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Hydro-geomorphic study on selected soil properties, classification and management considerations of soils on alluvial landforms in southeastern Nigeria

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ABSTRACT

The soils were characterized with regards to their macro morphology, physico-chemical properties and heavy metal contents. This is to infer their pedogenesis and propose agrotechnology transfers as well as management considerations necessary for sustainable cultivation. Reconnaissance survey was used for initial soil identification. Two categories of the flood plain soils were identified viz. the levee and the back-swamp. Three profile pits were dug on each identified category. The results showed that the soils on the back-swamps were poorly drained and the soils on the levee were well drained. Their colours varied from dull yellow (2.5 YR 6/5) to light gray (7.5YR 8/2) on the levee and dull reddish brown (5YR 6/3) to pale reddish orange (7.5YR 8/3) on the back-swamp. Mottling was observed in all the pits, indicating redoximorphism. Clay content was low to high and ranged from 4 to 30 %. It showed illuviation in the back-swamp. The soil pH was slightly acid. It has low exchangeable acidity of 0.2 to 5.83 cmol/kg and low cation exchange capacity ranging from 1.82 to 7.61cmol/kg. The low CEC values imply that the clay mineral dominant in the soils is non-expansible. The soils were not sodic as the mean values for exchangeable sodium percentage was <6 %. Prevailing pedogenic processes identified in the area, were eluviation, illuviation, gleization, pedoturbation, braunification, and leaching. The soils were classified as Entisols, suborder Psamment and inceptisols, suborder Ustepts and correlated in FAO/WRB as Fluvisols (Dystric fluvisols) and Gleysols. Management practices like drainage practices, use of organic manure to enhance the soil conditions were recommended.

1. Introduction

Api river floodplain, one of the alluvial landforms in south-eastern Nigeria, is a major agricultural basket of the region. The full potentials of Api river flood plain cannot be harnessed without the knowledge of the soil characteristics. The geomorphology of the area deserves to be studied as many wetlands experience only short periods of saturation. Some are never flooded due to differences in their geomorphic structures. Hence, the plant community and soil profile characteristics were used to determine the indirect evidence of flooding.

The characterization and proper identification of the alluvial landforms will enhance agricultural practices. Floodplain soils in Southeast Nigeria are very important. Moreover, hence, its potentials have not been fully exploited (Obi, 1984) despite their high fertility. The need to feed the teeming human population in the humid tropics has extended the frontiers of food production to these seemingly worthless soils, as shown by Brande (1980). However, there is a significant limitation to the utilization of these soil, which is caused by either low permeability of the soil or the presence of a high-water table (Akamigbo 1981). Okusanmi *et al.* (1987) saw the limitation of agricultural development as a lack of detailed information on soil and land characteristics in the tropics.

Soil morphology which is defined as the field observable attributes of the soil within the various soil horizons and the description of the kind and arrangement of the horizons

(Marbut, 2000) is very important in characterizing and classifying soils. It can keep a record of what happens in the soil. Marbut (2000) further stated that soils morphology is more reliable for soil classification than the theories of pedogenesis because theories of pedogenesis are both ephemeral and dynamic.

The soil physical and chemical characteristics underlined by the interaction of the pedogenic processes could be better utilized if well understood. Targulian and Krasilnikov, (2007) perceived pedogenesis as the integration of specific pedogenic processes each of them characterized by a specific set of solid-phase pedogenic feature. This study has thoroughly examined the pedogenesis of this area to provide information on the properties and nature of soils of the areas and how these properties influences or are influenced by flooding. This information will be resourceful on the land resource characteristic of the area, based on which conclusion can be drawn on the most appropriate land use to ensure sustained productivity of the soil as well as the appropriate control measure to adopt.

Farmers and other stakeholders need this information on the properties of the soil to make proper use of the soil. Api river floodplain in South-eastern Nigeria has not been fully harnessed as the soils are laid bare and misused. This study, therefore, objectively undertake to characterize, classify, and determine the contemporary pedogenic processes going on in the area. Also, to propose the best management strategies to be used to achieve sustained agricultural productivity.

2. Materials and methods

Study area description

The study area was at Api river flood plain in Opi, Nsukka East LGA of Enugu State, South-eastern Nigeria. Opi is approximately 8-9km South East of Nsukka tow, and the study area is approximately 10km from OPI junction. It is located within latitude 6°44′N- to 6°45′N and 7° 28 ′E to 7° 30′E see (Fig 1). The climate is humid tropical, and the mean annual rainfall ranges from 1750 – 2250mm. The mean annual temperature ranges from 29° C – 32° C. The relative humidity rarely falls below 60 % throughout the year except during the desiccation period of harmattan. The vegetation is mostly woody savanna with grasses and herbaceous undergrowth. The soils of the area are generally derived from the Alluvium of either false bedded sandstone or upper coal measure formations (Asadu, 1990). Geologically, the upper coal measure occupies the upper slopes, and top residual hills within the area but the residues from the area are often transported by fluvial, colluvial and erosion processes to the lower plain to form soils (Akamigbo and Asadu 1983).

Soil sampling

A reconnaissance survey was done with conventional materials and soils of different physiographic units were identified using auguring and vegetation pattern. The positions for sitting the profile pits were chosen based on the different physiographic units identified. Two physiographic units were identified; levee and the back-swamp and six profile pits comprising of three each on the two identified physiographic units were cited and studied.

Soil morphology characterization

Morphological properties of the soils such as colour, texture (field), structure, root abundance and boundary characteristics were studied and described according to the Guidelines for Soil Profile Description (FAO, 1977)

Core samples were collected from the depth ranges of 0-25cm, 25-50cm, 50-75cm and 75-100cm. At each physiographic unit, the infiltration rate was determined using double ring infiltrometers

Laboratory Studies

Laboratory investigations were carried out on the <2.00 mm particles, and the following properties were determined using routine laboratory procedures.

Particle size analysis was determined by Gee and Bauder (1986) method. The textural classes were determined from the USDA soil textural triangle. Bulk density was obtained by the method of Blake and Hartge (1986). Total Porosity was calculated from the values of the bulk density using the method described by Vomicil (1965). The other soil parameters determined were done using the standard soil testing procedures.

Statistical Analysis

This was done using the T-test analysis to establish the relationship that the profile means values had with the parameter means and standard error (S.E) between the profile pits. Analysis of the percentages of the studied parameters was done to check the levels of relationship within and among the pits. A genstat 2.0 software was used for the analysis

Soil Classification

The soils were classified according to USDA keys to Soil Taxonomy (2006) and correlated to FAO/UNESCO and World References Base (2007).

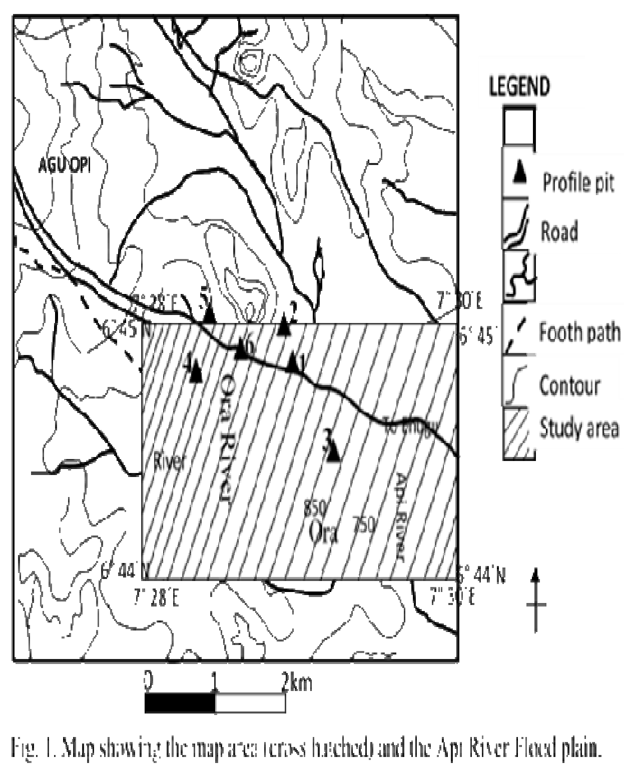

Fig. 1. Map showing the map area (cross hatched) and the Api River Flood plain. Nsukka, southeastern Nigeria

3. Results and Discussion

Geomorphological characterization

The differences between the levee and the back-swamps were recorded in Table 1. The top layers of both physiographic units were relatively dry unlike their sub-layers indicating high water tables in the area. Geomorphologically, the profiles on the levee showed layered features indicating seasonal sedimentation more than the back-swamp and also an indication of unconsolidated formation.

The structures of the soils on the levee ranged from weak to moderate crumbs while that on the back-swamps ranged from moderate to strong and very strong crumbs. The structure is primarily affected by organic matter and clay content. The weak structure of the levee, therefore, is attributed to the low clay content and perhaps a low organic matter of the area. However, this area could still be used for agriculture as it recorded more fine sand (59.9) than coarse sand (32.0). The more fine sand negates the nutrient loss as a result of the weak soil structure. This weak structures also relates to the low hydrology of the levee. The different water tables affected the morphology of these soils as seen in the profiles (Table 1). The color variation ranged from 2-5YR (6/3) dull yellow on the levee to (5 YR 4/4) Dull reddish brown on the back-swamp. The presence of iron concretion and mottling was predominant in almost all the soil profiles as observed. The different colours of the soils are due to varying levels of iron in each soil, and the back-swamp is darker because of the presence of the organic contents. The dark color is also an indication of poor drainage nature of the soils. The preference of mottles was brought about by the prevailing redoximorphic conditions in both units. Clay skins were also observed most likely due to the illuviation action of waters within the profile.

These are typical of seasonally flooded soils which possess coatings of clay on the soil peds. The presence of mottles may be attributed to the fluctuating water table, which causes certain elements; especially iron and manganese to be mobile when reduced and concentrated, (Gerard, 1992). It is worthy to note that under the reduced condition with very low redox potential, the mineralization is low. This will greatly affect the nutrient release of these soils. The soils of the low land show strong mottling of gray and red color due to periodical waterlogging. They dominate sandy materials due to the nature of the alluvial parent materials (Ofomata, 1975).

Table 1: Summary of the Morphological Properties of the Soils of Api River Flood Plain.

Soils on the levee

Profiles	Classification	Parent Material	Drainage	Brief Description
1	Entisol, Psamment, oxyaquic, group Quartzipsamment	Alluvium	Well-drained	Dull yellow (2.5 YR6/3) to (7.5 YR7/6), mottles, many pores, loose total sand differed slightly.
2	Inceptisol, Usteps, Haplustepts Fluventic Dystrustepts	Alluvium	Not well drained	Light gray (7.5 YR8/4) to bright yellowish brown (10 YR3/8, continuous pore and weak crumbs.
3	Entisol, Arent, Ustrents, Haplic ustrents	Alluvium	Well-drained	Dull orange (7.5 YR7/4) to orange 7.5 YR6/8· Buried horizon, mottle, and loose structures.
Soils on the Back-swamp				
4	Fluvents, Typic Fluvaquents	Alluvium	Imperfect/ poor drainage	Dull brown (7.5 YR 5/4) to light yellow (7.5 YR8/6), pores, fibrous root, and moderate crumbs.
5	Inceptisol, Usteps Haplustepts, Fluventic Dystrustepts	Alluvium	Poor drainage	Dull reddish brown (5. YR6/3) toyellow-orange (7.5 YR5/8). Many continuous pores, soil fauna. Mottles and non-sticky.
6	Inceptisol Usteps Haplusteps Fluventic Dystrustepts.	Alluvium	Poor drainage.	Pale reddish orange, (7.5 YR 8/3) to light yellow orange (7.5 YR 8/3), Moderate crumbs and slightly sticky.

Physical Properties

The results of the selected physical properties of the Api river soils are presented in Table 2. The soils are very deep (170-180cm) except for the back-swamp soils that were found to be shallow (50-75cm). The shallow depths observed on the soils of the back-swamp were due to restriction by high water tables encountered. These were associated with the poor drainage condition caused by the clay dominance in the back-swamp soils. The restrictions caused water impaired aeration and rooting of the crop, especially during the rainy season. Deep soil tillage practice will pulverize the soils and improve infiltration and drainage.

The particle size distribution analysis indicated that most of the profiles had coarse-textured soils, which ranged from 10-85. Table 2 also showed that profile 2 on the levee had more fine sand than its coarse sand, unlike the rest of the profiles. This could be the reasons that area intensively used for agriculture because fine sand retains more nutrients than coarse sand because of more surface area. Their textual classes ranged from sand to sandy loam along the levee and sandy loam to sandy clay loam on the back swamp. The coarse texture of the levee soils resulted from the settling of larger particles closer to the bank of the river; sedimentary differentiation. According to Webster and Wilson (1980), when a river floods, coarse suspended materials are deposited near the channels and the finer materials further away. The texture of the study area is, however, in affirmation with Akamigbo and Asadu (1986, which opined that the textures of soils of south-eastern Nigeria are related to their parent materials.

The clay contents in the study areas were low. The clay distribution is irregular. The profiles at the back-swamp had more clay contents than the ones on the levee. The mean value of the clay content of all the profile was 7.7±1.04 using simple T-test (Table 2). The highest clay content was recorded in the back swamp. The general low clay content of the area is attributed to the nature of its parent material, which is river alluvium, which is rich in the sand. Again the soils seem to be receiving sediments regularly and the elapsed time is not enough for the silt and fine sand to weather to clay. This study affirms the findings of Akamigbo and Asadu (1980) that parent materials control the genesis of most soils in southeast Nigeria. Low clay content could also be associated with the young age of the soil, as approved by Collins and Fenton (1982) as an index for measuring soil development.

The bulk density values ranged from low to moderate (1.46 g/cm^3 – 1.68 g/cm^3). The bulk density (BD) of the topsoils were lower, probably because of the organic matter in the topsoil. Organic matter has low bulk density and so can impart the property to the topsoil (Logan and Harrison, 1995; Asadu *et al.,* 2008). The mean value of the BD of the whole profile was 1.5g/cm^3±0.02. The highest mean value was recorded on the levee showing that it had less organic matter than the back-swamp. The sands of the levee exerted its effect on the BD of the studied area and recorded higher in the levee than in the back-swamp. The BD of the study area was not expected to cause root and water movement restriction (Ekwoanya and Ojanuga, 2001).

The saturated hydraulic conductivity mean values of the horizons of the profiles ranged from 23.3–143.1 cm/hr. The k_{sat} permeability rate was very slow using Darcy's rating. The soils on the back-swamps had higher hydraulic conductivity than the ones on the levee due to more water content. Statistically using simple T-test, the mean value of k_{sat} was 72.4 ±16.46. The porosity values, as shown in Table 2, was observed to be higher on the levee than on the back-swamps. This is in agreement with the FAO (1986) that the physical properties (texture) of soil affects other properties of soil like infiltration rate, moisture content, nutrient, and drainage.

Infiltration rates were low to moderate in the three profiles investigated ranging from 43-100 cm/hr using the ratings according to Obi and Akamigbo (1981) for infiltration of tropical soils, considering the rainfall intensity of the area. In all, the steady state was reached in about one hour 30 mins. The infiltration rate decreased with time due to the textural pattern of the soils. This could be a result of the nature of the parent materials. The reduced rate of infiltration could be attributed to the high water table of the area as well as the low-lying nature of the area, which is subject to periodic flooding. Ponding of water on the soil surface is some seasonal phenomena on the flood plain soils owing to reduced infiltration permeability, and runoff (Ekwoanya and Ojanuga 2001).

Chemical Properties

The result revealed that the chemical property values of the study site are generally low. The soils are strongly acidic to moderately acidic in reaction with an average pH of 5.5±0.03. The acidity may have resulted from leaching due to high rainfall intensity and also high groundwater table, especially during the raining season. The weak structure could have also contributed to the reason the site could easily leach. Enwezor (1976) attributed the cause of leaching of the soils to high rainfall intensity.

Notwithstanding, wet condition of soils could lead to the reduction and accumulation of heavy metals such as manganese and iron (Table 3) both of which promote soil acidity and high exchangeable acidity in the soil. Liming of the soils, however, not recommended because the soils are poorly buffered and could lead to more drastically consequences on soil structure and availability of P and micronutrients. The clay and organic content of these soils are very small for effective liming, but alternative solutions like biochar additions could be recommended. Biochar is not only alkaline but also a good soil amendment.

Available phosphorus ranged from 0.39 to 14 mg/kg with a mean value of 7.2 mg/kg. The low content of available phosphorus in these areas could be attributed to pH levels of the soils. Similar observations have been made by Ekwoanya and Ojanuga (2001) in similar soils. The low available phosphorous in the area could be due to the nature of parent material in the area and to limited extent, erosion, leaching, and low organic matter content. There is a possibility of the P being fixed due to pH.

Table 2: Mean values of the physical properties of the Api river flood plain profile pits

Profile	Particle size density Clay	Silt	TS	CS	FS	Total Porosity	Bulk density	K(sat)
	←			%	→		g/cm^2	cm/hr
1	5.6	3.1	91.3	58.4	32. 9	0.5	1.6	62.1
2	7.2	4.8	88.0	32.0	59. 9	0.5	1.5	23.3
3	9.4	2.6	88.0	54.5	33.5	0.5	1.6	71.7
4	11.9	6.4	81.9	51.9	30.3	0.5	1.5	49.2
5	5.1	0.6	94.4	63.1	31.3	0.4	1.5	80.0
6	7.0	7.6	82.9	50.5	32.4	0.5	1.5	143.1
Means	7.7	4.2	87.8	51.7	36.7	0.5	1.5	72.4
S	2.5	2.3	4.78	10.6	11.4	0.04	0.05	40.32
S.E ±	1.04	1.05	1.95	4.36	4.67	0.01	0.02	16.46

Legend: S.E ± = Standard Error, S = Variance, TS = total sand, CS = coarse sand, BD = Bulk density, TP = total porosity, K (sat) = hydraulic conductivity, FS = Fine sand.

Organic matter content ranged from very low to high (0.49 to 2.23) for all the profiles. The mean value of organic matter content is 0.3±0.02. The organic matter content decreased down the profile. The low organic matter content may be due to high oxidation and mineralization rates of organic matter as in the case of the levee. The back swamp was more reduced. Ojanuga (1971) observed that the low organic matter content of the area could be attributed to the return of litter or no agricultural residue, high rate of transformation and translocation of organic matter in the tropical soils.

Moreover, the area is under formation and not stable. It could also be due to continuous cropping and annual bush burning as observed in the area. Due to this low organic manure, use of crop residue, and farm yard manure was suggested. The corps residue is alternatively used as feed, bedding, and roofing materials, and usually little of it is returned to the soil (Kparmwang et al., 2001, Odunze, et al. 2003). For any sustainable cropping, there is need to add organic manure because of its contribution to enhancing the soil structure and crop yield. The low organic matter content poses the danger of soil deterioration, low plant nutrient reserve, and low CEC, especially under poor management practice, as observed in the study area.

The bases were low in both soils. The dominant exchangeable cations in the soils tend to be mainly calcium (Ca^{2+}) and magnesium ($Mg^{2+)}$ while low potassium (k^+) and sodium (Na^+) appeared to be the absence of minerals high in them in the parent materials (Table 3). Sodium had a mean value of 0.40.02, and K^+ was as low as 0.1. The low exchangeable bases have been attributed to leaching losses of these bases to the underground water table. The bases such as Na^+, K^+, Mg^{++}, Ca are easily displaced from the soil exchange complex by Aluminum ($A1^{3+}$) and hydrogen (H^+) under saturations giving rise to lowering of total exchangeable losses in the soil as well as percentage base saturation (Unamba Opara, 1998).The effective cation exchange capacity (CEC) values ranged from moderate to high. It averagely ranged from 26.7 to 31.5 on the levee and 19.1 to 55.5 Cmol/kg on the back swamp soil (Table 3). The CEC is also a reflection of the low total base-forming cations. The CEC is related to soil texture and OM content being generally low to moderate on the average. The relative high OM content resulted in relative high CEC. This is in correspondence to the places with higher clay content. The soils that had low OM and as well low CEC were having high leaching losses because so few ions were retained in exchangeable form. Such losses are serious when it involves plant nutrition (Ekwoanya and Ojanuga, 2001).

The Exchangeable Sodium Percentage (ESP) was used to measure the exchangeable sodium content of the studied area. The ESP ranged from 0.01-8.98% indicating low to moderate exchangeable sodium content. The highest value was recorded in profile 3 as 8.98 and lowest in profile 1 as 0.01 (data not shown). These values of ESP are below the critical limit of 15, which is an acceptable limit for sodic soils. The soils, therefore, are non-sodic. This range will not cause dispersion of soil particles so much to constitute a problem except irrigation is applied. Under irrigation, cautions have to be taken as it often leads to salt-built up. The clay minerals of the studied area were assumed to be mainly illite and kaolinite and two horizons of montmorillonite in the second and fourth profile (C_1, C2) and (B, C) respectively (Data not shown). This was inferred from the CEC range in the studied area. Boulet al. (1980) noted that the CEC range of 3-15cmol/kg by NH_4OAC (pH 7) has kaolinite minerals dominant in it. The CEC range of 20-40 represents illite clay minerals. Soils of intermediate texture and organic matter content have CEC between 20-40cmol/kg. Some sands low in the organic matter have extremely low organic matter.

Table 3: Mean values of the chemical properties of Api river flood plain profile pits

Profile	% BS	Ca^+	pH	CEC	Mg^{++}	K^+	Na^+	C	H^+	N
				----------cmol/kg---------				g/kg		g/kg
P_1	12.9	0.7	5.5	26.7	0. 9	0.1	0.4	2	2.1	1
P_2	9.6	0. 9	5.6	34.1	0.7	0.1	0.4	3	1.5	1
P_3	14.5	0.6	5.4	31.5	0. 9	0.1	0.4	3	0. 9	1
P_4	4.2	1.0	5.5	55.5	0.7	0.1	0.3	3	1.0	1
P_5	7.8	0.6	5.6	35.8	1.5	0.1	0.4	2	1. 9	0
P_6	12.6	0.5	5.6	19.1	1.0	0.1	0.3	2	1.3	1
Means	10.3	0.4	5.5	33.7	0. 95	0.1	0.4	3	1.5	0
S	3.84	1.19	0.08	12.2	0.29	0	0.05	0.5	0.5	0
S.E ±	1.6	0.08	0.03	4. 9	0.12	0	0.02	0.2	0.2	

Soil Genesis

Physical and chemical processes within the soil profile have been recognized as influencing soil development. Horizontal and vertical water movements both on the surface and sub-surface are the key pedogenic factor in this place. Addition, removal, transfer, and transformation brought about by the activities of underground and surface water from the basics of horizon differentiation or soil development. It is the soil forming or pedogenic process that determines the kind of soils that is ultimately formed. From the results obtained, the pedogenic processes going on in these alluvial plains of the lowland soils are eluviation and illuviation of colloidal soil components giving rise to message. Table 2 showed that P_1, P_4, P_2 had irregular clay percentage due to seasonal flooding. Leaching and enrichment were also evident in the area. The C/N ratio of less than 20:1 in the area indicated that mineralization was going on in the area. Laterization was also found to be going on in the study area. The deep red to bright red soil in the area is a product of laterization. The soils are subject to laterization because they tend towards acidic soils, they also lack much organic matter and decomposition and leaching is high. These soils should not be exposed to hot tropic sun by deforestation as this act will bake the soil dry and reduce infiltration, increase run off and reduced fertility. Other pedogenic processes in the area are decomposition and humification of organic matter. Results obtained showed that the soil is still developing and thus is a young soil. Poor horizon differentiation in the area especially in the P_1 and P_2 indicated that those profiles had layers and not horizon per se due to frequent sedimentation.

Soil Classification

The soils were classified into the soil orders and suborder categories using the nomenclature of revised USDA soil taxonomy of 2010 and correlated to the FAO/UNESCO soil map of the world legend (1988). The morphological and chemical data indicated that the soils were Entisols and Inceptisols.

Pedon 1, 3 and 4 which were developed on recent alluvium have no evidence of pedogenic horizon and therefore, belong to the *Entisols* order. Pedon 1 had mainly sand and clay distribution virtually uniform. Organic carbon distribution, not uniform, and base saturation is <50%. It belonged to the sub order Psamment, Great group Quartz Psamment and sub group Oxyaquic Quartizi Psamment. FAO/UNESCO/WRB correlated with Fluvisols, Dystric fluvisols. Pedon 3 was in the suborder Arents because it had fragments of the diagnostic horizon that were not arranged in any discernible order. Pedon 4 is classified as fluvents because it has 0.2% organic carbon or more irregular decrease in organic carbon content. The subgroup is Typic Fluvaquents because it has been saturation by NH_4OAC less than 50 % in some part within 100 cm in the mineral soil surface. Pedon 2, 5, 6 were classified in the order Inceptisols considering that they have less than 8%clay in the fine earth fractions; the ESP was less than 15% and had groundwater within 100cm of the mineral soil surface at sometimes during the year. The suborder Ustrepts was chosen because they have Ustic moisture regime and the great group Haplustepts and subgroup fluventic Dystrustepts looking at the irregular decrease in organic carbon content.

4. Conclusions

From the results, it can be concluded that the soils were formed from river alluvium. It is still young and in the early stage of horizon development. In general, these soils are classified as Entisols and formed on alluvium soils. The place is flat and constantly submerged; the soils are acidic and had low nutrient status due to the nature of the soils and constant agricultural practices going on in the area. There is a need to monitor the water table and develop good irrigation schedule. Material like biochar that could increase the pH of the soil with the ability to enhance the organic content of the soils could be recommended for an area like this as it has low buffer capacity. This implies that the area needs other management strategies like encouraging shifting cultivation and fallow system. Hence, contour ridging will ensure that most root crop zones are not within the waterlogged region. The furrows will drain excess water from the farmland.

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