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FERTILITY STATUS OF SELECTED SOILS OF JADA LOCAL GOVERNMENT AREA OF ADAMAWA STATE, NORTH EAST NIGERIA

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ABSTRACT

A study was conducted on the fertility status of selected soils of Jada Local Government Area of Adamawa State. Soil Samples were collected from four (4) selected wards; Jada, Wuro-Abbo, Mbulo and Kojoli, using cropping systems as criteria for the collection. Four profile pits were sunk from selected soils in each of the wards and twelve (12) augering points, three (3) in each ward at a distance of 2.5km away from the pit. Soils were analysed to determine the morphological, physical and chemical properties. Results obtained revealed that the soils were deep (>1.5m) and generally sandy loam textured with a moderately medium sub-angular blocky structure. The soils were yellowish brown (10YR 5/6) and strong brown (7.5YR) when moist to reddish in colour (2.5YR) under dry conditions at the surface indicative of prevalence of Fe (III) and Fe (II) oxides with bulk density mean values of 1.55 and 1.57g/cm^3 for pedons and augered samples respectively with mean porosity 46 % for all the samples. Chemical properties showed that the pH of the soils was moderately acidic (5.50-6.64) to neutral with low to moderate EC values in pedons and augered samples respectively. Organic carbon and net nitrogen averaged 9 g/kg and 6 mg/kg respectively. Available P averaged 3.7mg/kg and 0.84mg/kg for pedons and augered samples respectively. Exchangeable acidity, total exchangeable bases and ESP were low while ECEC was moderate to high in all the samples. The soils of the four districts were deep, moderate in structure and well drained, with low to medium organic carbon, N, P and K contents. Thus, according FCC nomenclature the soils of the four districts could be grouped in a single FCC class with sandy nature of the soil and low organic carbon (Sm) as limitations. The soil fertility and productivity of the areas could be improved and sustained through monitoring and balanced integrated nutrient management using both synthetic and organic fertilizers.

Keywords: Fertility Status; Jada Soils; Adamawa; North-east, Nigeria

INTRODUCTION

Land resources, soils in particular remain the most precious and important for ensured sustainable crop production and food security in the African continent. Soil fertility is the major determinant of agricultural production and thus its periodic evaluation is imperative at both national and global scale if the global food security is to be attained in the continent and Nigeria in particular. Tropical savanna soils have been reported to be inherently low in fertility status (Klinkenberg and Higgins, 1970; Jones and Wild, 1975). Apart from the inherently low fertility status, continuous cultivation, poor fertilizer management and other anthropogenic factors have further depleted the soil resources with consequent effects on their productive potentials which are influenced by morphological, physical and chemical properties. However, despite the low fertility status reported, there is paucity of scientific information on soils of Northern Nigeria, particularly relating to potential fertility status and capability for sustained crop production. The general works of D'Hoore (1964), Klinkenberg and Higgins (1970), Jones and Wild (1975), Singh (1997) explored classification and fertility limitations of the soils of Northern Nigeria in general while little effort is made towards re-evaluating the land resources of the region at micro-scale. With geometric increase in demand for land resources due to growing population, industrialization and urbanization, the need for inventory of soil resources as it relates to potential fertility with a view to improving and sustaining food production is very much imperative for achieving global and national food security through improved soil management. In addition, the data generated would serve as important information for policy makers particularly on fertilizer requirements of the area.

MATERIALS AND METHODS

Study Area

The study was carried out in Jada local government are of Adamawa State covering four villages of different districts (Jada, Mbulo, Kojoli, and Wuro-Abbo). Jada local government is located in the Sudan Savannah region of North East Nigeria and lies between latitudes 8°48' - 8°75N' and longitudes 12°17' - 12°38'E with an elevation of 360m above sea level. It has a landmass of 2,890km^2 (Adebayo and Tukur, 1992). The average annual rainfall for the state is 950mm.

Soil Sample Collection

Soil samples were collected using spiral auger in each of the four selected wards. Four profile pits were sited and dug in each of the wards with a dimension of 1.5m x 2m x 2m and soil samples were collected from different identified horizons. Surface (0-20) and sub-surface (20-50) soil samples were also collected at a distance of 2.5 km away to left and right of each sited pit. Samples Six Auger point by area, pit sample were five in Jada and WoroAbbo area while Mbolo has three samples and Kojoli has four samples per area. A total of 41 samples were collected. The soil sample collected were air dried, gently crushed with pestle and mortar, sieved, labeled and taken to the laboratory for physical and chemical analyses.

Laboratory Analysis

Particle size distribution was determined using Bouyoucos hydrometer method as described by (Jaiswal, 2004). Soil color was determined using Munsell color chart both in the dry and wet state. Soil structure, consistency and texture were described in accordance with Soil Survey Staff (1994). Soil pH and EC were measured in 1:2 soil to water ratio using pH and digital conductivity meters respectively. Calcium and magnesium were determined using Ammonium acetate method (Black, 1965). Potassium and sodium were determined using flame photometer. titrateable method was used to determine aluminum and hydrogen ions as described by Hesse (2002). The organic carbon of the soils were determined using Walkley and Black, Potassium dichromate wet oxidation method as described by Jaiswal (2004).The Bray 1 method was used for the determination of available phosphorus content of the soil (Bray and Kurtz, 1945). Total exchangeable bases (TEB) were calculated by the summation of sodium, potassium, calcium and magnesium. The ESP content was obtained by calculating and dividing the exchangeable sodium content of the soil by the TEB (soil) and was expressed in percentage. Summation method as described by IITA (1984) was followed to obtain the ECEC. Base saturation was calculated by dividing the sum of TEB by the ECEC and was expressed in percentage (Black, 1965). Soils were classified using the FCC classification system (Sanchez *et al.*, 2003).

Data Analysis

Data obtained were subjected to analysis of variance using SPSS statistical package version 20.0 software.

RESULTS AND DISCUSSION

Morphological Properties of the Soils

The results of morphological properties of the soils of the study area are presented in Table 1.The soils are generally deep with conspicuous horizons. Soils are yellowish brown to reddish in color in all the sampling areas. The dominantly reddish brown color recorded in all the pedons of Wuro Abbo, Mbulo, Jada and Kojoli may be attributed to the presence of Fe (III) and Fe (II) depending on oxidation-reduction reaction conditions which might have been influenced by the moisture condition in the soil. Sanchez (1976) reported that tropical soils with clayey texture under anoxic condition are usually dominated with ferric iron, hence the reddish coloration. Hesse (2002) attributed yellow colouration of soils to oxidized state of iron. Nwaka *et al.* (1999) while studying soils derived from basalt in the North Eastern Nigeria observed that there was prevalence of Fe (III) and Fe (II) in pedons that have undergone redox reactions. Raji *et al*. (1999) reported strong brown (7.5YR 5/6) sandy surface horizons over yellowish red (5YR 4/8) sandy loam subsurface horizons in the soils of Sokoto sandunes, North Western Nigeria. However, Olaniyan (2013) reported that Ap horizons of some selected Kwara State soils Southern Guinea Savannah to be dark coloured with values and chromas not exceeding 4. Variable colours were however reported at the subsurface (Olanyan, 2013). Similarly, Barnabas and Nwaka (2014) indicated that the soils of Jiwa, Southern Guinea Savannah were dominantly dark brown (7.5YR) to yellowish brown (10YR). The clearly developed horizons observed in the pedons are indication of fully developed soils that had undergone long period of pedogenesis. Fanning and Fanning (1989) revealed that pedogenic horizons develop over a long period of time during soil formation.

Table 1: Morphological properties of the soils

Pedon	Horizon Designation and depth	Profile depth (cm)	Dry soil Color	Moist soil Color	Structure	Cons
Jada	JP 0-20	0-20	10YR5/6	2.5YR4/3	Mmsbk	wnsn
	JP 20-55	20-55	10YR5/6	5YR5/4	mmsbk	Wsls
	JP 55-105	55-105	5YR6/6	2.5YR6/6	mmsbk	Wsls
	JP 105-140	105-140	5YR6/8	10R6/8	mmsbk	Wsls
	JP 140-200	140-200	7.5YR6/8	5YR5/8	mmsbk	Wsls
Wuro Abbo	wp 0-20	0-20	10YR4/6	2.5YR4/2	wmsbk	wnsn
	WP 20-40	20-40	7.5YR4/6	7.5YR4/6	smsbk	Wvs
	WP 40-75	40-75	5YR5/8	5YR5/8	mmsbk	Wvs
	WP 75-90	75-90	10YR6/8	5YR5/6	mmsbk	Wvs
	WP 90-200	90-200	2.5Y6/8	5YR5/6	mmsbk	Wsls
Mbulo	Mp 0-20	0-20	10YR5/6	2.5YR4/2	Mmsbk	Wsl
	Mp 20-75	20-75	7.5YR6/8	5YR5/4	mmsbk	wsls
	Mp 75-200	75-200	2.5YR5/8	10R6/8	mmsbk	wvsv
Kojoli	Kp 0-20	0-20	2.5Y5/6	2.5YR5/1	mmsbk	wvsv
	Kp 20-60	20-60	10YR5/8	10YR7/4	smsbk	wvsv
	Kp 60-130	60-130	2.5Y5/6	7.5YR8/1	smsbk	wvsv
	Kp 130-200	130-200	2.5Y7/6	7.5YR8/2	smsbk	wvsv

Key: Jp= Jada pedon, Wp= Wuroabbo pedon, Mp=Mbulo pedon, Kp=Kojoli pedon;
S=sand, SiC=silty clay, SL=sandy loam

Physical Properties of the Soils

The results of the physical properties of the soils of Jada, Wuro-Abbo, Mbulo and Kojoli are presented in Tables 2, 3 and 4 and 5 respectively. The soils of the pedons were dominantly loamy sand at the surface in Jada, WuroAbbo, Mbulo and Kojoli (Table 2). However, clay loam texture was dominant at the subsurface horizons of Jada and Kojoli auger points (Table 5), indicative of clay and Fe-hydroxides eluviation-illuviation process which may be due to the dominant factor influencing soil formation and the comparatively high precipitation levels being recorded in the area each season. Similar characteristics were reported to have been exhibited by soils of Sokoto sandunes (Raji *et al.*, 1999). Bulk density of the soils ranged from 1.48g/cm^3 to 1.69g/cm^3 with a mean value of 1.58g/cm^3 (Table 2) in the pedons with highest value of 1.69g/cm^3 at the surface in Jada and lowest value of 1.48g/cm^3 was recorded at the depth of 55-105cm. In W/Abbo, the bulk density ranged from 1.44g/cm^3 to 1.69g/cm^3 with a mean value of 1.56g/cm^3 in both pedons and augered samples with comparatively lower bulk density values in the augered sample points. In Mbulo however, the bulk density in the pedons ranged from 1.42g/cm^3 to 1.68g/cm^3 with mean value of 1.56g/cm^3. High bulk density of 1.68g/cm^3 was recorded at 0-20cm. In Kojoli the soils are sandy loam in texture (Table 2). The bulk density in the pedons ranged from 1.41g/cm^3 to 1.62g/cm^3 with a mean value of 1.47g/cm^3 (Table 2) while the augered samples had bulk density ranging from 1.30g/cm^3 to 1.68g/cm^3 with a mean value of 1.48g/cm^3 (Table 3). The highest value of 1.68g/cm^3 was recorded at Wuro-Abbo in the surface horizon (Table 4). The lowest bulk density of 1.30g/cm^{3}was recorded at Kojoli in the subsurface layer (Table 5) in the augered samples. The bulk density decreased with increasing depth in Mbulo soil pedon. The consistently higher bulk density at the surface and lowest at the sub-surface may be attributed to high cultivation and compaction at the surface layer. Holtz and Kovac (1981) and Lal (1985a) reported that rain drop impact and cultivation increased bulk density of soils. Similarly, Brady and Weil (2008) reported increased bulk density due to soil cultivation and compaction. The low bulk density at the sub-surface may however be related to the lower organic matter content at the sub-surface in addition to zero cultivation at the sub-surface. Raji *et al*. (1999) reported bulk density value of 1.55g/cm^3 and as high as 1.78g/cm^3 at the surface and subsurface horizons respectively for soils of Sokoto plains, Sudan Savannah. Lower bulk density value of 1.4g/cm^3 was reported for soils of Mambila Plateau (Nwaka *et al*., 1999). Much lower mean bulk density value of 1.35g/cm^3 was reported by Barnabas and Nwaka (2014) for soils of Jiwa, Sourthen Guinea Savannah. High bulk density may reduce water infiltration and increase chances of soil water erosion.

Unlike the high bulk density recorded at the surface, a slightly higher porosity was recorded at the sub-surface depth of 55-105cm with a percent porosity of 44% (Table 2). This may be due to the lower bulk density recorded at the sub-surface. In addition, there was lower organic matter content at the sub-surface compared to the surface horizon, thus resulting in higher soil porosity. The percentage porosity ranged from 36% to 44% with a mean value of 41.6%. The porosity increased with increasing depth which may be due to the reduced compaction. Percentage porosity in the pedons ranged from 39% to 47% with a mean value of 44.25% and ranged from 37% to 51% with a mean value of 44% in the augered samples (Table 3). The highest value of 51% was recorded at Kojoli in the subsurface layer (Table 2) and the lowest percent porosity of 37% was in the surface horizon of Wuro-Abbo (Table 2). High and low porosity values have also been reported by many authors (Brady and Weil, 2008, Nwaka *et al*., 1999). Percent porosity of < 5 % is rated low and > 40 % is rated very high (FAO, 1990).

Table 2: Physical properties of the soils from Pedons

Profile	Sand (%)	Silt (%)	Clay (%)	Textural Class	Colour (wet)	Colour (dry)	Bulk density (g/cm3)	Porosity (%)
JP 0-20	82.4	12.4	5.2	Loamy sand	2.5YR 4/3	10YR 5/6	1.69	36
Jp 20-55	78.4	11.6	10	Loamy sand	5YR 5/4	10YR 5/6	1.58	40
Jp 55-105	70.8	10.4	18.8	Loamy sand	2.5YR 6/6	5YR 6/6	1.48	44
Jp 105-140	80.4	12.4	7.2	Loamy sand	10R 6/8	5YR 6/8	1.63	38
Jp 140-200	76.8	10	13.2	Loamy sand	5YR 5/8	7.5YR 6/8	1.54	42
Mean	77.8	11.36	10.9				1.58	40
2								
Wp 0-20	82.4	12	5.6	Loamy sand	2.5YR 4/2	10YR 4/6	1.68	37
Wp 20-40	70.4	12.8	16.8	Loamy sand	7.5YR 4/6	7.5YR 4/6	1.49	44
Wp 40-75	66.8	11.2	22	Sandy loam	5YR 5/8	5YR 5/8	1.44	45
Wp 75-90	66.8	15.6	17.6	Sandy loam	5YR 5/6	10YR 6/8	1.48	44
Wp 90-200	82.4	12.4	5.2	Loamy sand	5YR 5/6	2.5Y 6/8	1.69	36
Mean	73.8	12.8	13.4				1.56	41
3								
Mp 0-20	80.4	14.4	5.2	Loamy sand	2.5YR 4/3	10YR 5/6	1.68	37
Mp 20-75	75.6	15.2	9.2	Loamy sand	5YR 5/4	7.5YR 6/8	1.59	40
Mp 75-200	62.2	13	24.8	Sandy loam	10R 6/8	2.5YR 5/8	1.42	46
Mean	72.7	14.2	13.1				1.56	41
4								
Kp 0-20	72.4	20.4	7.2	Loamy sand	2.5YR 5/1	2.5Y 5/6	1.62	39
Kp 20-60	58.4	18.4	23.2	Sandy loam	10YR 7/4	10YR 5/8	1.42	46
Kp 60-130	60.4	13.2	26.4	Sandy loam	7.5YR 8/1	2.5 Y 5/6	1.41	47
Kp 130-200	62.2	18.2	19.6	Sandy loam	7.5YR 8/2	2.5Y 7/6	1.45	45
Mean	72.68	13.59	13.73				1.55	41.4

Key: Jp, Jada pedon, Wp, Wuroabbo pedon, Mp, Mbulo pedon, Kp, Kojoli pedon

Table 3: Physical properties of augered soil samples

Sample	Sand (%)	Silt (%)	Clay (%)	Textural class	Bulk density (g/cm3)	Porosity (%)
JADA						
J1A	69.2	24	6.8	Sandy loam	1.62	39
J1B	43.2	22	34.8	Clay loam	1.33	50
J2A	67.2	26	6.8	Sandy loam	1.62	39
J2B	43.2	24	32.8	Clay loam	1.34	49
J3A	65.2	28	6.8	Sandy loam	1.61	39
J3B	41.2	24	34.8	Clay loam	1.33	50
Mean	65.8	30	24.6		1.45	44.33
KOJOLI						
K1A	47.2	36	16.8	Loam	1.45	45
K1B	37.2	24	38.8	Clay loam	1.3	51
K2A	45.2	36	18.8	Loam	1.43	46
K2B	41.2	24	34.8	Clay loam	1.33	50
K3A	53.2	32	14.8	Sandy loam	1.48	44
K3B	39.2	22	38.8	Clay loam	1.48	44
Mean	52.6	35	32.6		1.41	47
MBULO						
M1A	49.2	36	14.8	Loam	1.57	45
M1B	49.2	30	20.8	Loam	1.42	46
M2A	47.2	38	14.8	Loam	1.47	45
M2B	47.2	28	24.8	Loam	1.39	48
M3A	41.2	38	20.8	Loam	1.4	47
M3B	49.2	30	20.8	Loam	1.42	46
Mean	56.6	40	23.4		1.45	46
W/ABBO						
W1A	73.2	22	4.8	Sandy loam	1.68	37
W1B	65.2	22	12.8	Sandy loam	1.52	43
W2A	73.2	18	8.8	Sandy loam	1.59	40
W2B	67.2	20	12.8	Sandy loam	1.52	42
W3A	73.2	20	6.8	Sandy loam	1.63	39
W3B	63.2	16	*20.8*	Sandy clay	1.45	45
Mean	83.0	23.6	13.4	Loam	1.57	41

Key: J, K, M and W represents Jada, Kojoli and Wuro Abbo respectively ; A and B-represents surface and subsurface while 1, 2,and 3 represents frequency of sampling

Table 4: Some physical properties of surface augered soil properties

Sample	Sand (%)	Silt (%)	Clay (%)	Textural class	Bulk density (g/cm^3)	Porosity (%)
JADA						
J1A	69	24	7	Sandy loam	1.62	39
J2A	67	26	7	Sandy loam	1.62	39
J3A	65	28	7	Sandy loam	1.61	39
Mean	67	26	7	Sandy loam	1.62	39
KOJOLI						
K1A	47	36	17	Loam	1.45	45
K2A	45	36	19	Loam	1.43	46
K3A	53	32	15	Sandy loam	1.48	44
Mean	49	35	17	Loam	1.45	45
MBULO						
M1A	49	36	15	Loam	1.57	45
M2A	47	38	15	Loam	1.47	45
M3A	41	38	21	Loam	1.4	47
Mean	46	37	17	Loam	1.48	46
W/ABBO						
W1A	73	22	5	Sandy loam	1.68	37
W2A	73	18	9	Sandy loam	1.59	40
W3A	73	20	7	Sandy loam	1.63	39
Mean	73	20	7	Sandy loam	1.63	39

Table 5: Physical properties of sub surface augered soil samples

Sample	Sand (%)	Silt (%)	Clay (%)	Textural class	Bulk density (g/cm^3)	Porosity
JADA						
J1B	43.2	22	34.8	Clay loam	1.33	
J2B	43.2	24	32.8	Clay loam	1.34	
J3B	41.2	24	34.8	Clay loam	1.33	
Mean	42.53	23.33	34.13	Clay loam	1.33	
KOJOLI						
K1B	37.2	24	38.8	Clay loam	1.3	
K2B	41.2	24	34.8	Clay loam	1.33	
K3B	39.2	22	38.8	Clay loam	1.48	
Mean	39.2	23.3	37.5	Clay loam	1.4	
MBULO						
M1B	49.2	30	20.8	Loam	1.42	
M2B	47.2	28	24.8	Loam	1.39	
M3B	49.2	30	20.8	Loam	1.42	
Mean	48.53	29.33	22.13	Loam	1.41	
W/ABBO						
W1B	65.2	22	12.8	Sandy loam	1.52	
W2B	67.2	20	12.8	Sandy loam	1.52	
W3B	63.2	16	20.8	Sandy clay loam	1.45	
Mean	65.2	19.33	15.47	Sandy loam	1.50	

Chemical Properties of the Soils

The Chemical properties of the soils from the pedons and augered samples are presented in Tables 6, 7, 8 and 9. Soil pH ranged from 5.90 to 6.64 with a mean value of 6.30, and 6.2 to 7.60 with a mean value of 6.60 for pedons and augered samples, respectively. The highest value of 7.60 was recorded in Kojoli at subsurface layer in the pedons (Table 6). The pH is rated moderately to slightly acidic (Usman, 2005). Slightly acidic pH ranges have severally been reported to be the optimum for nutrient release and use for plant growth and development (Brady and Weil, 2008). However, the highest pH recorded in the augered samples (Table 7) may be due to the leaching of exchangeable bases down to the sub-surface horizon which may be as a result of high infiltration and continuous cultivation as a consequence of high precipitation levels at the time of sampling. In addition, since the soils are dominantly sandy loam, the texture might have contributed to increased porosity and leaching of bases. High moisture content accompanied by high soil porosity accelerates leaching of bases (Brady and Weil, 2008). Tropical soils are mostly acidic due to the dominance of iron and aluminum in the colloidal complex (Sanchez, 1976; Brady and Weil, 2008).

EC values in the pedons ranged from 0.10 to 0.70 dSm^{-1} with the highest recorded in Wuro Abbo pedon (Table 6). Comparatively higher EC values were recorded in the augered samples with a mean value of 0.8 dSm^{-1} for all the four districts evaluated. Highest EC value of 0.70 dSm^{-1} was recorded at the depth of 0-20cm in Wuro-Abbo pedon (Table 6), while the lowest value of 0.12dSm^{-1} was recorded at a depth of 20-75cm in Mbulo pedon (Table 6). EC is directly related to total dissolve solids (TDS) in soils. The comparatively higher accumulation of salts at sub-surfaces in both pedons and augered samples may be attributed to movement of salts from the upper to lower horizons in response high moisture availability. Soil EC values of < 4dSm^{-1} is rated non-saline and therefore safe for crop production (Brady and Weil, 2008). However, in most augered samples, EC values recorded were > 0.75dSm^{-1} indicating slight salinity in the soils. FAO (2006) rated soils with EC values > 0.75-2.0 dSm^{-1} at 25^oC to be slightly salty.

The organic carbon content values of the pedons ranged from 0.04 % to 1.2 % with Kojoli pedon recording higher values at both surface and sub surfaces (Table 6). Lowest values were however recorded in Wuro Abbo and Mbulo pedons. Results from Jada and Mbolo pedons also showed comparatively higher organic carbon content values at the subsurface horizons. This may be attributed to use of heavy implements thereby upturning the soil humus from the upper to lower horizons. Lal (1985b) reported that intense land clearing and ploughing using heavy implements upturn soils particularly those of the tropics and transport the organic residues to the lower horizon. In Kojoli pedon, except for the upper horizon the organic carbon content of the sub-surfaces were the same. Earlier, Jones (1970) reported that human interferences through cultivation, parent material and altitude have bearing on content and distribution of organic matter in soils. Usman (2014) also reported significant ($P<0.05$) changes of organic matter content distribution along altitudinal gradient of Atlantika mountain range at Koma, Nigeria. The augered samples showed that the organic carbon content values were generally higher at the surface (Table 8) compared to the sub-surface and ranged from 0.5 to 1.7 % (Table 9). Organic carbon content values in both the pedons and augered samples were less than 2 % (Tables 6 and 7). Jones and Wild (1975) reported similar values for tropical soils. Similarly, Lombin (1983), Mustapha and Nnalee (2007) and Hassan *et al.* (2013) reported similar low organic carbon content values for the Nigerian savannah soils. Mean organic carbon content of 6.5g/kg was reported by Barnabas and Nwaka (2014) for soils of Jiwa, Southern Guinea Savannah.

The available nitrogen or mineralizable nitrogen comprising of NH_4-N and NO_3-N ranged from 4.2-10.5 and 3-6.2mg/kg in pedons and augered samples respectively (Tables 6, 7, 8 and 9). The results show low levels of available nitrogen in the soils of the area. Greenland (1958) reported that the extent to which mineralizable nitrogen accumulates is related to the potentially minerazable nitrogen nutrifiable N in the soil which has been a function of the amount and nature of the organic matter particularly the carbon to nitrogen ratio. Raji and Mohammed (2000) reported that 80 % of the soils sampled in Nigerian savanna soils contain < 1 % organic carbon content while on 20 % contain greater than 1 % in localized sampled areas. Available phosphorus ranged from 0.14 to 3.57$mgkg^{-1}$ with a mean value of 0.84$mgkg^{-1}$ and 1.1 to 9.1$mgkg^{-1}$ with a mean value of 3.7$mgkg^{-1}$ for pedons and augured samples respectively (Tables 6, 7, 8 and 9). Lower available phosphorus contents were recorded in the pedons compared to the augered samples. This may be due to mining by plants as a consequence of continuous cultivation in the area where auger samples were collected as well as the sandy loam nature of the soils that allow nutrient movement beyond the root zone. Low AVP (< 10cmolkg^{-1}) were reported for Chouchi and Hong soils of Nigeria by Hassan *et al*. (2013).

The exchangeable bases; calcium, magnesium, potassium and sodium recorded in both the pedons and augered samples (Table 6 and 7) were generally medium to high indicative of prevalence of the bases in the colloidal complex. Calcium ranged from 1.0 to 6.8 cmolkg^{-1} with a mean value of 3.08 cmolkg^{-1}; the highest value of calcium was recorded at a depth of 60-130cm in Kojoli and the lowest in Jada at a depth of 55-105 cm. Magnesium ranged from 0.4 to 4.0 cmolkg^{-1}with a mean of 1.68 cmolkg^{-1} and highest value of 4.0 cmolkg^{-1} was recorded in Kojoli pedon at depth of 130-200cm and the lowest value in Mbulo at depth of 0-20 cm. Potassium ranged from 0.13 to 0.50 cmolkg^{-1}with mean value of 0.24cmolkg^{-1}; the highest value was recorded in Kojoli at a depth of 130 to 200 cm. Sodium ranged from 1.19 to 2.2cmolkg^{-1} with a mean value of 1.35 cmolkg^{-1}; the highest was recorded in Kojoli at a depth of 130-200cm and the lowest was in Jada at a depth of 0-20 cm and 20-55 cm. The exchangeable bases recorded in the lower horizons in both pedons and augered samples may be attributed to the leaching of the bases down to the subsurface particularly where high moisture condition prevails. Similar exchangeable bases values were reported by Hassan *et al*. (2013) for soils of Chouchi and Hong, Northern Guinea Savannah.

Table 6: Some chemical properties of the soils from the pedons

Pedon	pH	EC	OC	NH_4^-	NO_3^-	Net N	AVP	Na^+	K^+	Ca^{2+}	Mg^{2+}	TEB	H^+	Al^{3+}	TEA	ECEC	BS	SAR	ESP
		(ds/m)	(%)	← mg/kg			→	← cmol/kg								→	(%)		(%)
JP 0-20	6.2	0.4	0.0	3.2	4.6	7.7	3.6	1.2	0.2	1.8	1.1	4.3	0.8	2.4	3.2	7.5	57.5	1.0	27.5
JP 20-55	6.6	0.5	1.1	2.8	1.4	4.2	2.4	1.2	0.1	2.0	0.9	4.2	0.4	1.2	1.6	5.8	72.5	1.0	28.2
JP 55-105	6.4	0.4	0.5	1.1	3.9	4.9	0.4	1.3	0.3	1.0	1.6	5.1	4.4	4.4	4.4	9.5	53.5	1.0	25.5
JP 105-140	6.3	0.2	1.2	4.6	3.9	8.4	0.1	1.3	0.2	2.3	0.7	4.4	0.8	0.8	1.6	6.0	73.3	1.0	28.4
JP 140-200	6.6	0.4	0.4	5.1	5.5	10.5	0.5	1.4	0.1	3.0	0.6	5.2	3.2	3.2	3.2	8.4	61.8	1.1	27.7
2																			
WP 0-20	6.1	0.7	0.6	2.8	5.0	7.8	2.1	1.2	0.4	4.4	2.0	8.0	0.4	2.4	2.8	10.8	74.0	0.7	15.3
WP20-40	6.1	0.6	0.5	4.2	4.9	9.1	0.8	1.3	0.5	3.2	1.4	6.4	1.2	2.8	4.0	10.4	61.6	0.9	20.4
WP40-75	6.3	0.3	0.7	2.8	5.0	7.8	0.2	1.3	0.2	3.0	1.8	6.3	0.4	1.2	1.6	7.9	79.8	0.8	20.3
WP75-90	6.2	0.5	1.0	5.5	4.9	10.4	1.1	1.4	0.3	2.9	2.7	7.3	0.4	2.0	2.4	9.7	75.1	0.8	18.6
WP90-200	6.4	0.4	0.8	2.8	4.7	7.5	0.7	1.3	0.2	2.5	1.6	5.6	0.8	2.8	3.6	9.2	60.7	0.9	22.7
3																			
MP0-20	6.3	0.4	0.6	4.7	4.9	9.6	0.8	1.3	0.2	2.3	0.4	4.1	0.8	2.4	3.2	7.3	56.2	1.1	30.5
MP20-75	5.9	0.1	0.7	3.5	3.2	6.7	0.8	1.3	0.1	2.4	1.1	4.9	0.4	2.4	2.8	7.7	63.8	1.0	26.5
MP75-200	6.1	0.3	0.5	1.8	0.7	2.5	0.9	1.4	0.2	2.7	1.0	5.2	0.4	2.4	2.8	8.0	65.3	1.0	26.0
4																			
KP0-20	6.2	0.3	1.2	5.0	5.0	10.0	0.4	1.2	0.1	2.6	1.7	5.7	0.8	2.8	3.6	9.3	61.1	0.8	21.6
KP20-60	6.5	0.2	1.1	1.8	3.9	5.6	0.1	1.3	0.3	3.8	2.8	8.1	1.2	2.0	3.2	11.3	71.8	0.7	15.9
KP60-130	6.4	0.4	1.4	5.3	3.5	8.8	1.4	1.4	0.3	6.8	3.2	11.7	0.4	2.4	2.8	14.5	80.7	0.6	12.0
KP130-200	6.4	0.6	1.1	5.0	2.8	7.8	1.2	2.2	0.5	5.7	4.0	12.4	0.4	3.6	4.0	16.4	75.6	1.0	17.7

Table 7: Some chemical properties of augered soil samples

samples	pH	EC (dS/m)	OC (%)	AV-N (mg/kg)	AV-P (mg/kg)	Ca2+	Mg2+	Na+	K+	TEB	TEA	ECEC	BS (%)	SAR
						←			cmol/Kg			→		
J1A	6.4	0.7	1.4	3	3.3	2.4	0.4	0.1	0.3	3.2	1	13.2	24.3	0.1
J1B	6.4	0.8	0.7	4	4.2	7.2	0.6	0.3	0.3	8.4	0.6	14.4	58.4	0.2
J2A	6.4	0.5	0.9	4	3.8	4.8	0.5	0.4	1.5	7.2	1.4	21.2	33.8	0.2
J2B	6.3	0.9	0.9	4	3.7	4	0.9	0.3	0.3	5.4	1.4	19.4	28	0.2
J3A	6.3	0.7	0.9	3	3.1	7.2	1.2	0.3	1	9.7	0.8	17.7	54.7	0.1
J3B	6.2	0.8	0.6	4	3	4	0.7	0.2	0.6	5.5	1	15.5	35.3	0.1
KOJOLI														
K1A	6.2	0.8	1.2	2	3.7	4.8	1.3	0.2	1.2	7.5	1.4	21.5	34.7	0.1
K1B	7.4	0.8	1	3	6.2	8.8	1.3	0.5	0.9	11.5	1.2	23.5	48.9	0.2
K2A	6.7	0.8	1.1	4	3.5	7.2	0.3	0.2	0.5	8.2	1.2	20.2	40.6	0.1
K2B	7.6	0.7	1.4	4	9.1	9.6	1.7	0.4	0.9	12.7	0.6	18.7	67.8	0.2
K3A	6.8	0.8	1.2	3	3	8	0.3	0.3	0.6	9.2	1.4	23.2	39.5	0.1
K3B	7.5	0.7	1	3	1.1	8	1.3	0.6	0.7	10.6	0.6	16.6	63.8	0.3
MBULO														
M1A	6.8	0.8	1.7	4	3.1	7.2	0.8	0.2	0.4	8.7	2	28.7	30.2	0.1
M1B	6.3	0.8	1	3	3.7	2.4	1.3	0.2	0.4	4.3	1	14.3	30	0.1
M2A	6.9	0.8	1.6	6	3.1	9.6	0.5	0.3	0.4	10.7	1	20.7	51.7	0.1
M2B	6.2	0.9	0.6	3	3.8	4	0.7	0.4	0.4	5.5	0.6	11.5	47.8	0.3
M3A	6.6	0.8	1.3	4	3.7	6.4	0.9	0.1	0.5	7.9	2	27.9	28.4	0.1
M3B	6.3	0.7	0.7	4	3.7	3.2	0.4	0.1	1.2	4.9	1.8	22.9	21.3	0.1
W/ABBO														
W1A	6.3	0.8	1.1	3	3.1	11.2	1	0.1	1.9	14.1	1.4	28.1	50.2	0
W1B	6.2	0.8	0.9	3	2.6	7.2	0.3	0.2	0.8	8.5	1.2	20.5	41.4	0.1

W2A	6.5	0.7	1.2	3	3.5	3.2	0.5	0.3	1.8	5.8	1.4	19.8	29.4	0.3
W2B	6.3	0.8	0.6	3	3	6.4	0.1	0.1	1.9	8.5	1.4	22.5	37.9	0.1
W3A	6.7	0.8	0.5	2	4.1	4	0.4	0.5	0.7	5.5	0.6	11.5	48	0.3
W3B	7.3	0.7	0.7	2	4.8	0.8	1.5	0.2	1.8	4.3	1.2	16.3	26.4	0.2
Mean	6.6	0.8	1.0	3.4	3.7	5.9	0.8	0.3	0.9	7.8	1.2	19.6	40.5	0.2
$p<0.05$	*	NS	*	*	*	*	*	NS	*	*	*	*	*	NS

NS= Not Significant

Table 8: Some chemical properties of surface augered soil samples

samples	pH	EC (dS/m)	OC (%)	AV-N (mg/kg)	AV-P (mg/kg)	Ca2+	Mg2+	Na+	K+	TEB	TEA	ECEC	BS (%)	SAR	ESP (%)
						←			cmol/Kg			→			
J1A	6.4	0.7	1.4	3	3.3	2.4	0.4	0.1	0.3	3.2	1	13.2	24.3	0.1	4.1
J2A	6.4	0.5	0.9	4	3.8	4.8	0.5	0.4	1.5	7.2	1.4	21.2	33.8	0.2	5.5
J3A	6.3	0.7	0.9	3	3.1	7.2	1.2	0.3	1	9.7	0.8	17.7	54.7	0.1	2.7
Mean	6.4	0.6	1.1	3.3	3.4	4.8	0.7	0.3	0.9	6.7	1.1	17.4	37.6	0.1	4.1
KOJOLI															
K1A	6.2	0.8	1.2	2	3.7	4.8	1.3	0.2	1.2	7.5	1.4	21.5	34.7	0.1	2.3
K2A	6.7	0.8	1.1	4	3.5	7.2	0.3	0.2	0.5	8.2	1.2	20.2	40.6	0.1	2.1
K3A	6.8	0.8	1.2	3	3	8	0.3	0.3	0.6	9.2	1.4	23.2	39.5	0.1	2.9
Mean	6.6	0.8	1.2	3.0	3.4	6.7	0.6	0.2	0.8	8.3	1.3	21.6	38.3	0.1	2.4
MBULO															
M1A	6.8	0.8	1.7	4	3.1	7.2	0.8	0.2	0.4	8.7	2	28.7	30.2	0.1	2.5
M2A	6.9	0.8	1.6	6	3.1	9.6	0.5	0.3	0.4	10.7	1	20.7	51.7	0.1	2.4
M3A	6.6	0.8	1.3	4	3.7	6.4	0.9	0.1	0.5	7.9	2	27.9	28.4	0.1	1.6
Mean	6.8	0.8	1.5	4.7	3.3	7.7	0.7	0.2	0.4	9.1	1.7	25.8	36.8	0.1	2.2
W/ABBO															
W1A	6.3	0.8	1.1	3	3.1	11.2	1	0.1	1.9	14.1	1.4	28.1	50.2	0	0.3
W2A	6.5	0.7	1.2	3	3.5	3.2	0.5	0.3	1.8	5.8	1.4	19.8	29.4	0.3	6.0
W3A	6.7	0.8	0.5	2	4.1	4	0.4	0.5	0.7	5.5	0.6	11.5	48	0.3	8.6
Mean	6.5	0.8	0.9	2.7	3.6	6.1	0.6	0.3	1.5	8.5	1.1	19.8	42.5	0.2	5.0

Table 9: Some chemical properties of sub surface augered soil samples

samples	pH	EC (dS/m)	OC (%)	AV-N (mg/kg)	AV-P (mg/kg)	Ca2+	Mg2+	Na+	K+	TEB	TEA	ECEC	BS (%)
						←			cmol/Kg			→	
J1B	6.4	0.8	0.7	4.0	4.2	7.2	0.6	0.3	0.3	8.4	0.6	14.4	58.4
J2B	6.3	0.9	0.9	4.0	3.7	4.0	0.9	0.3	0.3	5.4	1.4	19.4	28.0
J3B	6.2	0.8	0.6	4.0	3.0	4.0	0.7	0.2	0.6	5.5	1.0	15.5	35.3
Mean	6.3	0.8	0.7	4.0	3.6	5.1	0.7	0.3	0.4	6.4	1.0	16.4	40.6
KOJOLI													
K1B	7.4	0.8	1.0	3.0	6.2	8.8	1.3	0.5	0.9	11.5	1.2	23.5	48.9
K2B	7.6	0.7	1.4	4.0	9.1	9.6	1.7	0.4	0.9	12.7	0.6	18.7	67.8
K3B	7.5	0.7	1.0	3.0	1.1	8.0	1.3	0.6	0.7	10.6	0.6	16.6	63.8
Mean	7.5	0.7	1.1	3.3	5.5	8.8	1.4	0.5	0.8	11.6	0.8	19.6	60.2
MBULO													
M1B	6.3	0.8	1.0	3.0	3.7	2.4	1.3	0.2	0.4	4.3	1.0	14.3	30.0
M2B	6.2	0.9	0.6	3.0	3.8	4.0	0.7	0.4	0.4	5.5	0.6	11.5	47.8
M3B	6.3	0.7	0.7	4.0	3.7	3.2	0.4	0.1	1.2	4.9	1.8	22.9	21.3
Mean	6.3	0.8	0.8	3.3	3.7	3.2	0.8	0.2	0.7	4.9	1.1	16.2	33.0
W/ABBO													
W1B	6.2	0.8	0.9	3.0	2.6	7.2	0.3	0.2	0.8	8.5	1.2	20.5	41.4
W2B	6.3	0.8	0.6	3.0	3.0	6.4	0.1	0.1	1.9	8.5	1.4	22.5	37.9
W3B	7.3	0.7	0.7	2.0	4.8	0.8	1.5	0.2	1.8	4.3	1.2	16.3	26.4
Mean	6.6	0.8	0.7	2.7	3.5	4.8	0.6	0.2	1.5	7.1	1.3	19.8	35.2

Exchangeable Acidity (EA) ranged from 1.6 to 4.4cmolkg^{-1} with a mean value of 2.97cmolkg^{-1} in the pedons (Table 6). Highest value of 4.4 cmol kg^{-1} was recorded at Jada at a depth of 55-105cm while the lowest value of 1.6 cmol kg^{-1} was recorded in Jada and Wuro Abbo at the depths of 20-55 cm and 40-75 cm respectively. The augered samples ranged from 0.6 to 2.0 cmol kg^{-1} with a mean of 1.17 cmol kg^{-1}(Table7). The highest value of 2.0 cmol kg^{-1} was recorded in Mbulo. The TEA are thus rated low (Kparmwang *et al*. 1998, Usman, 2005) and may probably be due to low exchangeable acidic cat ions (H^+ and Al^{3+}) at the exchange site of the soil colloidal complex (Halvin *et al*., 2003).The ECEC ranged from 5.82 to 16.4 cmolkg^{-1} with a mean value of 9.40 cmolkg^{-1} in the pedons. The highest value of 16.4 cmol kg^{-1} was recorded in Kojoli at a depth of 130-200cm, and the lowest value of 5.82 cmolkg^{-1}was recorded in Jada at the depth of 20-55cm.

In the augered samples, ECEC values ranged from11.54 to 28.65 cmolkg^{-1} with a mean of 19.58cmolkg^{1} with the highest value of 28.65 cmolKg^{-1} recorded in Mbulo soils and the lowest value of 11.54cmolkg^{-1} recorded in Wuro-Abbo (Table 7). Rayar and Haruna (1985) reported a mean value of 14.6 cmol kg^{-1} for semi-arid soils of Borno state. However, comparatively lower ECEC mean value (<10 mg/kg) was reported by Hassan *et al.* (2013) for Chouchi and Hong soils. The ECEC of the soils of the four districts is thus rated high (Kparmwang *et al*., 1998). The PBS ranged from 53.49 to 80.73 % with a mean value of 67.31 % in the pedons. The highest value of 80.73 % was recorded in Kojoli at the depth of 60-130 cm, and the lowest value of 53.49 % was recorded in Jada at a depth of 55-105 cm. In the augered samples percent base saturation (PBS) ranged from 21.34% to 67 % with a mean value of 40.52 %. Similar PBS values were reported by Saddiq *et al.* (2008) for some selected soils in Adamawa State. Thus, the PBS of the soil is rated low to medium (Kparmwang *et al*., 1998).

Exchangeable sodium percentage ranged from 12.02 to 30.49% with a mean value of 22.84% in the pedons (Table 2). The highest value of 30.49% was recorded in Mbulo at the depth of 0-20cm, and the lowest value of 12.02% was recorded in Kojoli at the depth of 60-130cm. ESP ranged from 1.53 to 8.63% with a mean value of 3.7% in the augered samples. A similar range of 0.4 to 2.5% with a mean of 1.3% was reported by Irmiya (2005) for Muchalla Flood plain in Mubi-North, Adamawa State. Similarly, a mean value 1.10% was reported by Saddiq *et al*. (2008) while evaluating some selected soils in Adamawa State. Therefore, the ESP of the soils of the four districts is rated low by (Kparmwang *et al*. 1998) and is unlikely to exert any negative effect on soil and plants.

Soil Variability

Physical properties show insignificant variation in texture within and amongst pedons. Similarly, there was no significant variation of bulk density in surface and sub-surface soils in both pedons and augered samples (Tables 2 and 3). However, there was variability of bulk density within pedons (Table 2). Porosity markedly varies in the pedons. Similarly, there was also marked variability of soil colour in the soil pedons. Variability of soil chemical properties shows that except for EC, Na and TEA, there was significant ($P<0.05$) variation of pH, TDS, AV-N, AVP, Ca, Mg, K, TEB, ECEC, BS and ESP amongst the locations (Table 7). The implication of the variability in these soil properties is that with similarity in organic carbon content, mineralizable (Net nitrogen), available phosphorus, and potassium contents in all the four districts, similar fertilizer requirements for improved crop production may be required. However, high variability in colour, TDS, Calcium, TEB, ECEC, BS and ESP particularly at surface and sub-surface requires close monitoring to avoid nutrient imbalances. Monitoring soil moisture condition is imperative to reduce the negative effects of anoxic condition which facilitates the conversion of Fe (II) to (Fe III) with consequent negative effects on crop performance particularly in Kojoli district.

Fertility Status of the Soils

In pedon 1, the pH is slightly acidic. The EC, AVP, TEB, ECEC were all low, while organic carbon is medium. Base saturation and ESP were high. The soils have high bulk density and a mean porosity value of 40 %. The soils are mostly silty clay with slightly sticky consistency and moderate medium sub-angular block structure. In pedon 2, the pH is slightly acidic with low EC, AVP, TEB, ECEC but with low organic carbon and high BS and ESP. The soils have high bulk density and a mean porosity of 41.6 %. The soils are mostly clay with slightly sticky consistency and moderate medium sub-angular block structure. Therefore, the soils in this pedon are of medium fertility. In pedon 3, the pH is slightly acidic with low EC, AVP, TEB, ECEC, organic carbon and high BS and ESP. The soils have moderate to high bulk density and a mean porosity of 41 %. The soils were all clayey in texture with slightly sticky consistency with a moderate to medium sub-angular block structure. In pedon 4, the pH is slightly acidic with low EC, AVP, and TEB but with medium ECEC and low OC, BS, and ESP. The soils have moderate bulk density and a mean porosity of 44.25 %. The soils are all clay with very sticky and very plastic consistency with a strong medium sub-angluar block structure. Although most soil properties significantly ($P<0.05$) vary spatially, the soils of the four districts exhibited similarities in their principal limitations. Overall, the soils of the four districts have two limitations; the sandy nature and low organic carbon content, thus classifying them into one FCC class Sm (Table 10) (Sanchez *et al.*, 2003).

Table 10: Fertility Capability Classification

Location	FCC Unit	Description
Jada	Sm	Sandy Soil (s) low in organic carbon (m).
Wuro Abbo	Sm	Sandy Soil (s) low in organic carbon (m).
Mbulo	Sm	Sandy Soil (s) low in organic carbon (m).
Kojoli	Sm	Sandy Soil (s) low in organic carbon (m).

CONCLUSION

The soils are deep with loamy to sandy loam texture and medium sub angular structure which are good for smooth growth and development of crop plants. Similarly, pH and all other critical soil fertility indices are favourable for crop production. However, the soils are sandy with low organic carbon content. Thus, the soils could be classified Sm in accordance with FCC classification system. Similarly, with slightly salty soil conditions, the soils require close monitoring of salt build up particularly in areas with high temperature and low precipitation levels. The fertility and productivity of the soils could therefore be improved to produce crops sustainably through careful soil monitoring and balanced fertilization using mineral and organic fertilizers.

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