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Morphological features of swamp soils within a coastal Landform: A case study of Ndokwa, Nigeria

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Abstract A survey on the morphological features of swamp soils within a coastal landform was assessed. The result showed that Abbi pedons were very dark brown (10YR 2/3), Onicha Ukwuani pedons were dark grey-brown (10 YR 3/1) and Ndemili pedons were ash brown (10 YR 5/6) in colour. Dark yellowish brown (10YR 4/3) mottled were common across locations. The soil structures were sub-angular and medium sub-angular blocky structures within pedons. The consistency was non-sticky and non-plastic at the horizon's surface while sticky and plastic were observed at the sub-surface soil layer. The textures across locations were inclusive of sand, clay, and loam. The soils ranged from wavy, smooth, irregular, diffused, abrupt, and gradual smooth boundaries. The soil characteristics such as soil colour, soil texture, and structure within 0-20cm and 20-40cm in surface soil layer showed variations across locations and the effects on soil fertility could be improved by good soil management, organic and inorganic fertilizer application.

Keywords: Morphological, Ndokwa, Swamp, Landform, Characterization

Introduction

Morphological features within a complex body are mostly visible across ecosystems where the water table fluctuation plays a fundamental role in soil and landform development. According to Boul *et al.* (2003), soil morphology is the characteristics of the soil apparent mostly at the various pedogenetic horizons and depiction of the various types and features of the horizons. Similarly, investigative measures that comprise a more difficult evaluation of soil characteristics such as depth intervals (measured topsoil to subsoil), texture, micro-relief, horizon, slope, vegetation, colour, parent material, erosion, elevation, boundary characteristics, structure, pores, consistence, root distributions, effervescence, and unique features which include: nodules,

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coatings, and concretions play a vital role in determining soil fertility and developmental project.

Morphology describes the spatial variation in soil characteristics used to differentiate between different soils concerning soil classifications (Soil Survey Staff, 1998). Morphological studies play an essential role in precise soil mapping and classification. According to Gobin *et al.* (2000), the soil profile development index was used in conjunction with standard descriptions of soil morphology and evaluation. Secondly, morphological variables similar to texture, and soil colors are liable for the distinct variations and effectiveness in characterizing soils. Gobin *et al.* (2000) also emphasized that soils are characterized based on soil characteristics such as colour and relate land use management and fertility to soil descriptions. Glayzation such as reduced soil conditions characterize the swamp soils. Unsaturated soils are typically aerated and characterized by yellowish-brown colour while saturated swamp soils are distinguished by grey colour within and below soil depth (Fletcher and Veneman, 2005).

Characterizing swamp soils for agricultural purposes does not only establish a relationship between weather conditions and soil properties but also provides preliminary knowledge on nutrient status, and limitations and ensures sound judgments on soil behaviour and specific land users (Esu, 2004). Most swampland has features depicting an aquic moisture regime which "implies a reduced regime that is virtually free from dissolved oxygen due to saturation by groundwater or by the water of the capillary fringe" (Soil Survey Staff, 1975). Swamp soils are distinguished by low chroma values when they merely undergo reduction. Conversely, anaerobic soils; reduced but not completely saturated with chroma equal to 3 or higher on ped surfaces accompanied by higher chroma may be saturated and reduced for short periods.

Swamps are more of mineral soils derived from geologic deposits. The characteristics vary in their pedogenetic formation, which depends on the climatic characteristics and residual deposits, depositional areas depend absolutely on topography. Mineral soils from swamp soils usually spread along the coastal landform. In this regard, the transitions within swamp soils are clear futures of colour variation regardless of landform from Abbi to Ndemili. These variations in geomorphological locations propel the need to understand the photographic appearance derived from dynamism in morphological variations within landforms. In this regard, the morphological characteristics of the swamp soils in Ndokwa West were studied for pedogenetic information essential for the possible utilization and management of swamp soils.

Materials and methods

Description of the study area

Ndokwa West lies between longitude 6^0 20′E, and 6^0 25′E and latitude 5^0 55′N and 5^0 40′N and occupied over 5% of the total landmass of Delta State. The annual temperature generally ranges from 25^0 C to 35^0 C but falls below 22^0 C during the harmattan period in December through to the end of February. The rainy season usually starts in April and ends in October with a double peak usually in July and September, while the dry season spans from November to March. The area's average annual rainfall exceeds 2600mm. The relative humidity is usually high averaging 85%. The mean annual temperature of the area is about 27^0 C with February and March being the warmest month. Yam, maize, pepper, cassava, oil palm, and vegetable crops are the principal crops grown in the area (Alama *et al*., 2019).

The area is distinguished by secondary vegetation due to the slash-and-burn system of land preparation practiced by farmers. The main swamps are covered with shrubs and trees and extensive fish ponds. Generally, the topography is gentle-sloping to almost flat in shape. The soils are mainly formed from alluvial and colluvial deposits.

Field survey and soil sampling

A detailed survey (1:10,000) was conducted and three locations (Abbi, Onicha-Ukwuani, and Ndemili) were selected to represent the treatment. Auger soil samples were randomly collected at three homogenous soil units identified. Three profile pits measuring 1.5m X 1.5m X 1.4m were delineated compared and described using a standard format developed following the guidelines for soil description (FAO, 2006; Soil Survey Division Staff, 2017). The various depths were 0-20, 20-40, 60-80, 80-100, 100-120 and 120-140cm respectively. The morphological properties were soil boundary, texture, colour, mottles, structure, consistency, rootlets, and other soil features were examined to determine which horizons are presented and at what depth their boundaries occur from each genetic horizon. Soil colour was ascertained based on the revised Munsell Soil Color Chart (1994). Soil structure was based on grade, size, and type of the soil aggregates while horizon boundaries were determined in terms of depth, distinctness, and topography. The soil consistency was identified in moist and wet moisture conditions.

Results

The result showed that the Abbi soils ranged from a very dark brown (10YR 2/3) to dark greyish brown (10YR 5/3) colours (Table 1). Onicha Ukwuani ranged from very dark brown (10YR 2/2) to dark yellowish-brown (10YR4/3) and Ndemili also ranged from dark brown (10YR 3/4) to light yellowish brown (10YR4/6). The most prominent soil colours across locations are light yellowish brown (10YR 5/5) and a serial ash yellowish brown (10 YR 5/6). Onicha Ukwuani pedons were characterized by a distinct yellowish-brown (10 YR 5/6) and light yellowish brown (10 YR 6/4) mottled colour (Pedon 2 and 4), while dark yellowish-brown (10YR 4/3) and dark yellowish-brown (10 YR 6/4) mottles were observed in Table 2. Ndemili also was characterized by a notable dark yellowish-brown (10 YR 4/3) to light yellowish brown, (10 YR 4/6) mottles (Table 3).

The results showed that sand (course) and loamy sand textures were dominant across locations in the surface horizons and were mainly derived from the alluvial deposit. Similarly, sandy clay loam texture and sandy clay texture were apparent in the horizons subsurface in pedons 2 and 4 (Table 2) indicating clay accumulation and structural stability across the location.

The soil structure in Abbi ranged from moderately to medium sub-angular and angular blocky structure to crumbly structure at the surface horizon and strong blocky structure to medium blocky structure on the subsoil horizon. A similar trend was also observed in Tables 2 and 3. Medium and coarse soil structures were observed at the surface horizon in Table 1. They were also. The weakly to fine-medium structure characterize the surface to the subsoil horizon in pedon 2 (Table 2). However, a strong angular blocky structure was also observed in pedon 3 in the subsoil horizon (Table 1). The moderate to strong blocky structure inclusion across locations was an indication of clay accumulation in the subsoil horizon. The results also showed that moderate and strong blocky structures were consistent with an increase in depth across the location.

The consistency of the area study was generally non-sticky (ns) and non-plastic (NP) in the surface horizons. This was observed across the pedons but varied in an occurrence at different horizons across locations. The consistency observed was slightly sticky and plastic, very sticky and very plastic in the subsoil horizons across locations (Table 1-3). Fine rootlet was generally apparent in the subsoil horizon across pedons and abundant rootlets on the horizon surface across locations. The soil boundary prominent in Abbi was abrupt at the surface horizons while diffused and clear smooth boundaries characterized the subsurface horizon (Table 1). Similarly, a gradual smooth boundary was present and consistent with an increase in depth of profile across pedons.

Table 1. Morphological properties of Abbi

Horizon	Depth (cm)	Colour	Mottles	TC	Structure	Const.	Rlts	Bdry
Pedon1				**Abbi West**				
Ai	0-20	5YR 3/1	Nil	S	MC	NS/P	FA	A
Ap	20-40	10YR 3/3	Nil	LS	MC, WM	NS/P	FW	A
AB	40-60	10YR 5/6	10YR 5/6	LS	WM, AB	SP	FW	D
Bt_1	60-80	10YR 5/6	10YR 5/5	SCL	AB	SP	F	D
Bt_2	80-100	10YR 5/5	10YR 5/4	SCL	ME, AB	SP	F	C
Bt_3	100-120	10YR 5/5	10YR 5/4	SCL	ME, AB	VS/P	F	CS
B_C	120-140	10YR 5/5	10YR 5/4	SCL	ME, AB	VS/P	F	CS
Pedon 2				**Abbi South**				
Ai	0-20	10YR 4/6	Nil	S	MC	NS/P	FW	A
Ap	20-40	10YR 4/5	Nil	LS	MC AB	NS/P	F	A
AB	40-60	10YR 4/5	Nil	LS	AB MC	NS/P	F	A
B	60-80	10YR 6/4	Nil	SCL	AB	SP	F	C
Bt_1	80-100	10YR 6/4	10YR 5/6	SCL	AB	SP	F	CS
Bt_2	100-120	10YR 6/3	10YR 5/6	SCL	AB	SP	F	CS
Bt_3	120-140	10YR 6/3	10YR 5/6	SCL	AB	VS/P	F	CS
Pedon 3				**Abbi South**				
Ai	0-20	7.5YR 5/3	Nil	S	MO	NS/P	AB	D
Ap	20-40	7.5YR 5/3	Nil	LS	MO	NS/P	M	D
AB	40-60	7.5YR 5/4	Nil	LS	MO, SG	NS/P	F	D
Bt_1	60-80	7.5YR 5/5	Nil	SCL	SG, AB	SS/ P	F	CS
Bt_2	80-100	10YR 5/5	Nil	SCL	SG, AB	VS/P	F	CS
Bt_3	100-120	10YR 5/5	Nil	SCL	SG, AB	VS/P	F	CS
Bt_c	100-140	10YR 4/3	Nil	SCL	MESB	VS/P	F	CS
Pedon 4				**Abbi East**				
Oi	0-20	10YR 2/3	Nil	S	MESB	FR	AB	A
Ap	20-40	10YR 3/3	Nil	LS	MESB	FR	AB	A
AB	40-60	10YR 2/3	10YR 5/4	LS	SB	SS/P	FW	D
Bt_1	60-80	7.5YR 6/3	10YR 4/3	SCL	SB	SS/P	FW	D
Bt_2	80-100	10YR 5/6	10YR 4/3	SCL	SB	SS/P	FW	C
Bt_3	100-120	10YR 5/6	10YR 4/3	SCL	SB	S/P	FW	CS
B_C	120-140	10YR 5/4	10YR 4/3	SCL	SB	VS/P	F	CS

Note:- **Texture** (TC) : S = sand, C = clay, L = loam, SL = sandy loam, LS = loam sand, SCL = sandy clay loam; **Structure:** MO = moderate, SG= strong, WM = weak to moderate, ME = medium, MC=medium and coarse, AB = angular blocky, , SB = sub-angular blocky; **Consistence (Const)**: Fr = friable, SP = slightly plastic, VP = very plastic, S = sticky, P = plastic; **Root Concentration (Rlts):** M = many, AB = abundant, FW = few, F =fine, FA = fabric **Boundary (Bdry):** A = abrupt, C = clear, D = diffused, S = smooth; colour: 10YR 4/3= dark yellowish brown, 10YR 5/6= yellowish brown, 10YR 2/2= very dark brown 7.5YR 5/5= yellowish brown, 10YR 4/5= light brownish gray, 10YR 6/3= light brownish gray.

Table 2. Morphological properties of Onicha Ukwuani

Horizon	Depth(cm)	Colour	Mottles	TC	Structure	Const.	Rtlts	Bdry
Pedon1			**Onicha**	**Ukwuani**	**West**			
Oe	0-20	10YR 2/2	Nil	S	MO,SB	NS	FA	A
Ap	20-40	10YR 3/3	Nil	SL	MO,SB	NS	FA	A
AB	40-60	10YR 4/3	Nil	SL	ME,SB	VS	F	D
Bt_1	60-80	10YR 4/4	10YR 4/3	SCL	ME,SB	VS	F	CS
Bt_2	80-100	10YR 4/5	10YR 4/3	SCL	ME,SB	VS/P	F	CS
Bc_1	100-120	10YR 4/5	10YR 4/3	SCL	ME,SB	VS/P	F	CS
Bc_2	120-140	7.5YR 4/5	10YR 4/3	SCL	ME,SB	VS/P	F	CS
Pedon 2			**Onicha**	**Ukwuani**	**North**			
Oe	0-20	10YR 5/2	Nil	L	WE	NS	FA	A
Ap	20-40	10YR 5/2	Nil	LS	FM, SB	NS	FW	CS
AB	40-60	10YR 5/2	Nil	LS	FM, SB	SS	FW	CS
Bt_1	60-80	10YR 5/2	10YR 4/3	SCL	FM ,SB	VS/P	F	CS
Bt_2	80-100	10YR 5/6	10YR 4/3	SCL	FM ,SB	VS/P	F	CS
Bc_1	100-120	10YR 5/4	10YR 4/3	SCL	FM, SB	VS/P	F	CS
Bc_2	120-140	10YR 5/4	10YR 4/3	CL	FM ,SB	VS/P	F	CS
Pedon 3			**Onicha**	**Ukwuani**	**South**			
Oe	0-20	10YR 4/4	Nil	S	SB	NP	AB	D
Ap	20-40	10YR 4/3	Nil	LS	SB	SS	AB	D
AB	40-60	10YR 5/6	Nil	SL	M ESB	SS	F	D
Bt_1	60-80	10YR 5/6	Nil	SL	M ESB	VS/P	F	CS
Bt_2	80-100	10YR 5/6	7.5YR 6/4	SCL	M ESB	VS/P	F	CS
Bc_1	100-120	10YR 5/3	10YR 6/4	SCL	M ESB	VS/P	F	CS
Bc_2	120-140	10YR 5/3	10YR 6/4	SC	M ESB	VS/P	F	CS
Pedon 4			**Onicha**	**Ukwuani**	**East**			
Oe	0-20	10YR 3/3	Nil	LS	WE	NS/P	M	A
Ap	20-40	10YR 3/3	Nil	L	MO	NS/ P	F_1	D
AB	40-60	10YR 4/3	Nil	L	ME SB	SS/P	F_1	CS
Bt_1	60-80	10YR 4/4	10YR 5/3	CL	M ESB	S, P	F	CS
Bt_2	80-100	10YR 4/4	10YR 5/3	CL	M ESB	VS/P	F	CS
Bc_1	100-120	10YR 4/4	10YR 5/4	CL	M ESB	VS/P	F	CS
Bc_2	120-140	10YR 4/4	10YR 5/4	CL	M ESB	VS/P	F	CS

Note:- Texture (TC): S = sand, C = clay, L = loam, SL = sandy loam, LS = loamy sand, SCL = sandy clay loam; Structure: WE = weak, MO = moderate, FM=fine medium, ME = medium, blocky, SB = sub-angular blocky; **Consistence (Const.):** SP = slightly plastic, VP = very plastic, S = sticky, P = Plastic; **Rootlets (Rtlts)**: M = many, AB = abundant, FW = Few, F =Fine, C = common, FA = fabric; **Boundary (Bdry):** A = abrupt, C = clear, D=diffused, S = smooth; Colour: 10YR 4/3= dark yellowish brown, 10YR 5/6= yellowish brown, 10YR 2/2= very dark brown, 10YR 4/5= light brownish gray, 10YR 4/4=yellowish brown, 10YR 6/4= yellowish gray (FAO, 2006; Soil Science Division Staff. 2017).

Table 3. Soil morphological properties in Ndemili

Horizon	Depth (cm)	Colour	Mottles	TC	Structure	Const.	Rtlts	Bdry
Pedon1				**Ndemili**	**West**			
A	0-20	10YR 3/4	Nil	S	SB	NS/P	AB	A
AB	20-40	10YR 5/3	Nil	LS	WESB	NP/P	AB	A
Bt_1	40-60	10YR 5/3	Nil	LS	WESB	SS/P	FW	A
Bt_2	60-80	10YR 5/4	Nil	SL	MOSB	SS/P	F	CS
Bt_3	80-100	10YR 5/4	10YR 4/3	SCL	MOSB	S/P	F	CS
Bc	100-120	10YR 5/4	10YR 4/3	SCL	MOSB	S/P	F	CS
Bc_1	120-140	10YR 5/6	10YR 4/3	SCL	MOSB	VS/P	F	CS
Pedon 2				**Ndemili**	**North**			
Oi	0-20	10YR 4/3	Nil	LS	WE	NS/P	AB	GS
A	20-40	10YR 4/3	Nil	LS	WE,SB	NP/S	F	CS
AE	40-60	10YR 4/4	Nil	SCL	MOSB	SS/P	F	CS
Bt_1	60-80	10YR 5/4	Nil	SCL	MOSB	S/P	F	CS
Bt_2	80-100	10YR 5/4	Nil	SCL	MOSB	S/P	F	CS
Bc	100-120	10YR 5/4	10YR 4/3	SC	MOSB	S/ P	F	CS
Bc_2	120-140	10YR 5/5	10YR 5/3	SC	MOSB	VS/P	F	CS
Pedon 3				**Ndemili**	**South**			
Ap	0-20	10YR 4/3	Nil	SIL	WM	NS/P	AB	GS
B	20-40	10YR 4/5	Nil	SL	WM	NS/ P	F	GS
Bt_1	40-60	10YR 4/5	7.5YR 5/3	SCL	MOSB	SS/P	F	GS
Bt_2	60-80	10YR 4/5	10YR 5/4	SCL	MOSB	SS/P	F	GS
Bt_3	80-100	10YR 4/6	Nil	SCL	MOSB	S/P	F	GS
Bc_1	100-120	10YR 4/6	Nil	SCL	MOSB	S/P	F	GS
Bc_2	120-140	10YR 4/6	10YR 3/4	CL	MOSB	S/P	F	GS
Pedon 4				**Ndemili**	**East**			
Ap	0-20	10YR 4/3	Nil	SL	MSB	NS/P	AB	A
B	20-40	10YR 4/3	Nil	SL	MSB	NS/P	AB	A
Bt_1	40-60	10YR4/6	7.5YR 4/6	SL	MSB	SS/P	AB	A
Bt_2	60-80	10YR 4/3	10YR 4/5	SL	MSB	SS/P	F	A
Bt_3	80-100	10YR 4/5	10YR 4/6	SCL	MSB	S /P	F	GS
Bc_1	100-120	10YR 4/5	10YR4/6	SCL	MSB	S/P	F	GS
Bc_2	120-140	10YR 4/5	10YR 4/3	SCL	MSB	S/P	F	GS

Note:- Texture (TC): S = sand, C = clay, L = loam, SL = sandy loam, LS = loam sand, SCL = sandy clay loam; **Structure:** WE = weak, MO = moderate, WM = weak to moderate, SB = sub-angular blocky, **Consistence (Const.):** N = non, S = slightly, V = very, S = sticky, P = plastic; **Boundary (Bdry):** A = abrupt, C = clear, D = diffused, S = smooth, G = gradual; **Rootlets (Rtlts):**, AB = abundant, FW = Few, **Colour**: 10YR 4/3= dark yellowish brown, 10YR 5/6= yellowish brown, 10YR 2/2= very dark brown 7.5YR 5/5= yellowish brown, 10YR 4/5= light brownish gray, 10YR 6/2= light brownish gray, 10YR4/6= light yellowish brown, 7.5YR 4/6 = dark yellowish brown. (FAO, 2006; Soil Science Division Staff. 2017).

Discussion

The various soil depths were attributed to textural differentiation. This agreed with Hazelton and Murphy (2007), who reported that soils within 0-50cm are suitable for crop production. The implication of such depth is that yield could be improved. This finding is in agreement with Richards (2008), who also reported that soil depth above 50cm is favourable for the production of crops. Root dispersion at a deeper depth, according to Whitmore and Whalley (2009) contributes to increased yield.

The colours showed variation across the coastal landform. This was an indication that the colours associated with the pedogenetic horizons are the product of the climatic variables and the time of soil formation promoting illuviation of clay and eluviations of organic parent material and the prolonged period of wetness, inundation, and the mobilization of Fe and Al and the characteristics of gleyzation and clay synthesis (Alama *et al*., 2019). These variations agreed with Hossain *et al*. (2011) who reported the same in their studies and were attributed to features of the redoximorphic process such as flooding/wetness resulting from alternating periods of reduction and oxidation of iron and manganese compounds and differences in organic matter decomposition in the soils. The colours in the subsoils were dark grey-brown (10 YR 5/4), dark yellowish (10 YR 4/3), and yellowish-brown in Ndemili showing that the soils were under submerged conditions and depositional pedogenetic processes are gleyzation (Akpan-Idiok *et al.,* 2016). The variation in soil colour among the pedons and within pedons could be ascribed to the difference in parent material, organic matter contents, and drainage conditions. This agreed with Nahusenay *et al.* (2014), who reported that color variations are a function of organic matter content and drainage conditions and that they can indicate a lack in some soil's physical qualities.

The observed mottled dark brown (10YR 4/3) were common in pedon 1 and 2 in Onicha Ukwuani and Ndemili and 10YR5/6 and 10YR6/4 in Abbi. These findings suggested that the colors linked with pedogenetic horizons resulted from climatic variables and soil formation that promote illuviation of clay and eluviation of organic parent material, as well as a prolonged period of wetness; inundation and the mobilization of Fe and Al are characteristics of gleyzation and clay synthesis. These findings agreed with IRRI (1985), who stated that the primary activities that could affect soil color that appears to be active in swamp soils are fluctuating water table, seasonal wetting and drying, textural differentiation, clay illuviation, clay synthesis, glayzation, carbonate accumulation, and possible mobilization of Fe and Mn. Alem *et al.* (2015) also reported that in the pedogenetic horizons they were evidence of changes in soil colours and mottling within and across locations.

The soils were characterized by moderate subangular and medium subangular blocky structures. This structural development may be a retic of a subsoil horizon occurring at a shallow depth but which has been overlain by deposit over time. The medium to moderate angular blocky structure across locations showed evidence of clay eluviations/illuviation, and evidence of kaolinitic mineralogy predominating the swamp landform. The presence of iron and perhaps aluminum were evidence of iron segregation (mottles). Although based on findings, soils containing Fe and Al can stabilize soil structure as long as the pH is less than 9.0 (Frenkel and Shainberg, 1980). Thus, the Abbi, Ndernili, and Onicha Ukwuani swamp soils were characterized as structurally stable.

The characteristics of the soil that determine its resistance to crushing and the capacity to be molded or changed in shape, such terms as loose, friable, firm, soft, plastic, and sticky define consistency (Brady and Weil, 2015). The non-sticky and non-plastic consistency was a common trend in the horizon's surface across locations. These may be credited to weathering process within the pedogenetic landform. The observed sticky and plasticity may be ascribed to clay accumulation in the subsurface horizon. This finding agreed with Raji (1995) who reported that sticky and plasticity in subsurface horizon could be ascribed to an increased content of clay which can also result in increased bulk density and decreased porosity and drainage of the soils. In research conducted in floodplain/wetland soils, Hossain *et al.* (2011) and Akpan-Idiok and Ukwang (2012) reported the same result, which they attributed to soil formation processes.

The soil texture is closely related to particle size distributions. The various landforms (Abbi, Onicha Ukwuani, and Ndemili) were characterized by an increase in sand fraction at the surface soil layer and a decrease in depth throughout the pedogenetic horizons. According to Suharta (2010) and Dou *et al.* (2016), sand fraction provides easier passage through its aggregation, retaining less water and nutrients, and thus may not meet the demands for plant growth, particularly during grain development. Alama *et al.* (2019) also reported that the processes which may have contributed to this trend could be the deposition, vertical/lateral clay dissolution, and the rate of soil formation; surface erosion, timber lumbering, grazing, tillage, trafficking, drainage, liming, sodium content, and manure activities. These factors have an impact on soils through the effects on soil structure, especially on the horizon surface (Brady and Weil, 2015).

Silt/clay percentages were smaller compared to the sand fraction. However, the value of clay was generally higher in the subsoil layer than in the surface soil layer throughout the mapping units. The increase in clay with depth may be ascribed to clay translocation and surface erosion due to runoff or a combination of these properties (Raji, 1995). In addition, the increased clay with depth was also attributed to irregular distribution and stratification of clay in the swamp soils, which perhaps, suggested different periods of depositions of sediments (Ayolagha, 2001). According to Dou *et al.* (2016), soil texture significantly affects crop production, especially in water retention. In China, when crop varieties were assessed in sandy and clay soil (Bouman *et al.,* 2006; Ye *et al.,* 2007) yield was more in clay compared to sandy soil at different nitrogen levels Ye *et al.* (2007). Tsubo *et al.* (2007) also found that rice cultivated in higher clay content soils had higher grain production and biomass accumulation compared to rice planted in lower clay (sand) content soils in Thailand under a rain-fed agricultural system.

The soil texture in Abbi differs compared to Onicha-Ukwuani and Ndemili swamp soils. This difference in texture could be ascribed to geology, human activities, and climatic factors. A similar trend was observed by Alama *et al.* (2019) in their study of swampland soils in Ndokwa. The presents of alternating fine and coarse texture may however be related to the rate of weathering and subsequent soil formation. Root concentrations observed in the study were more at the surface horizons and varied from Abbi to Ndemili. In most cases, they were many, few, and fine root concentrations in the subsurface horizons. In Onicha Ukwuani fine root concentration was more dominant compared to Abbi and Ndemili. This was an indication that rootlets in most of the pedons appeared as fabric in A horizon which are the layers of organic material as observed in Abbi and Ndemili. This agreed with Akpan–Idiok and Esu (2001) who reported that most swamp soils in Niger Delta mass of mangrove rootlets and plant materials occur as fabric or saprist organic material. Organic materials are fabric and sometimes in unrobed condition; that is, loss of 1/3 of the mass is un-decomposed of unidentifiable fiber. Secondly, studies also showed that vegetation recovery can highly increase soil stability by accelerating plant growth and promoting soil formation processes such as fine soil root concentration, organic matter, and dispersal of mycorrhizas in swamp soils (Burri *et al.,* 2009; Cislaghi *et al.,* 2019). An increase in the length of root and root biomass that was observed in surface horizons in Abbi and Ndemili can contribute to a higher soil-root interaction. Subsequently, Gray and Sotir (1996) and Teerawattanasuk *et al.* (2014) also reported that vast soil root will result in higher soil reinforcement that increases the shear strength of soil slope.

The distinctness and outline of horizons (boundary) in the pedons ranged from wavy, smooth, irregular, diffused, abrupt, and gradual to clear smooth boundaries and varied from Abbi to Ndemili. Secondly, the differences in boundary descriptions across pedogenetic horizons could be ascribed to repeated anthropogenic influence, vegetation, and soil-forming processes. This agreed with Alem *et al.* (2015) who reported that gradual/transformation or homogenization or erosion /depositional processes may be responsible for horizon differentiation such as soil boundary (Ande, 2010). In Abbi horizons, boundaries such as diffused, abrupt, and gradual were observed within pedons. This was an indication of repeated anthropogenic influences such as rigorous pond excavation, dredging of sand, and several agricultural practices such as land rotation. According to Brinson (1993), basic factor such as water source and hydrodynamic (for instance unidirectional and reversing flow) explains the differences among geomorphic landform that affect soil boundary in swamp soil. Factors such as hydrogeomorphic characteristics (Brinson, 1993) and hydrology controls soil boundary (abiotic) characteristics in swamp soils. Abiotic characteristics such as soil colour, soil texture, water quality, and soil boundary depend on the distribution and movement of water as well as the productivity of crops.

The findings showed that there were variations in morphological characteristics across swamp landforms (Abbi, Onicha-Ukwani, and Ndemili). The characteristics such as soil colour, soil texture, and structure within 0-20 and 20-40 in surface soil layer which was requirements for crop production and an agricultural project can be improved by a good soil management approach, liming, manuring, and fertilizer application.

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