CHARACTERIZATION AND CLASSIFICATION OF HYDROMORPHIC SOILS AT MAKUSIDI IN NIGER STATE, NIGERIA

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Abstract
This study was carried out to characterize and classify the hydromorphic soils at Makusidi in Wushishi Local Government Area of Niger State. Two pedons were dug representing upper and lower slopes of the field which were designated as MKS1 and MKS2 respectively. The pedons were described following the FAO guidelines for soil description. Soil samples were collected from each identified natural horizon and taken to the laboratory for analysis. Results revealed that MKS1 had very dark grayish brown (10YR3/2) at the topmost horizon and a very dark gray (10YR 5/1) at the subsoil. MKS2 had light brownish gray (10YR 6/2) overlying grayish brown (10YR 5/2) at the subsurface. Sand content ranged from 580 to 740 g/kg in MKS1and 430 to 920 g/kg in MKS2 silt ranged from 30 - 160 g/kg in MKS1 and 10- 160 g/kg in MKS2. Clay ranged from 170 to 270 g/kg in MKS1 and 70 to 410 g/kg in MKS2. The two pedons were slightly acidic with low organic carbon and available phosphorus contents and total nitrogen was irregularly distributed from low to medium down the two profiles, but exchangeable Ca, Mg, K and Na were found to be high at both study sites. The soils were classified under the USDA Soil Taxonomy as Typic Endoaqualfs (MKS1) and Arenic Epiaqualfs (MKS2) and correlated with WRB system as Stagnic Lixisols (Clayic) and Stagnic Lixisols (Arenic) respectively.
Keywords: Characterization, Classification, Hydromorphic soil, Makusidi, Niger State

Introduction

Hydromorphic soils of Africa's tropical and subtropical regions, such as the wetlands of West Africa (e.g., Fadama near River Niger), are vital for food production. However, effective exploitation requires a full understanding of soil resources and land features. To enhance crop output, dependable soil management approaches based on extensive knowledge of soil potentials, limits, and distribution are necessary (Nwaloka et.al., 2019). Soil results from both destructive activities (weathering of rock, microbial degradation of organic wastes) and creative processes (creation of new minerals like clays and organic compounds) (Brady and Weil, 2010). This synthesis leads to the production of horizontal strata called soil horizons, a distinctive property separating soil from deeper regolith minerals (Brady and Weil, 2010). Early Soil Science saw various ideas of soil across disciplines. Chemists considered it as a chemical storage, whereas geologists saw it as decomposed rock combined with biological materials. The agronomic concept describes soil as the natural substrate for plant growth, regardless of recognizable soil strata (Olushola, 2009). Soil is highly varied, comprising unique soils with various features and behaviors. It is a dynamic natural body made of mineral, organic components, and living organisms where plants thrive (Olushola, 2009; Clinton and Chinago, 2020). However, soil resources in the state are inadequately surveyed and identified, with limited surveys for specific development projects. This research intends to identify, characterize, classify the soils of the study region, and establish their potentials for rice production.

Materials and Methods

Study Area

The study site was a fadama plain at Makusidi which lies between Latitudes 9.57538° or 9° 34' 31" N and Longitudes 6.14659° or 6° 8' 48" E in Wushishi Local Government Area of Niger State situated at an elevation of 125 m above sea level. Niger State is characterized by sub-humid tropical climate having distinct rainy and dry seasons (Animashauna *et al.,* 2020). It receives annual rainfall from the range of 1200 mm in the north to about 1600 mm in the south spread between the months of May and October. Mean annual temperature is high throughout, about 32 °C with peaks in the months of March to June (Animashauna *et al.*, 2020). The State has 110,000 ha of hydromorphic (fadama) soils equivalent to about 3.5 % of its total land area (Lawal *et al*., 2012a). The natural vegetation in Niger state follows the rainfall pattern and other climatic elements. The vegetation of the State is broadly classified as Northern Guinea savanna with a dense population of grasses, shrubs and trees (Animashauna *et al.*, 2020).

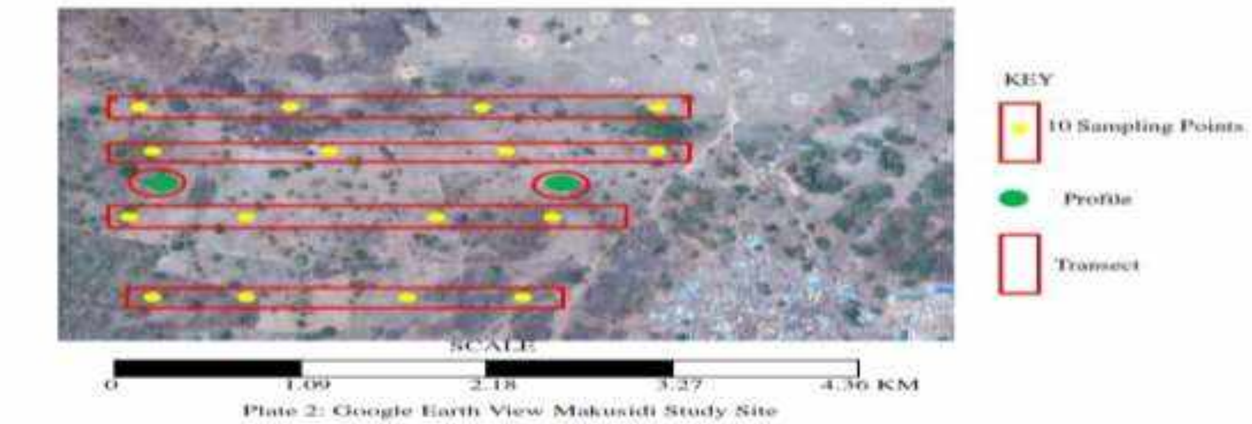

Figure 1: Showing Sampling Points in Makusidi

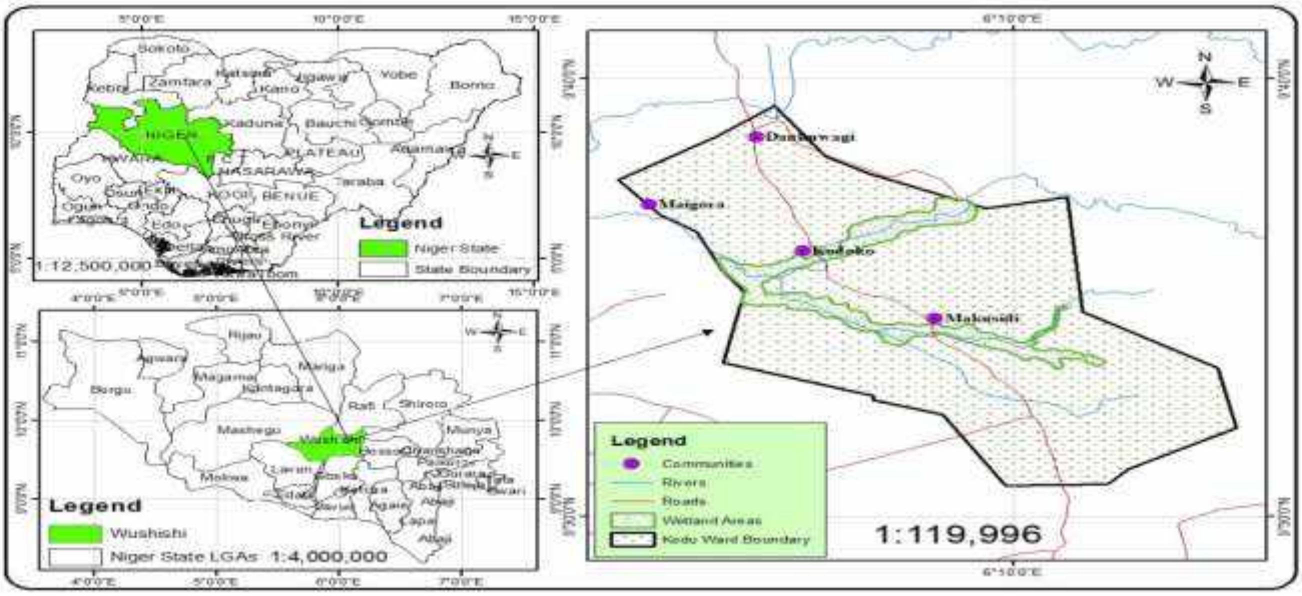

Figure 2: Map of the Study Area
Source: Niger State Geographic Information System (2023).

Sampling Techniques

Twenty (20) hectares of paddy field was studied. Auger points (0-15cm; 15-30cm) were established to identify the different soil bodies. Two soil bodies were stationed in the upper-slope and lower-slope. Two profiles each over these landscapes were dug and described. The profiles described were designated MKS1 and MKS2 from the upper-slope and lower-slope respectively. Soil colour was determined using Munsell Soil Colour Chart (Munsell Color Chart, 2000). Soil samples were collected from each identified genetic horizon and sent to the laboratory for routine analysis.

Analytical Procedures

The soil samples were air-dried, gently crushed using a mortar and pestle, and passed through a 2mm-sieve to obtain a fine earth separates. Soil analyses were carried out in the laboratory following the procedures outlined by the International Soil Reference and Information Centre and Food and Agriculture Organization (ISRIC/FAO 2002). Particle size analysis was determined using Bouyocous hydrometer method. The soil pH in H_2O 1:1 soil/water suspensions was measured with pH meter and also in $CaCl_2$ 1:2. Organic carbon was determined following Walkley-Black method; Total nitrogen (TN) was determined by Kjeldahl digestion procedure. Exchangeable bases, (Ca^{2+}, Mg^{2+}, K^+ and Na^+) were extracted with 1N NH_4OAC solution. Calcium and magnesium (Ca^{2+} and Mg^{2+}) in the extract were determined using Atomic Absorption Spectrophotometry; while potassium and sodium (K^+ and Na^+) were determined by flame photometry. Exchange acidity was determined by titration with standard NaOH. Cation Exchange Capacity (CEC) was determined by the neutral 1 N NH_4OAC saturation method. Percentage base saturation was computed by dividing the summation of exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+) by CEC and then multiplied by 100.

Results and Discussion

Morphological Properties and particle size Distribution of the Soils

The results of morphological properties and particle size distribution of the soils are presented in Table 1. The surface colour of MKS1 was very dark grayish brown (10YR 3/2) overlaying various shades of grey (10YR5/1), (10YR 6/1) amd (10YR7/1) colour in the subsoil. The subsoil was characterized with dark brown (7.5YR3/4) and yellowish brown (10YR5/8) mottle. The structure was crumb at the surface and graded to subangular, angular blocky and massive at the subsoil. MKS2 was characterized with a light brownish gray (10YR 6/2) colour overlying grayish brown (10YR5/2) to very dark gray (10YR 3/1) at subsurface. The structure was crumb at soil surface, subangular to massive at subsoil.

In (Table 1) sand values ranged from 580 to 740 g/kg and 430 to 920 g/kg for MKS1 and MKS2 respectively. Sand fraction was irregularly distributed in MKS1 and it decreased in a regular trend in MKS2. According to Ojanuga (2006), the floodplain soils of Nigeria are of alluvial origin and differed widely in their properties. It could therefore be explained that the dominance and variations in pattern of sand distribution between the profiles may be attributed to parent material rich in quartz mineral (Brady and Weil, 2010) and frequent cycles of alluvial deposition and sorting of soil materials as a result of geological processes involving clay migration through eluviation and illuviation, or surface erosion/ deposition by runoff, or by biological activities, or their combinations (Malgwi *et al*., 2000; Akintola *et al.*, 2009).

Silt content range very widely from 30 to 160 g/kg and 10 to 160 g/kg for MKS1 and MKS2 respectively. Variation in silt content of the soils may also be attributed to reasons explained for the sand. Except in the MKS2 where the pattern of distribution increased down the profile, in other pedon, silt was irregularly distributed.

Table 1: Morphological and Physical Properties of the Study Areas

Horizon	Depth (cm)	Munsell Colour Matrix	Mottle	Structure	Consistence	Root	Boundary	Textural Class	Sand	Silt	Clay	Silt/ Clay Ratio
									(gkg^{-1})			
MKS1					**(Typic Endoaqualfs)**							
Ap	0-27	10YR 3/2	_______	2cr	nstk .nplst (wet)	f.md. v.gd	d.s	SL	700	130	170	0.76
Btg1	27-59	10YR 3/1	7.5YR3/4	2sbk	sstk.splst (wet)	f.gd	c.w	SCL	580	160	260	0.62

Btg2	59-120	10YR 5/1	10YR5/8	3abk	sstk.splst (wet)	f.bd	c.s	SCL	630	100	270	0.37
Btg3	120-162	10YR 6/1	10YR4/6	M	sstk.splst (wet)	-	g.s	SCL	650	80	270	0.30
BC	162-200	10YR 7/1	10YR5/8	M	sstk.splst (wet)	-	-	SCL	740	30	230	0.13
MKS2					**(Arenic Epiaqualfs)**							
Ap	0-13	10YR 6/2	_______	1cr	nstk.nplst (wet)	f.md. v.gd	g.w	S	920	10	70	0.14
AB	13-45	10YR 5/2	_______	1sbk	nstk.nplst (wet)	f.md. gd	c.w	LS	850	60	90	0.66
Bt	45+	10YR 3/1	_______	2m	stk.plst (wet)	f.gd	-	C	430	160	410	0.40

Determined at wet and moist, **Note**: symbols or codes according to FAO (2006)
Texture: c = clay, s = sandy, sl = sandy loam, ls = loamy sand, scl = sandy clay loam, **Structure:** 1 =weak, 2 = moderate, 3 =strong, sg=single grain, cr=crumb, gr=granular sbk = subangular blocky, abk = angular blocky, m=massive; **Consistence:** nstk=non sticky,, sstk=slightly sticky, s=sticky, nplst =non plastic, splst = slightly plastic, vplst =plastic, lo=loose, sft=soft, fr=friable, firm, frm =vfrm=very firm, shrd = slightly hard, hrd = hard, hrd =hard; **Root**: f=fine, f.m-fine and many, md.b = medium and big bd = bad, gd = good, v.gd=very good. **Boundary**: a= abrupt, c= clear, g= gradual, = smooth, w =wavy d=diffuse.

Clay content ranged from 170 to 270 g/kg and 70 to 410 g/kg for MKS1 and MKS2 respectively. The two pedons showed a regular increase and subsequent accumulation in the pattern of clay down the successive soil horizons with an approximate value of 1.53 and 4.56 times higher, in clay content between surface and subsurface horizons in profiles of the MKS1 and MKS2. This may be due to the development of argillic horizon in the pedons. Schaetzl and Anderson (2005) associated the increase of clay down the soil profile with three pedogenic processes, namely, eluviation and illuviation of clay particles, neo-formation and transformation of primary minerals in the subsurface horizons. Consequently, the afore-mentioned processes facilitate the formation of an argillic horizon in soil (Esu, 2010; Soil Survey Staff, 1999, 2010). The ratios for MKS1 and MKS2 were 0.13 to 0.76 and 0.14 to 0.66. The trend followed the distribution pattern of silt in the profiles examined. Silt/clay ratios had been used to describe age and/ stage or weathering patterns in the soil. According to Ashaye (1969), a low silt/clay ratio of < 1 could mean that the soil had undergone ferralitic pedogenesis.

Chemical Properties of the Profiles

The chemical properties the soils profiles studied are presented in Table 2. Data interpretation was according to guidelines for rating of Nigerian soils by Esu (1991) and Chude *et al*. (2011). Generally, soil reaction (pH) measured in $CaCl_2$ was lower than that measured in H_2O. The observed differences may be attributed to significant displacement and subsequent hydrolysis of exchangeable aluminum and hydrogen ions complexed on the exchange sites of the soils extracted by salts (Esu, 2010). Soil reaction (pH) values MKS1 ranged from 5.4 to 7.0 and were rated as strongly acidic to slightly acidic while the pH values for MKS2 ranged from 5.7 to 6.0 and were rated moderately acidic. The acid condition of the soils at pedons 2 and 4 may be partly attributed to extensive seasonal aquic moisture characteristics of the soils which probably caused the leaching of basic salts out of the horizons sampled for the study. Lawal *et al*. (2012a) reported similar pH values for some hydromorphic soils developed on basement complex rocks and sedimentary rock formations in Niger State, Nigeria. In all the pedons, the pH values had showed an irregular trend down the soil profiles, a characteristic peculiar to hydromorphic soils (Ojanuga, 2006). Differences in pH values, especially among the horizons, may be associated in part, with the aluminosilicate clay minerals releasing aluminum and/ or hydrogen ions into the soil solution through isomorphous substitution (Tisdale *et al*., 1985), or maybe as a result of the effect of nutrient bio-cycling (Ogunwale *et al*., 2002).

Organic C content in the soil profiles ranged from 0.90 to 7.40 g/kg and 0.12 to 1.76 g/kg respectively for MKS1 and MKS2 eventually and was rated low except at the Bt-horizon of the bottomland where its concentration was rated marginally medium. The relatively higher organic C in the subsurface horizon, from a depth of 40 cm in MKS2, may be as a result of differences in organic matter contents of alluvial materials deposited during seasonal flooding (Ojanuga, 2006). Results obtained from the study corroborated the findings of Lawal *et al*. (2012b) which also reported low organic C content from studies in various hydromorphic soils underlined by Nupe sandstones within the same agroecological zone the current work was undertaken.

The total N content range at MKS1 had relatively low total N content which ranged from 0.04 g/kg to 0.12g/kg and was irregularly distributed while the MKS2 values ranged from 0.10 g/kg to 0.18 g/kg and had medium rating while pedon was rated low to medium according to Esu (1991). Brady and Weil (2010) reported that nitrogen has been a limiting factor in plant nutrient in tropical soils. Mustapha *et al*. (2003) and A.A. Panti *et al.*, (2023) also reported low nitrogen rates obtained from fadama soils in Bauchi State and fadama soils in Baddeggi, Niger State.

The result indicates that the soils are rated low to medium; the lower value of N content could be a result of losses of N through various sources. Nitrogen being a very mobile nutrient is very prone to losses through leaching and percolation under flooded situations, and volatilization once the flood water recedes. Nelson and Terry (1996) in their study observed a significant loss of soil total nitrogen after flooding.

The distribution pattern of available phosphorus (P) within the profiles was irregular and its values ranged from 3 to 5 mg/kg and 4 to 6 mg/kg in MKS1 and MKS2 respectively. According to Esu (1991), available soil P level of < 10 mg/kg is rated as low, 10 to 20 mg/kg as medium and > 20 mg/kg is rated high. Hence, the P status of the soils investigated falls under low soil fertility classification. These would confirm that soils of the Nigerian Savanna have inherently poor fertility status (Odunze *et al.*, 2004). Exchangeable calcium (Ca) of the soils of the entire pedons was within the range of moderate to high value (2 to 5 cmol/kg), but its distribution was irregular with an increase in soil depth. At the study site values ranged from 3.92 to 6.28 cmol/kg in MKS1, which was irregularly distributed down the profile too and in the bottomland, the values ranged from 2.80 to 5.12 cmol/kg, and Ca which increased down the profile. Adegbite and Ogunwale (1994) also found Ca to be the dominant cation in the soils of River Niger in nearby Kogi State which fall within the same ecological zone as Niger State, where this work was carried out. Mg concentration in MKS1 and MKS2 ranged from 2.42 to 3.52 cmol/kg and 1.36 to 2.00 cmol/kg respectively.

Table 2: Chemical Properties of Profiles of the Study Areas

Pedon No	Horizon	Depth cm	pH H_2O	pH $CaCl_2$	Org. C g/kg	TN	Av. P mg/kg	Exchangeable Bases Ca	Mg	K	Na	CEC	Exchange Acidity	%Base Saturation
								cmol/kg						
MKS1 (Typic Endoaqualfs)														
	Ap	0-27	5.4	4.2	7.40	0.04	4.0	3.92	2.42	0.47	0.09	11.37	0.05	60.69

Btg1	27-59	6.3	5.5	4.71	0.12	3.0	5.68	2.92	0.60	0.16	16.77	0.05	55.81
Btg2	59-120	6.7	5.8	4.71	0.08	3.0	4.84	3.52	1.08	0.24	18.77	0.05	51.57
Btg3	120-162	7.0	5.9	1.57	0.12	5.0	5.48	2.76	0.41	0.44	15.03	0.03	67.13
BC	162-200	7.0	5.8	0.90	0.11	3.0	6.28	2.60	1.08	0.44	15.98	0.05	65.08
MKS2 (Arenic Epiaqualfs)													
Ap	0-13	6.0	4.6	0.12	0.11	5.0	2.80	2.00	0.26	0.18	6.91	0.04	75.83
AB	13-45	5.7	4.0	1.79	0.10	4.0	3.12	1.72	0.13	0.20	7.68	0.07	67.32
Bt	45+	5.8	4.3	1.76	0.18	6.0	5.12	1.36	0.09	0.25	11.37	0.06	66.80

Source: A.A. Panti 2015

According to Esu (1991), the value of Mg in all the soils is rated high. The trend of distribution of Mg and Ca in the soils investigated was similar to the findings of Adegbite and Ogunwale (1994) and Lawal *et al*. (2012b) who also reported Ca as the dominant cation in the fadama soils of Abugi along the bank of River Niger under the same sub-humid central Niger-Benue trough agroecological zone of Nigeria. In Table 2, the K concentration was irregularly distributed in the profiles, the Ap-horizon and subsoil were rated medium, for the two pedons. In MKS1 ranged from 0.41 to 1.08 cmol/kg and in MKS2 values ranged from 0.09 to 0.26 cmol/kg and decreased progressively to a depth of 45 cm. According to Esu (1991) rating, MKS1 was rated high and MKS2 low to medium respectively. The surface horizons were medium to high in rating. Table 2 also presents the result of the exchangeable Na^+ and the values obtained at the study site, the values ranged from 0.09 to 0.44 cmol/kg and 0.18 to 0.25 cmol/kg in MKS1 and MKS2. The distribution of Na showed an increasing pattern down the profiles. Cation exchange capacity (CEC) the values obtained were in the range of 11.37 to 18.77 cmol/kg and 6.91 to 11.37 cmol/kg in MKS1 and MKS2. The cation exchange capacity of the soil was relatively high showing the capacity of the soils to retain nutrient elements. The exchange acidity of the study sites, had values ranging from 0.03 to 0.05 cmol/kg and 0.04 to 0.07 cmol/kg in MKS1 and MKS2. Percent base saturation of soils of the study site, had values obtained in the following order of 51.57 to 67.13 % and 66.80 to 75.83 % in MKS1 and MKS2 respectively.

Taxonomic classification of the Soils

The two pedons studied revealed evidence of clay accumulation in the subsurface. For the MKS1, there was 1.53 times clay in the subsurface (Btg1) than the surface (Ap) horizon. Similarly, MKS2 had 4.56 times more clay at Bt than AB horizon. Soil Survey Staff (2010) established a benchmark of 1.2 times clay between eluvial and illuvial horizons. Based on clay accumulation and base saturation > 50 %, both pedons were classified at Soil Order level as Alfisols. The pedons were further classified at Sub-order level as Aqualfs due to aquic moisture characteristic which do prevail for some time in normal years as evidenced by the presence of mottles in the subsurface horizons in MKS1 and saturated condition of the MKS2.

MKS1 at the Great-group level, MKS2 fall under Endoaqualfs because the subsurface horizons experiences water saturation over a period of time in normal years. Absence of further diagnostic features made this pedon to be placed under Typic Endoaqualfs at Sub-group level which correlated with WRB's Stagnic Lixisols Clayic.

MKS2 **a**t Great-group level was classified as Epiaqualfs because the surface horizon was saturated over a period of time in normal years. Sandy nature of the topmost horizon (Ap) extending to the top of an argillic horizon at a depth of 45cm below the mineral soil surface placed the pedon under Arenic Epiaqualfs at Subgroup level which correlated as Stagnic Lixisols Arenic.

Conclusion

Based on their properties the soils investigated fall under Alfisols with aquic moisture conditions favourable for paddy rice. It has a moderately to slightly acid status and may not require any amendment to make them conducive for the cultivation of rice. Low to medium fertility in terms of N, P and K would require amendment through application of appropriate compound fertilizer to make the soils profitable for rice production. Low organic carbon may require management practices that will encourage recycling of crop residues to enhance organic matter content of the soils.

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