Soil Fertility Capability Evaluation along River Kaduna Watershed, Northern Nigeria

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ABSTRACT

This study was conducted along the Kaduna River watershed with the goal of evaluating the fertility potential of the watershed soils. Six profile pits in all were excavated and described. The parameters used in the study to evaluate fertility capabilities were condition modifiers, substrata type, and type. The silt clay loam soil texture class dominated the examined soils. The textures of nearly all of the investigated soils (pits 1, 2, 3, 5, and 6) ranged from silt clay loam at the top horizons to silty loam or silt clay down the horizons. The only exception was Pit 4, where silty loam was predominant at both the top and sub layers. The pH of the soil was mostly neutral (pH > 5.0 <6.0), with Pit 4 being the lone exception. Pit 4's pH was higher (pH = 4.92) in terms of $CaCl_2$. All tested areas, with the exception of Pit 1, had a limitation of dryness (d) according to condition modifier classification, indicating a situation in which soils experience dryness > 60 consecutive days/year within 20 cm to 60 cm depth. With the exception of Pit 4, all other examined soils had Effective Cation Exchange Capacity (ECEC) values greater than 6 Cmolkg $^{-1}$ soil below, indicating significant exchangeable cation leaching. One of the main problems with the investigated soils was their low nutritional reserve (exchangeable K < 0.20 c mole kg -1 soil). Fertility Capability Classification placed Pit 1 as LCgv; Pit 2 Ldkv; Ldk in Pits 3, 5 and 6 and Ldek in Pit 4. Application of organic compounds rich in exchangeable basic cations especially K should be practiced by farmers near river Kaduna watershed. Also, the usage of river Kaduna for irrigation purposes should be increased to enhance dry season farming since rainfall duration is short in North Western Nigeria.

INTRODUCTION

Fasina *et al.* (2005) discovered that the main problem restricting agricultural growth and development in the tropics, particularly in Nigeria, is a lack of accurate information and proper knowledge of soil and land characteristics. As a result, a complete understanding of soil formation processes as well as soil physical and chemical features in connection to fertility is critical for maximizing the use of available soil resources for agriculture (Delgado and Gomez, 2016). The inherent ability of soils to give nutrients for crop growth and the maintenance of soil physical conditions to optimum crop yields, according to Raju *et al.* (2005), are the most essential components of soil fertility that basically define the productivity of agricultural systems. As a result, understanding the soil resources of any particular land is essential for planning its agricultural growth (Sangita, 2015).

Fertility of most of our upland soils is fast reducing due to continuous cropping of the limited available land for agriculture hence the need to explore watershed soils. The Fertility Capability Classification (FCC) is a technical system for grouping soils according to the kind of problems they present for agronomic management, though it was developed for upland soils, FCC was extended to wetland soils by Sanchez and Buol (Buol, 1986; Sanchez, 1997 and Adhikary *et al.*, 2010). Soil fertility capability classification (FCC) was created for interpretation purposes using soil taxonomy and other supplementary soil attributes information that is directly beneficial to plant growth (Buol *et al*., 1975)., Sanchez and colleagues (1982).

River Kaduna and its tributaries are very essential to the north central and North Western Nigeria as they supply irrigation water for dry season farming and their floodplains makes farming possible all year round. Most soils within the River Kaduna watershed are used for irrigation farming due to their proximity to the source of irrigation water. River Kaduna watershed constitutes, of numerous uplands and ridges as well as floodplains where agricultural activities take place. Many cereal crops, legumes and vegetables are farmed on these regions as these crops may easily be irrigated from the river. However, only little soil information is available to the farmers, extension agents, researchers and students on the soils of River Kaduna watershed. The fertility capability classification of watershed soil of River Kaduna will provide useful information for assessment and monitoring of the behaviour of the soils for agricultural uses. This research work will fill the information gap that is needed by stakeholders thereby enhancing agricultural productivity in the region as well as proper management and productivity of these soils. The major objective of this study is to carry out the Fertility Capability Classification of soils along River Kaduna, North Western Nigeria for sustainable utilization and management.

Materials and Methods

Location

River Kaduna watershed is located on the Latitudes 10o 36’ and 10° 60’ N and Longitudes 7o25’ and 7° 40’E respectively and in Kaduna state, North Western Nigeria. The study area has been characterized as a region where the rainfall is unimodal in pattern and between 900 – 1300 mm per annum (Uyovbisere and Lombin, 1991). The region also has an undulating plain topography, with general elevation ranging from about 450 to 700 m, covered in highly sandy soils, which are usually very low in organic matter, may degrade rapidly under conditions of intensive rainfall. The region is characterized by high annual average temperature (28-32°C), short wet season and long dry season (6-9 months). Generally, soil moisture and temperature regimes in the area are inferred to be ustic and isohyperthemic respectively. During the rainy season however, mean temperature drops to 25ºC – 28ºC (June to September) and decreases to less than 20ºC in the months between December and February (Gabasawa*et al.,* 2017). Tree cover varies from open woodland to light forest which has been reduced to bare land due to uncontrolled tree felling for fuel as well as farming activities (Carsky*et al.,* 1998) while abundant short grasses (<2 m) are also available (Sowunmi and Akintola, 2010).

Table 1: GPS Coordinates of Soils around River Kaduna

Location	Latitude	Longitude	Elevation (m)
Pit 1	10º.492267”	7 º.431442”	574
Pit 2	10 º.492842”	7 º.431392”	574
Pit 3	10 º.492200”	7 º.430547”	577
Pit 4	10 º. 493270”	7 º.429865”	579
Pit 5	10 º.493277”	7 º.429058”	577
Pit 6	10 º.492886”	7 º.477420”	583

Existing Information on Soil

Generally, soil such as that of dry land of Northern Nigeria are named as ‘Aridisols’ by soil taxonomists (Soil Survey Staff, 1975) and are characterized by less than 1200 mm annual rains which are usually slowly permeable, leading to most of the water being lost to run-off (Fitzpatrick, 1980). Most of the rainfall received by the river Kaduna watershed drains to the river itself and this causes flooding along the watershed at the peak of rainy season around October in most years. The watershed soon experiences aridity as the dry seasons sets in between December and May. Soils along River Kaduna watershed might have been formed under aridity from wind-stored desert sands that accumulated over long periods of time. In addition, some soils within this region of North Western Nigeria, in states such as Kaduna, Katsina, Kebbi, Sokoto and Zamfara have been also attributed to ferruginous tropical soils (D’Hoore, 1965) and characterized as having sandy texture, covering large areas of land with very low water-holding capacity and low organic matter, nitrogen and phosphorus content, neutral or moderately acidic in pH and also having a low cation exchange capacity.

Large expanse of arable land exists within the River Kaduna watershed having the potential for the production of largely grain crops like maize, sorghum, millet, rice and wheat.

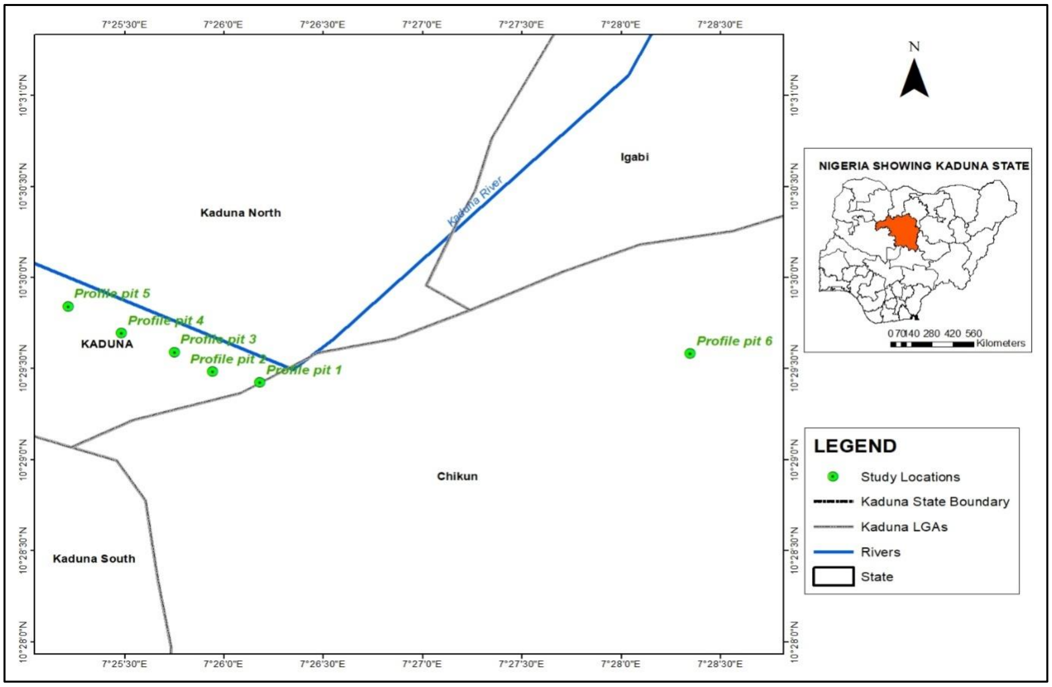

Fig. 1: Map of Study Area showing Sampling points

Vegetation

The vegetation around River Kaduna watershed is tropical guinea savannah located in North Western Nigerian. The increased activities of man which include bush burning, and increased farming have apparently converted major part of the original vegetation to bare lands. Fitzpatrick (1980) showed that the vegetation in such desert areas is usually sparse and the surface is bare for long periods. This may contribute to soil degradation by wind erosion and, hence, cause soil fertility to decline in the area. Such a problem is one of the major contributing factors to soil and environmental degradation. However, few shrubs and grasslands are still available. The region has been occupied by some grasses such as; Elephant grass *(Pennisetum purpurem)*, Giant star grass *(Cynodonplectostachyus)*, Wild groundnut *(Calopogoniummucunoides)*, butterfly pea *(Centrosemapubescens)*, Goat weed *(Sida acuta)*.

Socioeconomic Activities

The major occupation of the people of Kaduna is subsistence farming with food crops dominating the practice. Cereals are the most important stable food crop in this region (Muhamman and Gungula, 2006). Harris (2000) reported that "In sub-Sahelian northern Nigeria farmers focus on growing millet, sorghum, groundnut, sesame and cowpea and in the Sahelian part they resort to the most drought-tolerant crops: millet and cowpea". However, the main subsistence crops among them are sorghum and millet (both early and late varieties). Aregheore, (2005) noted that farmers grow crops such as millet, sorghum, maize, cowpea, groundnut, and sometime soybean in parts of Katsina, Kano, northern Kaduna, Sokoto and Zamfara states. The cropping systems of cereals predominate in the farming systems with one or several other crops in mixture. The mixture mostly found in the region is sorghum, millet, cowpea; sorghum, millet; sorghum/groundnut and sorghum/cowpea (Muhamman and Gungula, 2006). However, millet and sorghum are frequently grown on the same plot in areas such as Kano, Kebbi and Sokoto States. Millet is sown with the first rains and sorghum is interplanted later when the rain become more reliable (Mortimore, 1989). According to Asadu*et al*, (2004) crops that cover the soil, such as cowpea, are integrated in to different cropping system; crop rotation and mixed cropping. These systems include, maize, cowpea; yam, maize, cowpea; millet, cowpea; millet, sorghum, cowpea; and sorghum, millet, cowpea, okro, maize.

Field Work

A reconnaissance survey was carried out and the study location identified along a farming location lying along River Kaduna watershed. A region of the watershed was delineated into mapping units to represent some of the major cropping aspects of River Kaduna. Depending on the identified soil groups, Pedons were sunk in each of the delineated mapping units. A total six profile pits were dug cutting across the Kaduna River watershed. Soil samples were collected according to the profiles horizonation while core samplers were used to collect samples for bulk density. About 1kg samples were collected from the different horizons of each pedon. Samples were carefully packaged and labeled and transported to the soil laboratory of Ahmadu Bello University Zaria for analysis.

Laboratory Analysis

The sand, silt and clay contents of the soils were determined by hydrometer method using sodium hexametaphosphate (Calgon) as dispersing agent (Gee and Or, 2002). Bulk density (gcm^{-3}) was determined using the method described by Grossman and Reinsch (2002). Total porosity was calculated from particle and bulk densities of the soils. Moisture content was determined using gravimetric method (Obi, 1990).The silt clay ratio was calculated by dividing the value of silt with value of clay.The soil pH was determined using pH meter.Total nitrogen was determined by micro Kjeldahl method (Bremner and Mulvaney, 1982).Organic Carbon was determined by chromic acid wet oxidation method as described by Nelson and Sommers (1982). Available phosphorus was determined using Bray II solution (Olsen and Sommers, 1982).Total Exchangeable Acids (TEA) was determined by summing up all exchangeable acids (H^+ and Al^{+3}) while Total Exchangeable Bases (TEB) was determined by summing up all the exchangeable bases (Ca^{+2},K^+,Mg^{2+},Na^+).

Table 2: Fertility Capability Soil Classification System: Version 4

FCC class and short description	Symbols	Definitions and some interpretations
Type: texture is the average of plough layer or 0 to 20 cm depth, whichever is shallower	S	Sandy topsoil: loamy sands and sands
	L	Loamy topsoil: < 35% clay
	C	Clayey topsoil: > 35% clay
	O	Organic soil: >12% organic C to a depth of 50 cm or more (Histosols and histic groups) Substrata
Substrata type: used if textural change is encountered within top 50 cm	S	Sandy subsoil: texture as in type
Condition	modifiers	Identifying criteria (if more than one, they are listed in decreasing desirability)
Modifiers related to soil physical properties Waterlogging (gley): anaerobic condition, chemical reduction, denitrification; N2O and CH4 emissions	G	Aquic soil moisture regime; mottles < 2 chroma within 50 cm for surface and below all A horizons or soil saturated with water for > 60 days in most years
	g+	Prolonged waterlogging; soil saturated with water either naturally or by irrigation for > 200 days/year with no evidence of mottles indicative of Fe3+ compounds in the top 50 cm; includes paddy rice soils in which an aerobic rice crop cannot be grown without drainage; continuous chemical reduction can result in slower soil N- mineralization and Zn deficiencies in rice
Strong dry season (dry): Limits year-round cropping, interrupts pest cycles, Birch effect	D	Ustic or Xeric soil moisture regime: dry > 60 consecutive days/year but moist >180 cumulative days/year within 20 cm to 60 cm depth
	d+	Aridic or torric soil moisture regime: too dry to grow a crop without irrigation
Modifiers related to soil reaction Sulfidic (cat clays)	C	pH < 3.5 after drying; jarosite mottles with hues 2.5Y or yellower and chromas 6 or more within 60 cm sulfaquents, sulfaquepts, sulfudepts

Aluminium toxicity for most common crops	A	When > 60% Al saturation within 50 cm, or < 33% base saturation of CEC (BS 7) determined by sum of cations at pH 7 within 50cm, or pH < 5.5 except in organic soils (O)
	a-	10 to 60% Al saturation within 50 cm for extremely acid-sensitive crops such as cotton and alfalfa
No major chemical limitations (includes former h modifier)	No symbol	When < 60% Al saturation of ECEC within 50 cm and pH between 5.5 and 7.2
Calcareous (basic reaction): common Fe and Zn deficiencies	B	Free CaCO3 within 50 cm (fizzing with HCL), or pH > 7.3
Salinity	S	When > 0.4 sm-1 of saturated extract at 25°C within 1 m; salic groups; solonchaks
	s-	0.2-0.4 s m -1 of saturated extract at 25°C within 1m (incipient alkalinity)
Alkalinity	N	When > 15% Na saturation of ECEC within 50 cm; most solonetz
	n-	6% to 15% Na saturation of ECEC within 50 cm (incipient alkalinity)
Modifiers related to soil mineralogy	K	When < 10% weatherable minerals in silt and sand fractions within 50 cm, or siliceous mineralogy, or exchangeable K < 0.20 c mole kg -1 soil, or exchangeable K < 2% of sum of bases, if sum of bases is < 10 cmolc kg – 1 soil
High P fixation by Fe and Al oxides (> 10 mg kg – 1 P added to achieve adequate soil test levels); Ci soils have excellent structure but low water holding capacity; Ci sub soils retain nitrates	I	Dithionate-extractable free R2 O3: clay ratio > 0.2, or > 4% citrate dithionate – extractable Fe in of topsoil, or oxisols and oxic groups with C type, or hues redder than 5YR and granular structure
	i-	As above, but soils have been recapitalized with P fertilizers to supply long- term P to crops; soil test > 10 mg Kg – 1 P by Olsen method
	i+	as above; potential Fe toxicity if soils waterlogged for long time (g +) or adjacent uplands have I modifier
Amorphous volcanic (X-ray amorphous); high P fixation by allophone (> 200 mg Kg -1 P added to achieve adequate soil test levels); low N mineralization rates	X	Within 50 cm pH > 10 (in 1 M NaF) or positive to field NaFtest , or andisols and andic subgroups, other indirect evidences of allophone dominance in the clay size fraction, or > 90% P retention
	x-	P retention between 30% and 90% ; medium P fixers
Cracking clays (vertic properties): very sticky plastic clay, severe topsoil shrinking and swelling v	V	> 35% clay and > 50% of 2:1 expanding clays, or coefficient of linear expansibility > 0.09 or vertisols and vertic groups.
High leaching potential (low buffering capacity, low ECEC)	e	< 4 c mole kg – 1 soil as ECEC, or < 7 c mole kg – 1 soil by sum of cations at pH 7, or < 10 c mole kg – 1 soil by sum of cations + Al3+ +H+ At pH 8.2
Modifier related to soil biological properties (new)		
Low organic carbon saturation (soil organic matter depletion, C sequestration potential)	M	80% total organic C saturation in the topsoil compared with a nearby undisturbed or productive site the same soil, which is equal to 100% OR < 80% 333 Mm KMnO4-extractable topsoil organic carbon saturation compared with a nearby undisturbed or productive site of the same soil which is equal to 100%

Source: Sanchez *et al.,* (2003)

RESULTS AND DISCUSSION

Soil Physical Properties

Soil particle size distribution also known as soil texture of River Kaduna Watershed were as shown in Table 3. Sand, clay and silt were; 5, 40.5 and 55.2 % in pit 1; 8•5, 27.8 and 62.2 % in pit 2; 3, 36.25 and 60.3 % in pit 3; 23, 19.2 and 43.2 % in pit 4; 3, 31 and 65.25 % in pit 5; 6.5, 22 and 65.25 % in pit 6 respectively. The studied soils were dominated by soil texture class of silt clay loam. Almost all studied soils (pits 1, 2, 3, 5 and 6) had their textures ranged from Silt clay loam at the top horizons to silty loam or silt clay down the horizons. The only exception to this was the pit 4 which was dominated with silty loam at the top and its lower horizon.

The trend of distribution of sand showed a decrease in Pit 1 and 2, increased in pit 3, 4 and 6 with no defined trend in Pit 5. The clay content of the investigated soils showed an increase in all Pits (1 – 5) with exception of Pit 6 where clay rather decreased down the profile. Silt content had a decrease in Pit 1, 3, 4 and 5 while it increased in Pit 6 and Pit 2 which later decreased. The increasing clay content observed in most of the profile Pits (Pit 1 – 5) suggests that illuviation (clay movement down the profile) is taking place. These results clearly show that pit 1, 2, 3, 5 and 6 were in the Backswamp depositional area of the watershed. This is evident by the very low mean sandy (4, 10, 3.5, 12.8 and 4 % respectively) content of these locations. Profile pit 4 with relatively higher sand content (38.6 %) was located in the terrace area of the watershed. In these Backswamp soils, there was evidence of huge depositions of clay and silt. The dynamics of variability in the investigated soils using coefficient of variation suggests that; sand exhibited high variability (CV≥35%) except in pit 3 and 5 where it was moderate (CV≥15<35%). Clay exhibited mostly moderate variability (CV≥15<35%) except in pit 2 and 3 where it had low variability (CV≤15%) and pit 6 with high variability (CV≥35%). The silt content of the soils all indicated low variability (CV≤15%) except pit 4 where it varied highly (CV≥35%).

Table 3: Soil Properties of Studied Location

Horiz. Depth	pH	OM	Avail. P	Ca	K	Exch. Acidity (H+Al)	ESP	ECEC	Base Saturat.	Bulk. Den	Particle Size Distribution (%)				
	0.01 N $CaCl_2$	(g. kg^{-1})	(mg. kg^{-1})	(Cmol. kg-1)	(Cmol. kg-1)	(Cmol. kg-1)	%	(Cmol. kg-1)	%	(g.cm^{-3})	Sand	Clay	Silt	Silt/ clay	Text. Class (USDA
Pit 1															
0 – 25	5.80	5.07	15.26	9.40	0.61	0.10	5.24	13.35	99.25	0.96	6	26	68	2.62	Silty Clay Loam
25 – 50	6.00	4.39	6.69	4.60	0.19	0.20	3.41	6.45	96.90	1.14	4	42	54	1.29	Silty Clay
Mean	5.50	5.88	8.16	6.40	0.27	0.20	3.22	8.91	97.34	1.154	5	40.5	55.2	1.36	
CV (%)	14.37	71.5	52.1	49.16	69.1	61.24	44.14	48.44	1.88	11.19	50	21.81	13.70	44.86	
Pit 2															
0 – 25	7.70	4.06	32.93	6.00	0.29	0.20	1.40	7.84	97.45	0.89	11	27	62	2.29	Silty Clay Loam
25 – 50	5.60	5.74	4.63	6.00	0.17	0.60	2.39	8.78	93.17	1.00	6	32	62	1.94	Silty Clay Loam
Mean	5.74	5.64	9.91	5.12	0.17	0.80	2.28	7.66	89.00	1.20	8.5	27.8	62.2	2.24	
CV (%)	20.08	36.0	130.0	26.29	39.1	53.03	45.84	23.56	7.05	20.66	62.1	13.55	4.60	11.07	
Pit 3															
0 – 25	6.10	4.95	4.97	9.20	0.12	0.10	0.73	12.27	99.19	0.97	2	32	66	2.06	Silty Clay Loam
25 – 50	6.10	2.70	18.01	5.00	0.26	0.10	2.33	6.87	98.54	1.22	4	38	58	1.53	Silty Clay Loam
Mean	5.88	2.84	7.27	7.65	0.14	0.13	1.77	10.20	98.37	1.14	3	36.25	60.3	1.66	
CV (%)	4.89	51.6	98.8	50.8	59.2	40	57.38	48.26	1.40	10.75	28.6	9.66	7.29	17.12	
Pit 4															
0 – 25	4.80	1.67	2.40	4.40	0.20	0.60	6.53	6.02	90.88	1.33	18	15	67	4.47	Silty Loam
25 – 50	5.60	9.12	8.75	4.00	0.11	0.40	2.78	5.05	93.04	1.10	28	22	50	2.27	Silty Loam
Mean	4.92	3.69	4.39	4.76	0.13	0.76	3.37	5.53	89.01	1.19	23	19.2	43.2	2.25	
CV (%)	12.14	94.7	62.6	29.17	35.3	53.93	59.85	26.17	7.31	13.42	52.4	29.32	39.7	51.09	
Pit 5															
0 – 25	4.90	3.72	3.09	5.20	0.08	1.20	2.36	8.05	85.09	1.23	4	24	72	3.00	Silty Loam
25 – 50	5.30	1.67	2.40	6.60	0.18	0.40	4.27	9.36	95.73	1.29	2	30	68	2.27	Silty Clay Loam
Mean	5.15	3.70	4.50	5.50	0.13	0.85	2.28	8.16	89.17	1.21	3	31	65.25	2.10	
CV (%)	4.62	77.9	54.3	14.08	40.2	61.88	71.76	10.18	7.74	6.59	33.	17.07	8.79	40.76	
Pit 6															
0 – 25	5.60	0.34	2.92	5.20	0.18	0.40	0.96	7.26	87.28	1.44	4	30	66	2.20	Silty Clay Loam
25 – 50	5.70	2.03	2.40	6.60	0.11	0.20	2.03	8.88	97.75	1.59	9	28	63	2.25	Silty Clay Loam
Mean	5.70	1.26	3.82	4.35	0.13	0.25	1.50	6.90	94.45	1.46	6.5	22	65.25	2.97	
CV	1.43	55.1	56.5	44.64	28.2	40	55.22	25.15	5.14	7.33	62.3	37.11	5.51	27.65	

According to Smith *et al.* (1998), there is a high correlation between specific surface area, soil compatibility, compressibility, and measurements of particle size distribution specifically, the percentage of silt and clay and organic matter. These factors all have an impact on the productivity of soils. Thus, except in oxide soils, soil fertility within a mineralogical class correlates with clay content. This conclusion indicates that there will probably be less plant development, particularly for annual crops, in the Backswamp due to its high clay content, which was caused by debris deposited by the River Kaduna due to the occasional flooding activities in most years.This is due to clay's interacting effect on the water and nutrient condition of the soil (Scholes *et al*, 1994; Iheka *et al.*, 2015). The availability of these nutrients is dependent on the activities of the clay in the soil. Because clay soils have the capacity to hold and trap specific nutrient elements in their colloidal surfaces, they are appropriate for heavy tuber crops and perennial crops whose roots naturally have the capacity to absorb nutrients.

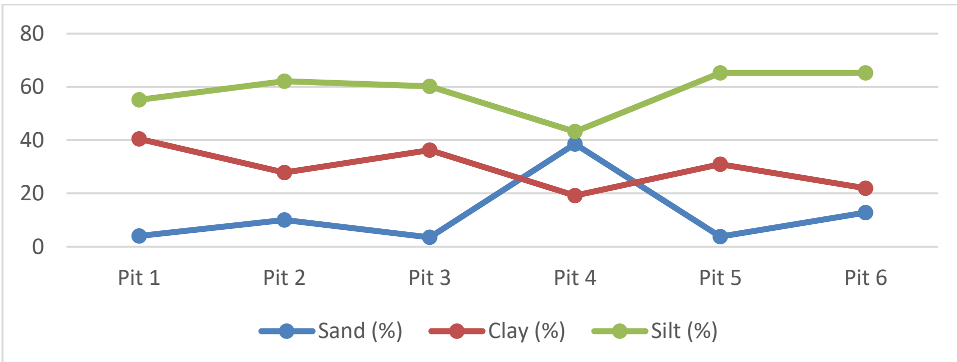

Fig. 2: Particle Size Distribution

Soil Chemical Properties

Soil Reaction

Soil pH was investigated in 0.01N $CaCl_2$ as shown in Table 3. The trend of distribution of pH across horizons was not in any particular form as it either decreased or increased within the horizon in all investigated profile pits. Mean soil pH in $CaCl_2$ for the different pits are; Pit 1; 5.50; Pit 2; 5.74; Pit 3; 5.88; Pit 4; 4.92; Pit 5; 5.15 and Pit 6; 5.70 as measured in $CaCl_2$. Soil pH was moderately acidic (pH > 5.0< 6.0) when measured in $CaCl_2$. The exception to this trend was observed only in Pit 4 where pH was more acidic; 4.92 as measured in $CaCl_2$. This higher pH when compared to other locations may be attributed to a more degree of weathering taking place in this location. It is worthy to note that this location has the highest sand content (38.6%) which will possibly encourage the leaching of exchangeable cations which predisposed the soil to acidic condition.

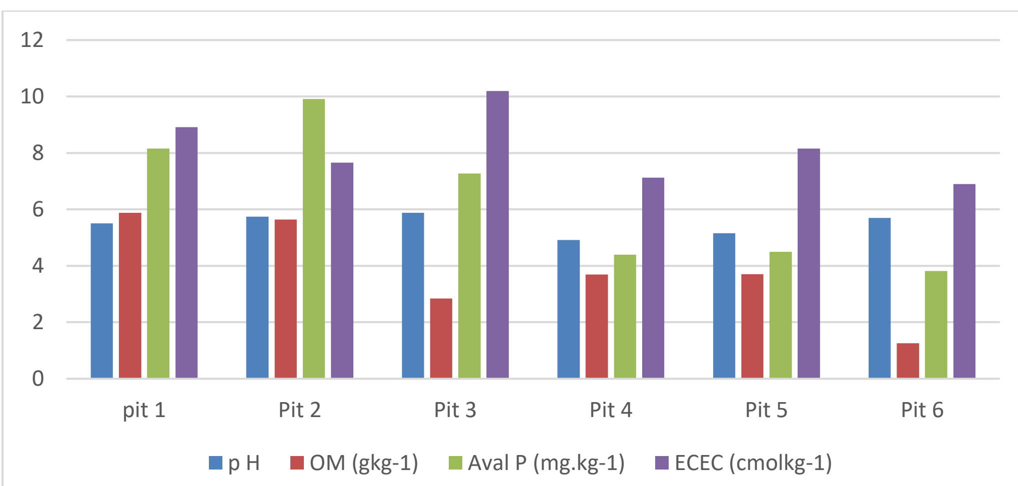

Fig. 3: Chemical Properties of Studied soils

Soil Organic Matter

Soil organic matter means were as shown in Table 3. OM recorded 5.88; 5.64; 2.85; 3.69; 3.70 and 1.26 gkg^{-1} in pits 1 – 6 respectively. Organic matter distribution displayed an irregular pattern in virtually all the profile pits studied, concentrating more towards the middle of the horizons in each profile pit examined. A deviation from this trend was observed in Pits 3, 4 and 6 where there was a consistent decrease of OM down the profile although the surface horizons of Pit 4 and 6 were lower than the horizon immediately after it. Organic matter is a product of dead and decayed organic materials (litters) on the surface of the soil and these products decrease down the profile in a normal soil. These OM contents of these soils are very low and poor (<20 gkg^{-1}). Tabi *et al*, (2012) recognized OM of <20 gkg^{-1} as low. The reason for this may be due to the fact that these locations have been under intense farming activity which takes organic substances from the soil without adequate restoration or rejuvenation. The soils under investigation have equally been affected by continual overflow of the River Kaduna leading to the high silt and clay presence observed in most of the studied soils. This situation has altered the physical and chemical properties of the soil as observed by the irregular distribution of soil OM. Organic matter varied highly (CV≥35%) in all studied soils of River Kaduna watershed.

Available Phosphorus

The available P content of the studied soils had no particular trend of distribution down the horizons in most of the studied soils although it ultimately decreased in Pits 1 – 3 and increased in Pits 4 – 6. Decrease in P with depth can be due to decrease in organic matter content with depth. Organic matter plays a key role in P availability due to its ability to coat aluminum and iron oxides, which reduces P sorption (Debicka*et al.*, 2015).Mean available P distribution as shown in Table 3, were 8.16, 9.91, 7.27, 4.39, 4.50 and 3.82 $mgkg^{-1}$in Pits 1 – 6 respectively. The Available P status indicated that Pits 1, 2 and 3 had moderate P contents (5 - 15 $mgkg^{-1}$) while low (< 5$mgkg^{-1}$) according to Tabi *et al.* (2012) in Pits 4, 5 and 6. Among the factors which affect P availability is the pH status of the soil. When the pH too low (high acidity) or too high (high alkalinity), the available P may be fixed under any of these circumstances. All studied soils had pH suggesting slightly to moderately acidic. Locations within Pits 4 and 5 had pH 4.92 and 5.15 respectively indicating more acidity compared to other locations. This may have caused the low available P obtained in these locations. Available P varied highly (CV≥35%) in all investigated soils along River Kaduna watershed.

Exchangeable Cations

The exchangeable bases were major nutrient cations and includes Ca, Mg, K and Na as shown on the Table 3. The distributions of means of exchangeable bases are as follows; Calcium (Ca) – 6.40, 5.12, 7.65, 4.76, 5.5 and 4.35 for Pits 1 – 6. For Magnesium (Mg) – 1.73, 1.42, 2.14, 1.27, 1.48 and 1.36 in Pits 1 – 6. Potassium (K) – 0.27, 0.17, 0.14, 0.13, 0.13 and 0.13 for Pits 1 – 6. Also, Sodium (Na) – 0.28, 0.18, 0.15, 0.23, 0.20 and 0.11 for Pits 1 – 6 respectively. There was no particular trend of distribution of exchangeable bases across different profile pits although most of the profile pits had highest concentrations in lower horizons. However, Ca distribution was moderate (5 – 10 $cmolkg^{-1}$) in Pits 1, 2, 3 and 5 and low (<5 $cmolkg^{-1}$) in Pits 4 and 6 when Ca critical limits were considered according to (Tabi *et al.*, 2012). Furthermore, Pit 1 had a moderate (1.5 – 3.0 $cmolkg^{-1}$) Mg content while the Pits 2 – 6 all had low (< 1.5 $cmolkg^{-1}$) Mg concentrations. Potassium and Na were low across their respective horizons having ranges of < 0.3 $cmolkg^{-1}$ in all studied locations. The low exchangeable bases observed may have been caused by excessive leaching taking place in the studied soils.

Obasi *et al.*, (2015) noted that most tropical soils are prone to leaching. Also, the dynamics of moisture within River Kaduna watershed and continuous farming activities may have depleted the exchangeable basic cations, leading to their low availability. Effective Cation Exchange Capacity (ECEC) was moderate (6 – 12 cmolkg-1) in all studied soils from Pits 1 – 5 and low in Pit 6 where it was <6 cmolkg-1. The ECEC distributions were as follows as shown in Table 3. 8.91, 7.66, 10.20, 7.12, 8.16 and 5.90 cmolkg-1 in Pits 1 – 6 respectively. Landon (1991) pointed critical ECEC as follow; low (<6 cmolkg-1), medium (6 – 12 cmolkg-1) and high (>12 cmolkg-1). The percentage base saturations were high in all the locations - 97.34, 89.00, 98.37, 89.01, 89.17 and 94.45% in pits 1 – 6 of the studied soils. The coefficient of variation of Effective cation exchange capacity (ECEC) indicated high (CV≥35%) in Pits 1 and 3, moderate (CV≥15<35%) in Pits 2 and 4 while low (CV≤15%) in Pit 5. Base saturation exhibited low (CV≤15%) variability in all investigated soils.

Table 4: Fertility Capability Studies

Locations	Type	Subtrata Type	Modifiers					FCC
			d	e	g	k	v	Classification
Pit 1	Silty Clay Loam	Silty Clay	-	-	+	-	+	LCgv
Pit 2	Silty Clay Loam	Silty Clay Loam	+	-	-	+	+	Ldkv
Pit 3	Silty Clay Loam	Silty Clay Loam	+	-	-	+	-	Ldk
Pit 4	Silty Loam	Silty Loam	+	+	-	+	-	Ldek
Pit 5	Silty Loam	Silty Clay Loam	+	-	-	+	-	Ldk
Pit 6	Silty Clay Loam	Silty Clay Loam	+	-	-	+	-	Ldk

Soil Fertility Capability Classification

The fertility capability classification was presented in Table 4 using parameters based on the soil fertility classification guide in Table 2 (Sanchez *et al.,* 1982). Considering Type and Subtrata type of the FCC classification, the soil texture class of silt clay loam predominated in the soils investigated. The textures of almost all of the soils studied (pits 1, 2, 3, 5, and 6) ranged from Silt clay loam at the top layers to silty loam or silt clay down the horizons. The lone exception was Pit 4, which was dominated by silty loam in its upper and lower horizons. Classification under condition modifiers revealed that all studied locations had a limitation of dryness (d) in all investigated locations except Pit 1 which was slightly flooded due to the time of sampling, suggesting a situation according to Obasi *et al.,* (2020) in which soils experience dryness> 60 consecutive days/year within 20 cm to 60 cm depth. Rainy season in the region mostly span from June to early October while dry season extends from November to May in a normal year. Cation Exchange Capacity (CEC) or Effective Cation Exchange Capacity (ECEC) (e) was not a limitation in the studied soils except in Pit 4 where ECEC values was less than 6Cmol.kg $^{-1}$ soil. Effective Cation Exchange Capacity < 6 Cmol.kg^{-1} suggest serious leaching of exchangeable cations (Landon 1991). This may be as a result of low rainfall associated with North Western Nigeria which had led to low leaching of exchangeable cations enhancing their availability in most studied locations. The modifier g which signifies a waterlogged condition was partially observed in locations of Pits 1 and 2 which as a result of time of sampling when moisture was still in parts of that location. The studied soils had a major challenge of low nutrient reserve, (exchangeable K < 0.20 c mole kg -1 soil, or exchangeable K < 2% of sum of bases, if sum of bases is < 10 Cmol.kg $^{-1}$ soil). In the investigated soils, only pit 1 had exchangeable K > 0.2 Cmolkg^{-1} while all other locations were lower. Condition modifier V, suggesting vertic properties were only observed in Pits 1 and 2 where rice cultivation was practiced. This effect was not well pronounced as the soil texture was similar to that obtained in other studied locations. Fertility Capability Classification placed Pit 1 as LCgv; Pit 2 Ldkv; Ldk in Pits 3, 5 and 6 and Ldek in Pit 4.

CONCLUSION

The soil texture class of silt clay loam predominated in the soils examined, according to the fertility capability classification parameters based on the soil fertility classification guide of Type and Subtrata type of the FC classification. Nearly all of the soils under study (pits 1, 2, 3, 5, and 6) had varying textures, from silty loam or silt clay at the horizons to silt clay loam at the upper layers. Pit 4 was the only exception, with silty loam predominating in both its upper and lower layers.Classification under condition modifiers showed that, with the exception of Pit 1, which was slightly flooded at the time of sampling, all investigated locations had a limitation of dryness (d). With the exception of Pit 4, where ECEC values were less than 6 Cmol.kg – 1 soil, Cation Exchange Capacity (CEC) or Effective Cation Exchange Capacity (ECEC) (e) was not a constraint in the examined soils.Low nutrient reserves (exchangeable K < 0.20 c mole kg -1 soil) posed a significant problem for the investigated soils as only pit 1 exhibited exchangeable K > 0.2 Cmolkg-1 in the tested soils; exchangeable K was lower in all other places. Condition modifier V indicates that only the rice-growing areas in Pits 1 and 2 had vertic qualities when the soil texture at this location was comparable to that seen in other analyzed locations, this effect was not as noticeable. Pit 1 was classified as LCgv by Fertility Capability Classification, Pit 2 as Ldkv, Ldk in Pits 3, 5, and 6, and Ldek in Pit 4.

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