river. It was a free survey by the transect approach. Traverse was cut across running from the upland passing through terrace and to the back-swamp. A pedon was dug on each physiographic position (upland, terrace and back-swamp) giving rise to a total of three pedons, described and sampled according to genetic horizons for characterization and classification (FAO, 2006; Soil Survey Staff, 2014). Core samples of each horizon were obtained for estimation of bulk density and hydraulic conductivity. Equal number of core samplers of volume 98.21cm^3 (i.e. diameter of 5cm and height of 5cm) were also used to collect samples for bulk density determination. Also, soil samples (except those for bulk density determination and hydraulic conductivity) were air-dried, sieved with a 2mm mesh sieve, re-bagged, relabeled, and stored for laboratory analysis. The soil samples were analyzed for certain selected morphological, physical and chemical properties.

Particle size distribution was determined by the hydrometer method according to the procedure of Gee and Or, (2002). Bulk density was determined by the core method (Grossman and Reinsch, 2002). Gravimetric moisture content was determined by oven-drying saturated soil samples for 24 hours and the amount of moisture was calculated in per cent (Obi, 1990). Ksat was determined using the constant head parameter method as described by Topp and Dane (2002). Soil pH was determined in 1:2.5 soil-liquid ratios using a pH meter (Thomas, 1996). Total nitrogen was determined by Kjeldahl digestion method (Bremmer 1996). Organic carbon was determined by the wet digestion method (Nelson and Summers, 1982). Available phosphorus was determined using the Bray II method as described by Olsen and Sommers (1982) Exchangeable acidity was determined by leaching the soil with 1N KCl and titrating with 0.05N NaOH (Mclean, 1982). Exchangeable bases were extracted with 1N NH_4O_{AC} solution, with exchangeable calcium and magnesium obtained by EDTA complexometric titration. Exchangeable potassium and sodium were estimated by flame photometry (Jackson, 1962). Cation exchange capacity (CEC) was determined by aluminium acetate leaching at pH 7 (Blackemore *et al*., 1987). Other derivative parameters which are not directly determinate in the laboratory by experimentation were estimated or calculated from the values of the measurable properties listed above. % Total porosity (F) = 1 – bulk density (g/cm^3) / particle density (2.65g/cm^3) x 100. % Base saturation = Total exchangeable bases/cation exchange capacity x 100.

The variability of soil properties within the pedons was determined using the coefficient of variation (CV), ranked by Wilding (1985) and Wilding *et al.* (1994), where CV < 15 % is low variation, CV ≥15 % ≤ 35 is moderate variation, and CV > 35% is high variation. The statistical analyses were done using GENSTAT statistical software version 8.1. Soil classification was done using USDA Soil Taxonomy (Soil Survey Staff, 2014) and World Reference Base (WRB) IUSS Working Group WRB (2015) classification systems.

3.0 Results and Discussions

3.1 Morphological properties of soils

Results of the morphological properties of the study area are presented in Table 1. The geomorphic surfaces had a level or flat (back-swamp) to undulating (upland and terrace) topography on coastal plain sands parent material influenced by alluvium deposition. The soils were all deep (> 150cm) and well-drained except in subsoil of back-swamp (Bt3) with moderate drainage at the 125 – 160cm depth. They have dark brown (10 YR 4/3) to yellowish brown (10 YR 5/6) sandy loam – sandy clay loam surfaces over reddish-brown (5 YR 5/4) to red (2.5 YR 5/8) sandy loam – sandy clay loam subsoils. The red colour could be a result of the presence of sesquioxides. Colour is a function of textural make-up, chemical and mineralogical compositions of soils influenced by the topographic position and moisture regime (Udoh and Lekwa, 2014). The structure of the soils varied from weak, very fine to moderate crumb, moderate subangular and angular blocky and single grained. The presence of high clay fractions could be attributed to the subangular and angular blocky, while single grained structure as witnessed in A horizon of the Upland (0 -15 cm) could be a result of the inert nature of the parent material (Udoh and Lekwa, 2014). The consistency of these soils using the feel method indicated coarse-textured, high sand content, very friable, friable and firm soils. Root abundance in the different horizons were common and medium roots surface soils and some subsurface soils; while very fine and fine few roots in most of the horizons. The boundary forms ranged from abrupt to clear in Terrace and Upland, and gradual to clear in back-swamp. The horizon boundaries, from abrupt to clear depict distinctness, while gradual to clear describes the landscape position (topography) (Udoh and Lekwa, 2014).

Physical properties of soils

Results of the physical properties of soils of the study area are presented in Table 2. Sand ranges from 626 to 806 g/kg of the fine earth fraction (< 2 mm) of the soils. The surface horizons showed a high content than the subsurface horizons. Mean values of 698, 723 and 647 g/kg were obtained in back-swamp, Terrace and Upland respectively. The pedons recorded low variation (CV ≥ 2.53 % ≤ 6.41 %), which is a result of the homogeneity of the soils studied. Sandiness of the soil could be related to the parent material (alluvium) from where the soils were formed. Silt ranges from 40 to 140 g/kg of the fine earth fraction of the soils. Mean values of 100, 50 and 45 g/kg were recorded in back-swamp, Terrace and Upland respectively, with a moderate variation of (CV ≥ 21.91 % ≤ 31.62 %), in all pedons studied. Clay ranges from 154 to 334 g/kg of the fine earth fraction of the soils, with low variations (CV ≥ 6.20 % ≤ 11.29 %) in back-swamp and Upland, and moderate variation (CV 17.29 %) in Terrace. The B horizons of most of the soils are higher in clay content than the overlying and underlying horizons. This could be as a result of fine particle deposition or illuviation, faunal activities and erosion (Osujieke *et al*., 2018). Silt/clay ratio (SCR) ranges from 0.12 to 0.72 with moderate variations (CV ≥ 19.73 % ≤ 24.32 %) in Terrace and Upland and high variation (38.87 %) in back-swamp. This ratio is less than unity (< 1) in all soils studied, which showed that soils had undergone ferralitic pedogenesis or intense weathering (Landon, 1991; Essoka and Esu, 2000). Silt/clay ratio is used as a yardstick to evaluate clay migration, stage of weathering and age of parent material of soils (Yakubu *et al*., 2008). Bulk density ranges from 1.17 to 1.39 g/cm^3 in all profiles with mean values of 1.24, 1.26 and 1.32 g/cm^3 in back-swamp, Terrace and Upland respectively, and recorded a low variation (CV ≥ 4.71 % ≤ 8.30 %) as a result of homogeneity down the profiles.

Bulk density increased with depth in all pedons, which could be due to less organic matter content, compaction/sorting of materials of overlying layer and clay movement down the profile (Onweremadu *et al*., 2007, Ndukwu *et al*., 2009, Anikwe, 2010). Bulk density values of the pedons were within the range for root penetration, aeration, movement of nutrients and water for tropical soils (Landon, 1991; Brady and Weil, 2002). Moisture content ranges from 13.59 to 30.12 % in the soils, with mean values of 22.33, 20.41 and 21.10 % in back-swamp, Terrace and Upland respectively. However, the pedons recorded a low variation (CV ≥ 12.43 % ≤ 14.05 %) in Terrace and Upland, and a moderate variation (CV= 29.75 %) in back-swamp. High mean value and moderate variation recorded in back-swamp could be attributed to the organic carbon content, as an increase in organic matter increases moisture contents in soils, and vice versa (Ndukwu *et al*.;2009; Anikwe, 2010). Total porosity contrasted with the distribution of bulk density and ranged from 47.55 to 55.85 %, with mean values of 53.36, 52.58 and 50.38 % in back-swamp, Terrace and Upland respectively. The pedons had low variation (CV ≥ 4.34 % ≤ 7.31 %); and high values were recorded in surface horizons, which indicates the availability of soil air, water, aerobes and root abundance, which have beneficial effects on the agronomic stability of soil sphere (Oti, 2007). KSat values ranged from 0.33 - 1.64 cm^3/hr, with mean values of 1.14, 0.81 and 0.66 cm^3/hr in back-swamp, Terrace and Upland respectively. Moderate variation (CV ≥ 26.19 % ≤ 29.24 %) was obtained in the back-swamp and Terrace, while high variation (49.39 %) was recorded in Upland. The KSat values were slow to moderate (CV ≥ 0.80 % ≤ 6.0 %) (Landon, 1991), which could be attributed to the texture, structure, bulk density and organic matter contents of these soils (Osujieke *et al*., 2018). Clay dispersion ratio (CDR) ranges from 48.31 to 91.07 %, with low variation (CV ≥ 7.71 % ≤ 11.93 %) in back-swamp and Upland, while Terrace had moderate variation (19.16 %). Mean values of 57.12, 67.03 and 54.13 were obtained in back-swamp, Terrace and Upland respectively. Soils were sandy, and the coarse nature of the studied soils can in turn encourage erodibility due to an increase in the water table, rainfall and parent material. Soils were least susceptible to erosion with abundant macro pores capable of allowing entry and movement of water into the deeper layers of the pedons. All soils studied were erodible; having a CDR > 15% (Onweremadu, 2007).

Chemical properties of soils

Results of the chemical properties of soils are presented in Table 3. The soil reaction pH (H_2O) and pH (KCl) ranges from moderately acid (5.37 – 5.93) (CV ≥ 0.81 % ≤ 3.99 %) and strongly to moderately acid (4.58 – 5.11) (CV ≥3.06% ≤ 30.33%) respectively. Mean values of pH (H_2O) and pH (KCl) in back-swamp, terrace and upland were 5.58, 5.45, 5.43 and 4.90, 4.86, 4.88 respectively. The pH difference {i.e pH(KCl) - pH (H_2O)} was negative in all horizons indicating the nature of silicate mineralogy in the soils. The pH of soils was generally acidic with a somewhat increase down the depth which could be due to flooding and leaching of basic cations (Ogg *et al*., 2017). Organic carbon content (g/kg) of soils ranged from 0.09 to 1.98 with high variation (CV ≥ 73.96 % ≤ 85.56 %) and mean values of 0.91, 0.79 and 0.84 obtained in back-swamp, terrace and upland respectively. Organic carbon decreased down the horizons, showing high values in surface soils which could be due to decomposed, fresh and undecomposed plant materials. Floodplain soils are known for contrasting values in organic carbon content as a result of constant fluvial deposition and slow microbial decomposition due to water saturation (Uduak *et al*., 2014). The low organic carbon content of these soils could be improved using an alternative solution like biochar and fertilizer additions. Total nitrogen (TN) values ranged 0.02 to 0.19 % with high variation (CV ≥ 63.04 % ≤ 80.85%), and back-swamp, terrace and upland recorded mean values of 0.10, 0.09 and 0.09 respectively. Like organic carbon content, total nitrogen had higher values on surface soils though the most deficient nutrient in most tropical soils and generally below the critical level in soils studied (< 1.0) (Esu, 1991). It could be due to the high rate of mineralization, leaching and immobilization. Available phosphorus (AP) ranged from 2.20 to 5.40 mg/kg with moderate variation (CV ≥ 15.27 % ≤ 34.94%) and mean values of 3.0, 2.40 and 3.68 obtained in back-swamp, terrace and upland respectively. The values of AP were higher in upland than back-swamp and terrace, and these low values could be due to pH levels (strong adsorption of nutrients by soil colloids), erosion, leaching and low organic matter (Uzoho, 2005; Umeugochukwu *et al*., 2019). Among the exchangeable cations calcium ranged from 0.40 to 2.40 cmol/kg with moderate to high variation (CV ≥ 23.76 % ≤ 60.96%) and mean values of 1.36, 1.27 and 0.63 recorded in back-swamp, terrace and upland respectively; magnesium ranged from 0.40 – 1.20 cmol/kg (CV ≥ 38.50 % ≤ 55.94%) with mean values of 0.64, 0.67 and 0.60 in back-swamp, terrace and upland respectively; potassium ranged from 0.01 to 0.09 cmol/kg (CV ≥ 41.61% ≤ 68.18%) with mean values of 0.04, 0.02 and 0.04 in back-swamp, terrace and upland respectively; sodium ranged from 0.01 to 0.24 cmol/kg (CV ≥ 43.48% ≤ 60%) with mean values of 0.16, 0.14 and 0.03 in back-swamp, terrace and upland respectively. The soils were low in exchangeable bases (although calcium (Ca^{2+}) and magnesium (Mg^{2+}) were dominant) which could be as a result of parent materials, leaching and easily displacement in solution by aluminium (Al^{3+}) and hydrogen (H^+) ions. The cation exchange capacity (CEC) values ranged from 3.40 to 6.80 cmol/kg with moderate variation (CV ≥ 17.71% ≤ 28.83%) and mean values of 5.32, 4.67 and 5.10 were recorded in back-swamp, terrace and upland respectively. The values of CEC obtained in these soils were low (< 6.0 cmol/kg) to moderate (6 – 12 cmol/kg) (Noma *et al.,* 2005). Back-swamp had higher values than terrace and upland which could be as a result of organic carbon and texture of soils. Base saturation (%) ranged from 24.19 to 65.21 with moderate to high variation (CV ≥ 23.52% ≤ 35.44%) and mean values of 38.72, 23.52 and 32.94 obtained in back-swamp, terrace and upland respectively. The values were higher in surface than subsurface soils, which could be due to the high accumulation of organic residues (especially in back-swamp), brought about by the floodwater. Generally, the values were low (< 50%) which could be attributed to leaching, low organic carbon and an increase in the fine sand content (Obi, 2003). These low values indicate low nutrient reserve as seen in some floodplain soils of southeastern Nigeria.

Classification of soils

The soils were classified according to the USDA Soil Taxonomy (Soil Survey Staff 2014) and correlated with the World Reference Base (WRB) for soil resources (FAO/IUSS 2015) legend. Considering the criteria of the USDA Soil Taxonomy (Soil Survey Staff 2014), all soils of the representative sites met the requirement for placement in the soil order-Ultisols (acidic and leached soils within the profile), low CEC of < 16 cmol/kg and base saturation (CEC at 1N NH_4O_{AC} pH 7.0) of less than 50 % at the 200cm depth below the minimal soil surface. The soils also occur in an environment with udic soil moisture regime (soil moisture control section is not dry in any part for as long as 90 cumulative days in normal years) and are free and well-drained. Therefore, these qualify the soils for placement in suborder Udults. The soils have a vertically continuous subsurface horizon, minimum thickness of surface horizon is 15cm, do not have a densic, lithic, paralithic or petroferric contact within the 150cm of the mineral soil surface. The soils have an argillic or kandic diagnostic subsurface horizons within the profile, organic matter content decreases progressively with depth, and qualifies as a sub-group of Kandiudults. The soils great groups were Arenic Kandiudults, as the soils met the sandy or skeletal particle size class criteria throughout a layer extending from mineral soil surface to the top of their kandic horizons. The World Reference Base (WRB) for soil resources (IUSS 2015) legend for these soils is Dystric Acrisols.

Table 1: Morphological properties of soils of the studied sites

Horizon	Depth (cm)	Colour (moist)	Textural Class	Structure	Consistency (moist)	Root	Drainage	Horizon boundary
BACKSWAMP								
A	0 – 26	B 10YR 5/3	SL	1, vf, cr	very friable	c,m	well drained	gradual/ smooth
AB	26 – 55	B 7.5YR 5/4	SL	1, vf, sbk	friable	vf, fw	well drained	clear/ smooth
Bt1	55 – 96	YB 10YR 5/6	SCL	1, vf, sbk	friable	m, c	well drained	clear/ smooth
Bt2	96 – 125	RB 5YR 5/4	SL	1, m, sbk	firm	f, fw	well drained	gradual/ wavy
Bt3	125 – 160	R 2.5YR 5/6	SCL	1, m, sbk	firm	-	moderately drained	-
TERRACE								
A	0 – 24	B 10YR 4/3	SL	1, vf, cr	friable	f, fw	well drained	abrupt/ wavy
AB	24 – 46	LB 7.5YR 6/4	SCL	1, vf, sbk	friable	f, fw	well drained	clear/ smooth
Bt1	46 – 68	YB 10YR 5/4	SCL	1, f, sbk	firm	c, m	well drained	gradual/ smooth
Bt2	68 – 92	RB 2.5YR 5/4	SCL	2, m, sbk	firm	c, m	well drained	clear/ smooth
Bt3	92 – 134	R 2.5YR 5/6	SCL	2, m, sbk	firm	-	well drained	clear/ smooth
Bt4	134 – 200	R 2.5YR 5/8	SCL	2, m, sbk	firm	-	well drained	-
UPLAND								
A	0 – 15	B 10YR 4/3	SCL	1, vf, sg	friable	c, m	well drained	abrupt/smooth
AB	15 – 68	YB 10YR 5/4	SCL	1, vf, sbk	firm	f, fw	well drained	gradual/smooth
Bt1	68 – 126	R 2.5YR 5/6	SCL	1, f, sbk	firm	f, fw	well drained	clear/ smooth
Bt2	126 – 200	R 2.5YR 5/8	SCL	2, m, abk	very firm	-	well drained	-

Colour (moist): B=brown, RB=reddish brown, YR=yellowish red, LB=light brown, R=red, YB=yellowish brown; **Structure**: sg = single grained, sbk= sub-angular blocky, cr=crumb; 1=weak, 2=moderate; vf=very fine, m=medium, f=fine, **Roots**: m,fw=medium, few; m,vf=medium, very few; m,c=medium, common; f,fw=fine, few;m,m=medium, many; m,fw=medium,few. **Boundary form**: w,c=wavy, clear; s,c=smooth, clear; s,d= smooth diffuse

Table 2: Physical properties of soils of the studied sites

Hori-zon	Depth (cm)	Sand (g/kg)	Silt (g/kg)	Clay (g/kg)	SCR	BD (g/ cm^3)	MC (%)	TP (%)	KSat (cm^3/hr)	CDR (%)
BACKSWAMP										
A	0 – 26	666	140	194	0.72	1.17	13.59	55.85	0.86	63.17
AB	26 – 55	706	100	194	0.52	1.23	19.32	53.58	1.02	58.16
Bt1	55 – 96	706	80	214	0.37	1.12	27.68	57.74	1.14	58.16
Bt2	96 – 125	706	120	174	0.69	1.27	30.12	52.08	1.03	54.76
Bt3	125 – 160	706	60	234	0.26	1.39	20.96	47.55	1.64	51.36
Mean		698	100	202	0.51	1.24	22.33	53.36	1.14	57.12
CV (%)		2.56	31.62	11.29	38.87	8.30	29.75	7.31	26.19	7.71
Ranking		LV	MV	LV	HV	LV	MV	LV	MV	LV
TERRACE										
A	0 – 24	806	40	154	0.26	1.21	20.12	54.34	0.62	91.07
AB	24 – 46	706	60	234	0.26	1.20	22.32	54.72	0.69	58.16
Bt1	46 – 68	726	40	234	0.17	1.25	19.28	52.83	1.06	55.12
Bt2	68 – 92	706	60	234	0.26	1.31	23.20	50.57	0.86	64.97
Bt3	92 – 134	666	60	274	0.22	1.22	21.40	53.96	1.09	63.17
Bt4	134 – 200	726	40	234	0.17	1.35	16.12	49.06	0.52	69.71
Mean		723	50	227	0.22	1.26	20.41	52.58	0.81	67.03
CV (%)		6.41	21.91	17.29	19.73	4.85	12.43	4.34	29.24	19.16
Ranking		LV	MV	MV	MV	LV	LV	LV	MV	MV
UPLAND										
A	0 – 15	666	40	294	0.14	1.24	23.40	53.21	0.94	63.17
AB	15 – 68	646	40	314	0.13	1.29	18.26	51.32	0.64	48.31
Bt1	68 – 126	626	40	334	0.12	1.35	18.84	49.06	0.43	51.07
Bt2	126 – 200	646	60	294	0.20	1.38	23.91	47.92	0.33	53.95
Mean		646	45	309	0.15	1.32	21.10	50.38	0.66	54.13
CV (%)		2.53	22.22	6.20	24.32	4.71	14.05	4.68	49.39	11.93
Ranking		LV	MV	LV	MV	LV	LV	LV	HV	LV

SCR=silt clay ratio, SL=sandy loam, SCL=sandy clay loam, MC=moisture content, BD=bulk density, TP=total porosity, Ksat=saturated hydraulic conductivity ,CDR = clay dispersion ratio

Table 3: Chemical Properties of soils of the studied sites

Horizon	Depth (cm)	pH (H_2O)	pH (KCl)	OC (%)	TN (%)	Avail P (mg/kg)	Ca	Mg	K	Na	TEB	TEA	CEC	BS (%)
					Cmol/kg									
BACKSWAMP														
A	0 – 26	5.39	4.88	1.98	0.19	2.80	2.40	1.20	0.09	0.22	3.91	0.60	6.80	57.50
AB	26 – 55	5.46	4.78	1.14	0.16	3.20	1.20	0.40	0.03	0.02	1.65	0.72	5.20	31.73
Bt1	55 – 96	5.67	4.99	0.66	0.05	3.10	2.00	0.80	0.02	0.16	2.98	1.04	5.60	53.21
Bt2	96 – 125	5.93	5.11	0.53	0.05	2.30	0.80	0.40	0.06	0.24	1.50	1.28	6.20	24.19
Bt3	125 – 160	5.45	4.75	0.26	0.02	3.50	0.40	0.40	0.02	0.17	0.99	1.12	2.80	35.36
Mean		5.58	4.90	0.91	0.10	3.0	1.36	0.64	0.04	0.16	2.06	1.02	5.32	38.72
CV (%)		3.99	3.06	73.96	80.85	15.27	60.96	55.94	68.18	53.09	54.53	29.73	28.83	35.44
Ranking		LV	LV	HV	HV	MV	HV	HV	HV	HV	HV	MV	MV	HV
TERRACE														
A	0 – 24	5.44	4.96	1.64	0.18	2.20	1.60	1.20	0.04	0.15	3.00	1.44	4.60	65.21
AB	24 – 46	5.43	4.77	1.58	0.13	2.20	1.20	0.80	0.03	0.20	2.23	1.04	5.40	41.30
Bt1	46 – 68	5.38	4.58	0.92	0.11	2.70	0.80	0.40	0.02	0.19	1.41	0.96	3.60	39.17
Bt2	68 – 92	5.49	4.88	0.26	0.06	2.40	1.60	0.80	0.01	0.06	2.47	1.12	5.80	42.59
Bt3	92 – 134	5.43	4.95	0.26	0.04	3.10	1.20	0.40	0.02	0.14	1.76	1.44	5.00	35.20
Bt4	134 – 200	5.50	4.99	0.09	0.03	2.00	1.20	0.40	0.02	0.08	1.70	0.88	3.60	47.22
Mean		5.45	4.86	0.79	0.09	2.40	1.27	0.67	0.02	0.14	2.10	1.15	4.67	45.12
CV (%)		0.81	3.21	87.75	63.04	16.56	23.76	49.03	41.61	43.48	28.09	21.01	19.67	23.52
Ranking		LV	LV	HV	HV	MV	MV	HV	HV	HV	MV	MV	MV	MV
UPLAND														
A	0 – 15	5.39	4.72	1.85	0.17	5.40	0.80	0.40	0.07	0.04	1.31	1.04	3.40	57.06
AB	15 – 68	5.48	4.99	0.84	0.08	3.40	0.40	0.40	0.03	0.02	0.85	0.72	4.60	24.34
Bt1	68 – 126	5.37	4.79	0.35	0.06	2.30	0.70	0.80	0.02	0.01	1.53	0.64	5.20	32.88
Bt2	126 – 200	5.46	5.02	0.31	0.04	3.60	0.60	0.80	0.05	0.05	1.50	0.80	5.00	39.00
Mean		5.43	4.88	0.84	0.09	3.68	0.63	0.60	0.04	0.03	1.30	0.80	5.10	32.94
CV (%)		0.98	30.33	85.56	64.77	34.94	27.36	38.50	51.16	60.00	24.19	21.63	17.71	31.46
Ranking		LV	MV	HV	HV	MV	MV	HV	HV	HV	MV	MV	MV	MV

pH $H_2$0= pH in water, pH Kcl= pH in Kcl, TN=total nitrogen, AP=available phosphorus, TEB=total exchangeable bases, TEA=total exchangeable acidity, CEC=cation exchange capacity, BS=base saturation)

Table 4: Taxonomic Classification of soils studied

Geomorphic units	USDA (Soil Survey Staff 2014)	(IUSS 2015) legend
Back swamp	Arenic Kandiudult	Dystric Acrisols.
Terrace	Arenic Kandiudult	Dystric Acrisols.
Upland	Arenic Kandiudult	Dystric Acrisols.

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