PROPERTIES AND CLASSIFICATION OF TSUKUNDI FADAMA SOILS IN TARABA STATE, NORTHEAST NIGERIA

P.E. Imadojemu
[1]Department of Soil Science and Land Resources Management, Federal University Wukari, Taraba State
Corresponding Author: imadojemu@fuwukari.edu.ng

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Abstract: This study was undertaken to characterize and classify Tsukundi fadama soils in Wukari LGA of Taraba state, Nigeria. The geomorphic units were delineated into mapping units based on their physiographic positions (upper slope, mid-slope and valley bottom) and degree of submergence along transect spaced at 300 m across the slope. Sampling was based on genetic horizon differentiation. The soil depth at these mapping units (MUs) is deep < 120 cm indicating a moderate profile and a slope gradient of < 2%. The MUs has restriction zone of hardpan or sesquioxides/ plinthic horizons. The colour matrix of dark yellowish brown, strong brown and reddish yellow are associated with minerals such as goethite (FeOOH) and hematite (Fe_2O_3) and gibbsite [$Al(OH_3)$]. Dark red (10YR3/6) to reddish yellow (7.5YR6/6) are indication that the soils were either imperfectly drained or poorly drained during rainy season. Soil colours ranged from Black (7.5YR 2.5/1) in Ap horizon to reddish yellow (7.5YR 6/6) to strong brown (7.5YR 5/6) to gray (5YR 5/1) to light gray (5YR 7/1) in Bt1, Bt2 and Bt3 horizon respectively. The percentage sand averages were 804.1 g/kg, 680 g/kg and 788 k/kg in pedon SSS, MSS and LSS respectively. The clay contents of the soils increased with depth generally indicating the illuviation (translocation movement) soil finer particles down the profile and SCR was indicative of a young soil with weatherable mineral reserves. The delta pH (ΔpH) of the soils showed all negative values; this indicates that the soil colloids contained appreciable silicate clay minerals with relatively constant surface charge while the CN ratio ranged from 7.68 – 30.0. The percentage base saturation (B-sat) was largely dominated by exchangeable cations in moderately to very high rating and their mean values are 77%, 68% and 80% for MUs SSS, MSS and LSS respectively. TN had highly significant positive correlation with sand (0.61**), SCR (0.55**), BD (0.46**) while significant negative relationship clay (-0.75**), Po (-0.49**). The soils were classified as Alfisols/Entisols mix (USDA) and correlates to Eutric Arenic Fluvisols/ Luvisols (WRB).

Keywords: Fadama, Soil Properties, Nutrient Dynamics, Classification, Food Security

Introduction

Fadama is a Hausa word for low lying swampy land consisting fluvial and alluvial deposits and containing extensive exploitable aquifer. Nature of soil affects its utilization, including its uses for agricultural production (Brady and Weil, 2014). Water and soil are the most critical factors in agriculture. Fadama soils offers great potential for all season crop production and aquaculture. An inland basin floodplain system holds enormous potential for sustainable agriculture. In Nigeria, owing to the teeming human population and ever increasing food/feed needs, through the assistance of World Bank (WB), the government has focused attention on fadama resources. According to Sanchez (2019) approximately 795 million people, mostly in the tropics were hungry in 2015.

Most of the positive impacts of fadama soil resource for local farmers are evident in household improved general well-being. However, the sustainability of such improvement is hindered by inadequate information for farmer's/users thereby increasing its susceptibility to abuse and mismanagement. According to the report of World Bank (2004), fadama farming systems are predominantly subsistence in nature and highly dependent on the vagaries of weather while it's potential for irrigation using underground and surface water remains hugely underdeveloped.

Floodplains systems are characterized by a high degree of variability in both frequency and period of inundation of various parts of the floodplain. Such variations profoundly affect the processes underlying nutrient transformation. The seasonal submergence and drying are the most active factors in developing redoximorphic features such as mottles, iron and manganese concretions, chroma diagnosis of 2 or less gleyed soil matrix. The mineralogical characteristics such as quartz, kaolinite, illite, vermiculite, and interstratified clay are common in silt-clay fraction of the floodplain soils (Ogban and Babalola, 2009; Egbuchua and Ojobo,2011) while Imadojemu (2021) reported kaolinite 25.3 %, gibbsite 23%, microcline 19.8%, quartz 16.5% and phlogopite 15.4% for soil mineralogical composition in floodplain soils of Tsukundi. Worldwide, floodplains soils are useful for agricultural production as they constitute a huge reserve of available nutrients for utilization by crop plants. The soils are also used for aquaculture (Sheriff, *et al.,* 2008; Nagabhatal and Van Brakel, 2010), soils of flood plains have been characterized by moderate to high contents of basic cations, organic carbon, moderate to strong acidity and rated moderate to high in fertility status (Ogban and Babalola, 2009; Ukabiala, 2012). For a world population with 10 billion people by mid-century, food production must be more than double through intensification and extensification- land-use change (Sanchez, 2019). Fadama soils are fertile especially if recently formed (Esu and Akan- Idiok (2010). The usefulness of soil classification was recently more appreciated by ecologists (Schimel and Chadwick, 2013). The aim of this study was to characterize and classify the fadama soils with a view to understanding the nutrient status and enhancing sustainable use.

Materials and Method

The study area (Tsukundi) lies between 7°35'- 8°15'N and 9°08'- 10°23' E with an average elevation of 180 M.A.S.L (figure 1) in Wukari local government area of Taraba state. The soils are sandstone derived from basement complex and alluvial deposits. The hydrology is governed by river Donga, River Donga is an international (transboundary) water body in the northeast state of Taraba, it originated from the republic of Cameroon in the Bamenda highlands (northwest) and a major tributary of river Benue. The Agroecological zone is Subhumid Jalingo-Donga-Ganye high plain (FAO/National Programme for Food Security, 2005) and it is characterized by tropical hot/wet weather with distinct rainy and dry seasons (Aw Koppen's climate classification); as modified by Peel et al (2007). The relative humidity varies as the season (about 40 % in January and 90 % in July) with mean annual temperature of about 29°C and the dry and wet seasons are controlled by the annual migration of the inter-tropical zone of convergence (ITZC). The vegetation is secondary regrowth due to the influence of man, through bush burning, land clearing and land cultivation. The area lies in the southern guinea savannah with green vegetation and scanty tall trees (Ukpai, 2021). The vegetation is woody savannah characterize by mango (*mangifera indica*), wide palm, *Daniella olivera,* Shea tree (*Vitellaria paradoxa*). The hydrology is governed by river Donga. The geologic materials are sandstone and basement complex with basaltic intrusion giving rise to sandy loamy soil. The major farm produce are Rice (*Oryza sativa*), Sugarcane (*Saccharum officinarum*), Yam (*Dioscora spp*), Melon (*Citrullus lanatus*), Soy Bean (*Glycine max*), Maize (*Zea mays*), Cassava (*Manihot spp*), others are Amaranths. Other socioeconomic activities are fishing, river sand mining and burn bricks making from top soil mining along the floodplains. Indigenous grasses identified in the fields were *Andropogon gayanus* (Gamba grass), Brachiaria *decumbens* (Signal grass), *Cenchrus ciliaris* (Buffel grass), *Digitaria smutsii* (Finger grass), *Panicum maximum* (Guinea grass), *Hyparrhenia rufa* (Shuchi grass). The abundance of these pasture acts as attractants to cattle herders (Fulani pastoralist).

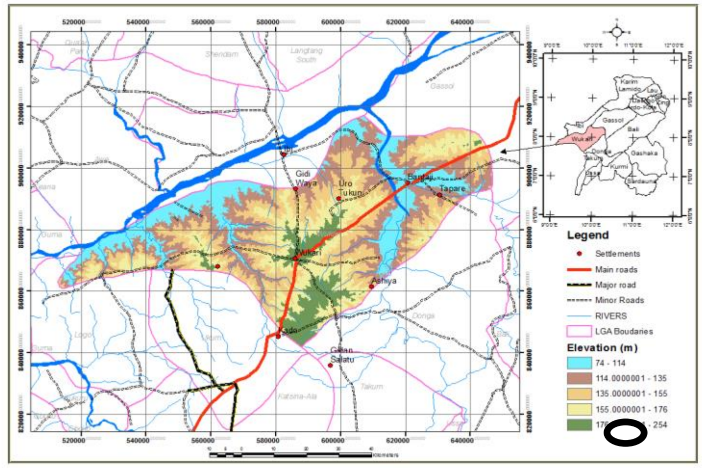

Figure 1: Location and Elevation map of Study site in Wukari LGA

Field Work

Three mapping units were identified and classified based on physiographic position along the toposequence and associated land-use types in the two study sites. A purposive sampling technique was adopted in the study. A transect was used to delineate the slope. Reconnaissance survey was carried out in order to obtain general information about the study area during the flooding periods. The geomorphic units were delineated into mapping units based on their physiographic positions (upper slope, mid-slope and valley bottom) and degree of submergence along transect spaced at 300 m across the slope (Imadojemu, 2021). These slope positions also corresponded to different land-use upon which three profile pits were sunk according to the procedures of Soil Survey Staff, (2006). Sampling was based on genetic horizon differentiation. All profile pits were geo-referenced with hand held GPS receiver. The profiles were described based on genetic horizons differentiation in-situ. Forty soil samples were taken for routine physical and chemical analysis.

Table1: Layout of Field Sample Collection on Geomorphic Units in the Fadama

Geomorphic Units	No. of Profiles	Depth of water(cm)	Distance within MU	Distance B/w MU
Severely mud flat	3	50-100 (SSS)	500m	300m
Back swamp	3	30-50 (MSS)	500m	300m
Levee	3	<30 (LSS)	500m	300m

SSS= seriously submerged soils, MSS= moderately submerged soils, LSS= lightly submerged soils

Note: Only one soil profile pit were presented and described per MU while sample collected from other profile pits were composited for laboratory analysis

Laboratory Analysis

The pH was determined by glass electrode pH meter both in 1:2.5 soil/ liquid suspension of water and KCl (Henderson *et al.,* 1993). Particle size analysis was by hydrometer method (Gee and Or, 2002). Organic carbon was determined by wet dichromate method by Udo *et al.,* (2009). Total nitrogen was determined by micro-Kjeldahl digestion method as modified by Udo *et al.,* (2009). Extraction of available phosphorus was done using Bray 1 method. Exchangeable cations (K^+, Ca, Mg^{2+}, and Na^+) were extracted by neutral normal ammonium acetate, K^+ and Na^+ in the extraction were determined by flame photometer (Udo *et al.,* 2009)while Ca^{2+} and Mg^{2+} were by atomic absorption spectrophotometer. Cation exchange capacity was by summation method. Exchangeable acidity was determined in 1NKCl extracting solution with 0.5N NaOH using phenolphthalein indicator by titration method of Mclean as described by Udo *et al.,* (2009). Bulk density was measured by core method (Grossman and Reinsch, 2002). Total porosity (P_o) was obtained from bulk density (ℓp) values with assumed particle density (ℓs) 2.65 g cm^{-3} as follows, Porosity (Po) =100 – (ℓp/ℓs) ×100/1. The following micro nutrients Fe, Zn, Mn and Cu were analyzed with atomic absorption spectrophotometer after wet digestion with concentrated HCl and HNO_3. The data collected were analyzed using descriptive statistics and coefficient of variability among soil properties were measured using coefficient of variation (CV) and rank according to the procedure of Wilding et al., (1994).

Results and Discussion

The Morphological Properties of Soils

The Morphological properties of the Tsukundi soils are shown in Tables 2a, 2b and 2c. All the horizons have well drained upper horizons and poorly drained sub soil horizon this may be due to the coarse nature of the top and finer nature of the sub profile. Pedon 1, 2 and 3 occurred on the seriously submerged soils (SSS). The soils depth at these MUs is deep > 120 cm indicating a moderate profile and a slope gradient of < 2%. The MU has restriction zone of hardpan or sesquioxides/ plinthic horizons which is why it can retain water. The colour metrix of dark yellowish brown, strong brown and reddish yellow are associated with minerals such as goethite (FeOOH) and hematite (Fe_2O_3) and gibbsite [$Al(OH_3)$] (Akpan-Idiok *et al.*, 2013; Aki *et al*., 2014: Aki *et al.*, 2016). The colours of the mottles also agrees with the findings of Aki *et al.*, 2016, that dark red (10YR3/6) to reddish yellow (7.5YR6/6) are indication that the soils were either imperfectly drained or poorly drained during rainy season. Soil colours ranged from Black (7.5YR 2.5/1) in Ap horizon to reddish yellow (7.5YR 6/6) to strong brown (7.5YR 5/6) to gray (5YR 5/1) to light gray (5YR 7/1) in Bt1, Bt2 and Bt3 horizon respectively. Pedon 2 has dark yellowish brown (10YR4/4) in the Ap horizon while the subsoil horizons had pale red (10R6/2) and light gray (10R7/1) while pedon 1 has colour in the Ap horizon as weak red (2.5YR4/2). The subsoil horizons are dark reddish brown (2.5YR3/4), light reddish brown (2.5YR6/3) just below that was the pinkish white (2.5YR8/2) and this indicated that anaerobic condition exists in the deeper subsoil. Pedons 1, 2 and 3 occurred on the moderately submerged soils (MSS). The soil depth at this MU is greater than 120 cm indicating a deep profile and a slope gradient of < 2%. The MU has restriction zone of hardpan or sesquioxides/ plinthic horizons. The mean MASL for the MUs was 106, they are all well drained (it is also imperfectly drained and seasonally flooded). The Ap horizons colours are generally strong brown (2.5YR4/3) in pedon 1 and brown (7.5YR4/40 in pedon 2 while pedon 3 has a very dark gray (10YR3/1). The subsurface horizons are strong brown (7.5YR4/6) to dark grayish brown (10R4/2) in pedon 1, strong brown (7.5YR7/4) to reddish yellow (7.5YR8/6) in pedon 2 and yellowish red (5YR5/6), gray (5YR5/1) and very pale brown (10YR8/3) in pedon 3. The strong brown and reddish brown in the upper slopes are indication of good soil air supply in the profile though soils in alluvial deposits or floodplains are poorly drained and have mottles of distinct colours indicative of anaerobic condition during periods of submergence. Pedons 1, 2 and 3 occurred on the lightly submerged soils (LSS). The soil depth at these MUs is deeper than the MSS,> 200cm indicating a deep profile, they are all well drained (it is also imperfectly drained and seasonally flooded). The Ap horizons colours are generally brown (7.5YR4/4) in pedon 3 and dark reddish brown (2.5YR3/3) in pedon 2 while pedon 3 had black (7.5YR2.5/1). The subsoil colours were reddish yellow (7.5YR6/6, strong brown (7.5YR4/6) and yellowish brown(10YR5/8) for pedon 3, the major metrix for pedon 2 were pale red (2.5YR7/2) and yellowish brown (10YR5/8) and dark grayish brown (10YR4/2) while that of pedon 3 were reddish yellow (7.5YR6/6), strong brown (7.5YR5/6), gray (5YR5/1) and light gray (5YR7/1). The dominance of reddish-yellowish brown is an indication of good soil air supply. The changes in structure down the profile were seen to be connected to clay accumulation leading to clay bulge. The alternate flooding and drying have impact on all the soil characteristics.

Table 2a: Morphology Of Soil Of Tsukundi Fadama At Seriously Submerged MU

Coordinate	Horizon	Depth	Colour	Mottling	Text.	Str.	Consist	Bound.	Drainage	Veg.	Root pres.
					SSS Wukari pedon 1						
$7^{0}52^{1}51.3^{11}$N	Ap	0-16	Weak red 2.5YR4/2	A	S	Granular	Friable	SC	WD/SF	grassland savannah with no shrubs	Many (vf-m)
$10^{o}01^{1}30.2^{11}$E	AB	16-30	Dark Reddish brown 2.5YR ¾	A	LS	Granular	Friable	SC	WD/SF		Common (vf-f)
104Masl	Bt1g	30-70	Light Reddish Brown 2.5YR 6/3	cM(7.5YR6/6)	LS	SAB	Extremely firm & Sticky	SC	WD/SF		common(vf-m)
	Bt2g	70-110	Pinkish white 2.5YR 8/2	cM(7.5YR6/6	LS	SAB	Extremely firm & Sticky	SC	WD/SF		Few (f)
					Pedon 2						
$7^{o}53^{1}11.6^{11}$N	Ap	0-15	Dark yellowish brown 10 YR 4/4	cM(2.5YR5/8)	LS	Granular	Friable/firm	SC	WD/SF	grassland savannah with no shrubs	Few (vf-m)
$10^{o}01^{1}21.2^{11}$E	ABg	15-27	Pale Red 10R 6/2	cF10YR7/6&3/6	S	SAB	Friable/firm	SC	WD/SF		Few (vf)
111Masl	Bt1g	27-94	Light Gray 10R7/1	cM(10YR5/6)	LS	AB	Firm	SC	WD/SF		few(vf)
					Pedon 3						
$7^{o}38^{1}9.17^{11}$N	Ap	0-20	Black 5YR1/1	A	SL	Granular	Friable	C	WD/SF	grassland savannah with no shrubs	Many (vf-c)
$9^{o}08^{1}10.23^{11}$E	AB	20-46	Light Reddish brown 5YR 7/4	A	SCL	SAB	Friable	C	WD/SF		Common (f-c)
100Masl	Bt1	46-67	Yellowish Red 5YR 5/6	cC(7.5YR7/8)	SC	AB	Extremely firm & Sticky	C	WD/SF		Few (vf-m)
	Bt2b	67-108	Black 5YR 2.5/1	A	SL	AB	Extremely firm & Sticky	C	WD/SF		v.Few (f)
	Bt3	108-120	Brownish yellow 10YR6/6	cF(10YR/8/6)	SC	AB	Extremely firm & Sticky	SC	WD/SF		v.Few (f

Table 2b: Morphology Of Soil Of Tsukundi Fadama At Moderately Submerged MU

Coordinate	Horizon	Depth	Colour	Mottling	Text.	Str	Consist	Bound.	Drainage	Veg.	Root pres
					MSS Wukari pedon 1						
7°52^{1}50.0^{11}N	Ap	0-08	Reddish brown 2.5 YR 4/3	A	LS	Granular	Friable/firm	SC	WD/SF	grassland savannah with no shrubs	Many (vf-m)
10°01^{1}33.5^{11}E	AB	08-20	Strong Brown 7.5YR 5/8	A	LS	Granular	Friable/firm	SC	WD/SF		Few (vf-f)
103Masl	Bt1	20-40	Strong Brown 7.5 YR 4/6	cM(7.5YR5/6)	SL	SAB	Friable /firm	SC	WD/SF		few(vf-f)
	B2	40-70	Brown 7.5YR 5/4	cM(7.5YR3/1)	SL	SAB	firm & Sticky	SC	WD/SF		Few (vf)
	Bt3g	70-113	Dark Grayish Brown 10YR4/2	cF(7.5YR5/6)	LS	SAB	Extremely firm & Sticky	SC	WD/SF		Few (vf)
					Pedon 2						
7°53^{1}20.4^{11}N	Ap	0-20	Brown 7.5 YR 4/4	A	LS	Granular	Friable/firm	CW	WD/SF	grassland savannah with no shrubs	common (vf-f)
10°01^{1}24.2^{11}E	AB	20-38	Strong Brown 7.5YR 5/6	cM(7.5YR7/8	LS	SAB	Firm	CW	WD/SF		Few (vf-f)
111Masl	Bt1	38-57	Strong Brown 7.5 YR 4/6	cM(7.5YR7/8)	LS	SAB	Firrm	CW	WD/SF		few(vf-f)
	Bt2	57-110	Reddish Brown 7.5YR 8/6	cM(7.5YR3/1&6/6)	SL	AB	Hard	CW	WD/SF		Few (vf)
					Pedon 3						
7°35^{1}8.17^{11}N	Ap	0-20	Very dark gray10 YR 3/1	A	SCL	SAB	Friable	SC	WD/SF	grassland savannah with no shrubs	Many (vf-m)
9°07^{1}11.21^{11}E	AB	20-33	yellowish red 5YR 5/6	F(5YR5/6)	CL	AB	Friable/firm	SC	WD/SF		Few (vf-c)
104Masl	Bt1	33-72	Yellowish Red 5 YR 5/8	A	SCL	AB	firm & Sticky	SC	WD/SF		Common (vf-f)
	B2	72-90	Gray 5YR 5/1	cF(5YR7/3	CL	AB	firm & Sticky	SC	WD/SF		v.Few (f)
	Bt3	90-120	Very pale brown 10YR8/3	cF(5YR7/6)	CL	AB	Extremely firm & Sticky	CS	WD/SF		v.Few (f

Mottle: A= absent, cc = common and coarse, cm = common and medium, cf= common and fine,
Texture: SL = sandy loam, scl= sandy clay loam, sc= sandy clay, ls= loamy sand
Structure: AB = angular blocky, WMSAB = weak medium subangular blocky,
Root presence: vf-c = very fine- fine-medium-coasre
Horizon boundary: c= clear, sc= smooth and clear, cw= clear and wavy, sw = smooth and wavy
Mottle: A= absent, cc = common and coarse, cm = common and medium, cf= common and fine,
Texture: SL = sandy loam, scl= sandy clay loam, sc= sandy clay, ls= loamy sand
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Root presence: vf-c = very fine- fine-medium-coasre
Horizon boundary: c= clear, sc= smooth and clear, cw= clear and wavy, sw = smooth and wavy
Horizon: Ap =plough layer, Bt= argillic horizon, AB= transition horizon, g= strong gleying, r= weathered bedrock, q= silica accumulation, b = buried horizon, v= plinthite (hard, iron enriched subsoil). Drainage: WD= well drained; SF= seasonally flooded

Table 2c: Morphology of Soil of Wukari Fadama at Lightly Submerged MU

Coordinate	Horizon	Depth	Colour	Mottling	Text.	Str.	Consist	Bound.	Drainage	Veg.	Root pres.
					LSS Wukari pedon 1						
7°52^{1}51.0^{11}N	Ap	0-20	Brown7.5YR4/4	A	S	Granular	Friable	SC	WD/SF	grassland savannah with no shrubs	Many (vf-c)
10°01^{1}41.2^{11}E	AB	20-35	Reddish yellow 7.5YR 6/6	A	S	Granular/crumby	Friable	SC	WD/SF		Many(vf-c)
102Masl	Bt1	35-85	Strong brown 7.5YR 4/6	A	LS	SAB	firm & Sticky	SC	WD/SF		Many(vf-m)
	Bt2	85-128	Yellowish Brown 10R 5/4	cF(2.5YR5/8)	LS	AB	Very firm & Sticky	SC	WD/SF		Few(vf-f)
	Bt3	128-200	Yellowish Brown 10YR 5/8	cF(2.5YR2.5/1&4/8)	LS	AB	Very firm & Sticky	SC	WD/SF		Few(vf)
					Pedon 2						
7°53^{1}27.9^{11}N	Ap	0-18	Dark Reddish brown 2.5 YR 3/3	A	SL	Granular	Friable	CW	WD/SF	grassland savannah with no shrubs	common (vf-f)
10°01^{1}27.2^{11}E	AB	18-58	Pale Red 2.5YR 7/2	cF(10YR6/8&3/3)	Si-loam	SAB	Firm	CW	WD/SF		Few (vf-f)
109Masl	Bgq	58-97	Yellowish Brown 10 YR 5/8	cM(5Y3/1)	S	Granular(gritty)	Friable & gritty to touch	CW	WD/SF		A
	Bt1g	97-120	Dark grayish Brown 10YR 4/2	cM(2.5YR5/4)	Ls	AB	firm & Sticky	CW	WD/SF		A
					Pedon 3						
7°37^{1}7.15^{11}N	Ap	0-20	Black 7.5YR2.5/1	cC(7.5YR6/6)	SCL	Granular	Friable	C	WD/SF	grassland savannah with no shrubs	Many (vf-m)
9°09^{1}9.23^{11}E	AB	20-34	Reddish yellow 7.5YR 6/4	cC(7.5YR7/4)	SC	SAB	Friable	SC	WD/SF		A
100Masl	Bt1	34-49	Strong brown 7.5YR 5/1	cC(7.5YR5/8)	SC	AB	firm & Sticky	SC	WD/SF		A
	Bt2	49-82	Gray 5YR 5/1	cF(5YR5/6)	SC	AB	Very firm & Sticky	SC	WD/SF		A
	Bt3	82-120	Light gray 5YR 7/1	A	SC	AB	Very firm & Sticky	SC	WD/SF		A

Mottle: A= absent, cc = common and coarse, cm = common and medium, cf= common and fine,
Texture: LS = sandy loam, scl= sandy clay loam, sc= sandy clay, ls= loamy sand
Structure: AB = angular blocky, WMSAB = weak medium subangular blocky,
Root presence: vf-c = very fine- fine-medium-coasre
Horizon boundary: c= clear, sc= smooth and clear, cw= clear and wavy, sw = smooth and wavy
Horizon: Ap =plough layer, Bt= argillic horizon, AB= transition horizon, g= strong gleying, r= weathered bedrock, q= silica accumulation, b = buried horizon, v= plinthite (hard, iron enriched subsoil) Drainage: WD= well drained; SF= seasonally flooded

The Physical and Chemical Properties of Soils

Some physical and chemical properties of the studied soils are presented in table 3. Physical properties of soils are very important for agricultural production and the sustainable use of soil. Some soil properties, such as low hydraulic conductivity, can limit the free supply of water and oxygen to the roots and affect negatively to the agricultural yield (María-Belén et al 2018). The soils here are moderately deep reaching 200 cm before plinthitic restriction are encountered though they are seasonally well drained even though the profile base are somewhat moist. The soils in Tsukundi fadama are alfisols / inceptisols mix but with several genetic horizons differentiation (figure 2a-c). The SSS, MSS and LSS mapping units (MU) are the pedons I, 2 and 3. The soil texture in these MU are sand (S), loam sand (LS) and sandy loam (SL) in the Ap horizons of pedons I, 2 and 3 respectively. The subsurface horizons are either SL, LS, SCL or SC. The preponderance of sand in particle size distribution (PSD) is typical of tropical soils especially of savanna ecosystem where Maniyunda and Raji, (2018) had already reported a similar dominance of sand. The percentage sand averages were 804.1 g/kg, 680 g/kg and 788 k/kg in pedon SSS, MSS and LSS respectively. The clay contents of the soils increased with depth generally indicating the illuviation (translocation movement) soil finer particles down the profile. All the identified Bt horizons had mild presence of sesquioxide (Fe-Al) concretition. This may be due to translocation of clay following illuviation and plinthization (lateritization- which is vividly manifested in tropical soils). Soils with higher sand content are prone to soil erosion and leaching. Clay in the subsoil horizons (Bt) was nearly three time greater than the value obtained for the Ap horizons these type of observations were made earlier by Obi and Akinbola, (2009); Maniyunda and Raji, (2018). Fadama soils sediments are annually supplied with high volumes of colloidal particles and clay particles that are important to fadama users because of its ability to hold nutrient and water (Imadojemu *et al.,* 2017).The mean clay content were 60.6 g/kg, 73.4 g/kg and 39.2 g/kg for SSS, MSS and LSS respectively. The mean SCR were 2.81, 4.61 and 2.14 for MUs SSS, MSS and LSS respectively. Van Wambeke, (1962); Yakubu and Ojanuga, (2009) had reported that SCR below 0.15 was indicative of an old soils (senile) while SCR above 0.15 was indicative of a young soil with weatherable mineral reserves. The mean bulk density values obtained indicated that air and water movement in the soil are at optimum Esu (2010). The total porosity values followed had inverse relationship with bulk density. The moisture content was low owing to the fact that field study were carried out in the month of February/March for ease of accessibility and when most of the floodwater had receded in the terrain.

The pH in water ranged from 6.69 – 5.78. The acidity decreased as the profile depth increased and it was moderately acidic to slightly alkaline soil according to the rating of Chude *et al.,* (2011) while the pH(KCl) ranged from 5.78- 4.75. The delta pH(ΔpH) of the soils showed all negative values; this indicates that the soil colloids contained appreciable silicate clay minerals with relatively constant surface charge which according to Okusami *et al.,(1987).* Soils with -ΔpH indicates that clay has exchangeable capacity which are regarded as cation exchangers. It was observed that top soil (Ap horizon) to subsoil had stability in decreasing acidity, this may be due to microbial transformation of soil organic matter and microbial intermediate by-product common to anaerobic (reducing) condition in floodplain systems. Virtually all aspects of the soil properties ranging from nutrient availability and absorption by plants to effects on microbial population and activities, plant growth and distribution are influenced by the soil acidity (Imadojemu, 2021). The mean soil organic carbon SOC at Ap horizons were 14.8 gkg^{-1}, 15.60 gkg^{-1} and 3.20 gkg^{-1} for MUs SSS, MSS and LSS respectively. The level of SOM mean values were 25.50 gkg^{-1} , 27.00 gkg^{-1}, and 5.50 gkg^{-1} for MUs I, 2 and 3 respectively. However, the soil had very high SOC; soil with >20 gkg^{-1} were rated as very high according to Enwezor *et al.,* (1990). The total nitrogen (TN) contents are low to moderately high with mean values of 1.55 gkg^{-1}, 1.90 gkg^{-1} and 2.10 gkg^{-1} Enwezor *et al.,* (1990). The total nitrogen content of the topsoil was higher (0.40- 2.60g/kg) than those reported by Wapa and Olowookere (2013) for the southern Guinea Savanna (0.07-0.15 g/kg). Factors responsible for the low to moderately high contents of TN first is the sediment enrichment (aquic / ustic moisture regime) on annual basis and the isohyperthermic soil temperature of the forest-grassland-shrub ecotone and the reaction, temperature and velocity (RTV rule) which leads to denitrifiction and volatilization as well as the management practice of the fadama resource (crop removal) and erosion and run-off, leaching of mineralized nitrogen (Osodeke, 2017). The C/N is important for determining mineralization and immobilization of nitrogen, the C/N ranged from 7.68 – 30.0 which is which is around 25 marked that favours mineralization as stated by Paul and Clark (1989). C/N ratios indicate the advanced stage of organic matter decomposition (Ukaegbu *et al.,* 2015). The available phosphorus (Av. P (mg/kg)) in the profile decreased with depth and had a range of 0.15 – 13.63 (mg/kg) with mean values of 7.77, 6.14 and 0.28 (mg/kg) for pedons I, 2 and 3 respectively. The Available P was rated low to moderate, according to Enwezor *et al.,* (1990). However, Osodeke (2017) described P as one of the most important plant nutrient elements and one of the most limiting nutrient elements in agricultural soil due to its high disposition to fixation by several soil constituents. The soil total exchangeable acidity (TEA) is governed by the presence of high amount of Aluminum and hydrogen in the soils of the tropics. The amount of TEA in the soil is responsible for the declining fertility status of tropical soils as they take hold of the exchange site and dominate it (Igwe *et al.,* 2002). The mean values of TEA were 0.70 cmol/kg, 1.10 cmol/kg and 0.56 cmol/kg for MUs SSS, MSS and LSS respectively. However, the contribution of Aluminum (% Al saturation) to the TEA was very low (<10%), this implies that TEA contributed to ECEC is virtually due to H^{+}. The low Al presence may be due to the near neutral soil pH (significant negative correlation between Al and pH), ferrolysis, drainage and mineral type found in the study area (Imadojemu, 2021). The exchangeable Ca constitutes above 70 % of the TEB and this agreed with Maniyunda (2018) who observed similar trend in lithosequence study in the sub-humid savanna of the northwestern Nigeria while this findings also agreed with Samndi (2011) who reported that a higher TEB value in the top soils are due to the recirculation of Ca, Mg and K to the surface through organic matter mineralization. The Mg levels in the soil were rated moderate in the MU and therefore is not a limiting factor for crop production (Oko-Oboh *et al.*, 2016). The low Na level indicated that salinity problem does not arise. Effective cation exchange capacity (ECEC) had a mean of 2.61 cmol/kg, 3.26 cmol/kg and 2.77 cmol/kg. The ECEC was low when compared to the ratings of Landon, (1991). The ECEC of soils is dependent on the amount of clay and organic matter. The percentage base saturation (B-sat), was largely dominated by exchangeable cations in moderately to very high rating and their mean values are 77%, 68% and 80% for MUs SSS, MSS and LSS respectively. The base saturation was high to very high according to the rating of (FMANR (1990) and Landon, (1991). Such high %BS holds promising future only if fadama soil is put to sustainable use and the very high %BS saturation favour the classification of such soils order as alfisols.

Table 3: Mean Values of Some Physical and Chemical Properties of Soil of Tsukundi Fadama

soil parameter	Unit	SSS	MSS	LSS	Range	CV
Sand	g/kg	804.1	680	788	838-782.4	16.2
Silt	g/kg	135.3	248.8	172.8	172.8-102.8	51.2
Clay	g/kg	60.6	73.4	39.2	103.6-34.8	38.4
SCR		2.81	4.61	2.14	4.67-0.99	76.6
TC		LS	SL	LS		
BD	g/cm^3	1.87	1.96	1.93	2.13-1.61	18.8
Po	%	29.34	18.87	24.3	39.25-19.62	25.8
MC	%	14.77	23	14.1	21.50-10.30	33.7
pH	H_2O	6.28	6	6.2	6.69 - 5.78	3.8
pH	KCl	5.31	5	5.2	5.78 - 4.75	5
ΔpH		-0.97	-1.04	-0.99	1.06 - 0.58	31
SOC	g/kg	14.8	22.5	20.6	8.90 - 24.9	42.1
TN	g/kg	1.55	1.9	2.1	2.60 - 1.10	44.14
C/N		9.5	14.38	10.09	12.63-7368	46.6
av.P	mg/kg	7.77	3.56	4.69	13.63-3.29	75.8
Ca	cmol/kg	3.79	1.33	1.37	1.76-0.64	25.7
Mg	cmol/kg	0.56	0.67	0.75	0.84-0.29	33.5
K	cmol/kg	0.05	0.02	0.07	.070 - 0.05	209.9
Na	cmol/kg	0.02	0.09	0.21	0.03- 0.02	38.7
TEB	cmol/kg	1.94	2.18	2.21	2.70-.1.0	20.6
TEA	cmol/kg	0.69	1.1	0.56	1.44-0.21	21.3
CEC	cmol/kg	10	23	13.4	12.40-7.60	27.6
%BS	%	77	63	80	86-65	11.7
ECEC	cmol/kg	2.61	3.26	2.77	4.14-1.21	16.8
Ca/Mg	cmol/kg	2.3	2	2.02	2.6-2.1	25.1
Al sat	cmol/kg	9	26	24	0.8-20	62.7

SSS= Seriously submerged soils, MSS= moderately submerged soils. LSS= lightly submerged soils

Cv (%)= coefficient of variation ranked according to Wilding et al (1994)

Table 4 showed the relationship between chemical and physical properties. pH had highly significant negative correlation with sand (-0.51**), BD (-0.42**) silt (-0.10), SCR (-0.45**) and highly significant positive correlation with clay (0.71**), Po (0.41**), MC (0.12). OC had highly significant positive correlation with sand (0.57**), SCR (0.56**), BD (0.54**), Po (0.55**) while it was only significant negative relationship with clay (-0.73**) and a non significant with MC (-0.17) and silt (-0.03). TN had highly significant positive correlation with sand (0.61**), SCR (0.55**), BD (0.46**) while significant negative relationship clay (-0.75**), Po (-0.49**) but a non significant negative with MC (-0.15) and silt (-0.01). Av.P had highly significant positive correlation with sand (0.53**), SCR (0.35*), BD (0.51**) while significant negative relationship with clay (-0.61**), Po (-0.52**) with non significant negative correlation with MC (-0.19) and silt (-0.05). TEA had highly significant positive correlation with (-0.62**), clay (0.75**), Po (0.57**) and silt (0.03) while it had a highly significant negative relationship with SCR (-0.48**), BD (-0.52**). TEB had highly significant negative correlation with sand (-0.64**), silt (-0.04), SCR (-0.45**), BD (-0.50**) as well as highly significant positive correlation with clay (0.81**), Po (0.53**). CEC had low correlations with sand (-0.18), clay (-0.04), silt (0.31*), SCR (0.27), BD (0.07), Po (-0.04) and MC (0.20).

Table 4: Correlation Matrix of Physical and Chemical Properties of Wukari Tsukundi Fadama Soils

	Sand	Clay	Silt	SCR	BD	Po	MC	pH water	OC	TN	Av P	TEA	TEB	CEC	*Ca: Mg*	C:N	ECEC	BS
Sand	1																	
Clay	-.766**	1																
Silt	-.583**	-0.07	1															
SCR	0.128	-.611**	.572**	1														
BD	.518**	-.525**	-0.14	0.237	1													
Po	-.542**	.547**	0.149	-0.26	-.99**	1												
MC	-0.073	0.08	0.01	-0.06	-0.08	0.07	1											
pHwater	-.52**	.71**	-0.08	-.45**	-.42**	.41**	0.12	1										
OC	.57**	-.73**	0.03	.564**	.54**	-.55**	-0.17	-.72**	1									
TN	.614**	-.750**	-0.013	.550**	.46**	-.486**	-0.15	-.65**	.96**	1								
AvP	.53**	-.61**	-0.05	.35*	.51**	-.52**	-0.19	-.57**	.63**	.64**	1							
TEA	-.62**	.75**	0.03	-.483**	-.52**	.570**	-0.01	.51**	-.63**	-.69**	-.59**	1						
TEB	-.637**	.811**	-0.04	-.454**	-.50**	.529**	-0.02	.768**	-.679**	-.713**	-.61**	.816**	1					
CEC	-0.18	-0.04	.314*	0.27	0.06	-0.04	-0.2	-0.17	0.29	0.21	-0.15	0.10	0.09	1				
Ca:Mg	-0.08	0.15	-0.06	0.02	.34*	.33*	0.28	0.12	-0.17	-0.11	-0.1	-0.14	-0.02	-0.16	1			
C:N	-.49**	.45**	0.18	-0.24	-0.23	0.26	0.08	0.23	-.43**	-.568**	-.38*	.48**	.55**	0.16	-0.05	1		
ECEC	-.65**	.82**	-0.02	-.47**	-.51**	.545**	-0.03	.738**	-.684**	-.726**	-.62**	.88**	.99**	0.10	-0.05	.56**	1	
BS	-0.11	0.20	-0.09	-0.07	-0.19	0.178	0.101	.594**	-0.23	-0.168	-0.09	-0.02	.468**	-0.02	0.13	0.12	.37*	1

**. Correlation is significant at the 0.01 level *. Correlation is significant at the 0.05 level of probability

Soil Classification

The soil were classified according to the USDA Soil Taxonomy (2010) and correlated with the World Reference Base (WRB, 2022) and compared to the soil characterization, classification and survey by Esu (2010). Tsukundi SSS MU, the soil were classified (Table 5) in the order as Alfisols/Entisols mix because of the presence of Bt horizon and the absence of lamellae, the surface horizon were diagnosed as Epiarenic, suborder as aqualf/ fluvaquent owing to the aquic moisture regime, great group as Argillic Endoaqualf as the most horizons are argllic along with high OC contents as well as the high %BS while the preponderance of sand showed Psammentic (USDA) correlates to Arenic (WRB). The subgroup was classified Eutric Psammentic Endoaqualfs, The family was classified Typic Psammentic, Kaolinitic Superactive Isohyperthermic, aqualfs/fluvaquents (sandy kaolinitic), Series was Wukari Sandy Loam. This corresponds to Arenic Luvisols/ Fluvisols Hypereutric and Gleyic characteristics (WRB, 2022) while for Wukari Tsukundi MSS MU had similar classification with the SSS owing to hydrosequence, the soil were classified (Table 5) in the order as Alfisols/Entisols mix because of the presence of Bt horizon and the absence of lamellae, suborder as aqualf/ fluvaquent owing to the aquic moisture regime, great group as Argillic Endoaqualf as the most horizons are argllic along with high OC contents as well as the high %BS while the preponderance of sand showed psammentic (USDA) correlates to Arenic (WRB). The subgroup was classified Eutric Psammentic Endoaqualfs/ Endoaquents. The family was classified Sandy Loam, Kaolinitic Superactive, Isohyperthermic, aqualfs/fluvaquents (sandy kaolinitic), Series was Wukari Sandy Loam. This corresponds to Arenic Luvisols/ Fluvisols Hypereutric and Gleyic characteristics (WRB, 2022).

In the relatively less ponded MU (LSS), the soils tends to have more bright hues (reddish brown) due to aeration, this MU was classified as in the order as Alfisols/Entisols mix because of the presence of Bt horizon and the absence of lamellae, suborder as utsalfs/ ustifluvent owing to the ustic moisture regime, great group as Argillic Haplaqualfs as the most horizons are argllic along with high OC contents as well as the high %BS while the preponderance of sand showed psammentic (USDA) correlates to Arenic (WRB). The subgroup was classified Eutric Psammentic Haplaqualfs. The family was classified Sandy Loam with abrupt endosiltic horizon, Kaolinitic Superactive Isohyperthermic aqualfs/ fluvaquents (Sandy Kaolinitic). Series was Wukari Tsukundi Sandy Loam. This corresponds to Arenic Luvisols/ Hypereutric characteristics (WRB, 2022).

Table 5: Soil Classification For Tsukundi Fadama

MU	USDA soil taxonomy (2010)						WRB (2006)
Pedon	Soil order	Sub-order	Great group	Sub- Group	Family	Series	
Tsukundi (SSS)	Alfisols/ Entisols	Aqualf/ Aquents	Haplaqualfs	Hapl psammentic Endoaqualfs	Typic psammentic	Wukari	Arenic Luvisols
Tsukundi (MSS)	Alfisols	Aqualf /Aquents	Endoaqualfs	Eutric Psammentic Endoaqualfs	Sandy loam kaolinitic superactive isohyperthermic aqualf-ent	Wukari	Arenic Fluvisols/ Luvisols
Tsukundi (LSS)	Alfisols/ Entisols	Ustalf	Haplustalf	Haplustalf psammentic	Abrupt endosilitic, Coarse sandy loam kaolinitic superactive isohyperthermic ustalfs/ustifluvents	Wukari	Arenic Luvisols

Conclusion

Nigeria is vigorously pursuing food security through food (agricultural) production to enable her cope with the rapidly growing population and urbanization. The morphological feature in the soil showed stonelines, an evidence of lithic discontinuity confirming the colluvial and alluvial nature of the soil. The study area is a low land with gentle slope on a plain with 0 - <4 % slope gradient. The preponderance of sand fractions in all the horizons indicated that quartz was still in abundance, shining micaceous flakes was visible in all three LGAs. These MUs have evidence of faunapedoturbation while the highest silt value was observed in pedon 6 in Wukari Tsukundi with an abrupt textural change underlain by sand (95.80%). The clay contents showed clay bulge in the Bt (argillic) with 19.48%, 48% and 34.08%. The soils have very slightly acidity which favours optimum micronutrient release; and prevailing anaerobic condition during the submergence favour Iron/Magnesium concretion, the soils are low to high in exchangeable bases that is dominated by calcium and magnesium. The usefulness of negative delta pH indicates that the soils are net exchanger of ions. The total nitrogen (TN) contents are low to moderately high. However, the soil had very high SOC/SOM. The C:N ratio increased with increasing depth. The dominance of Ca in the TEB indicated that the soil were calcareous. The soil were classified in the order of Alfisol/Entisols mix (USDA) and correlated to Eutric Arenic Fluvisols/ Luvisols (WRB)

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