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Soil characterization and classification of selected agro ecological zones of Northern Nigeria

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Abstract

Good knowledge of soil properties is a prerequisite to the sustainable use of soil resources and improving productivity. This study aimed to assess the soil properties of selected agro-ecological zones (AEZs) of Northern Nigeria, characterize and classify them. The study was conducted in 2017 in three AEZs namely: Northern Guinea Savanna (Tudunwada, Kano state), Sudan Savannah (Kafin Madaki, Bauchi state), and Southern Guinea Savannah (Kubwa, FCT Abuja). A total of 6 profiles pits of 200 cm depth (2 for each AEZ) were dug and described. Bulked soil samples from study locations were prepared and analyzed in the laboratory. The soil analysis results revealed that the soils were very strongly acidic to slightly acidic (4.66- 6.49). The soil fertility was generally low as reflected in low organic carbon (<10 gkg^{-1}), total nitrogen (<1.5gkg^{-1}), low to medium available phosphorus (4.78-10.43$mgkg^{-1}$), and low cation exchange capacity except for Kubwa study site with high CEC (12.50-15.30cmol kg^{-1}). The soils were classified according to USDA soil taxonomy and world Reference base (WRB) with Tudunwada and Kubwa study sites (NGS and SGS) as Alfisols while Kafin Madaki Ganjuwa (Sudan savanna) as Inceptisols. The varying properties, fertility status and types of soils identified in the study areas provide adequate information to design soil management options and further research on each site's soils. Generally, the soils require management practices such as the use of organic manure and liming to curb the effects of low fertility and acidity limitations.

Keywords: Soil Characterization; Soil Classification; Agroecological Zones

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1.0 Introduction

There is an increasing demand for information on soil properties. Lack of information on soil resource of any region contributes to the problems of sustainable crop production. Several types of research have been carried out on soil properties within the savanna, and however, with variations in soil properties within different climatic zones and parent materials, there is need for site-specific descriptions of soil properties in the study areas. Soil as a landscape component occupies a central position in the landscape balance due to its diverse functions. It is a dynamic system within which a series of changes (addition, losses, modification and alterations) continually occurs. These changes directly affect the soils' properties and productive potential (Oriola and Hammed, 2012).

Soil properties are essential as they determine the type of plants the soil can support, their potentials and limitations. It is therefore essential to describe the properties of soils as they provide the farmers with information on their distribution, potentials, limitations and constraints so that appropriate management systems can be designed (Msanya *et al*.,2003) In modern agriculture, a good knowledge of soil properties is a prerequisite to the sustainable use of soil resources and improve productivity. Soil properties such as texture, structure determine the amount of water and nutrients that can be retained within a particular soil, drainage characteristics and consequently leaching losses of nutrients. Savanna landscapes of Africa occupy a vast area, varying significantly in both climate and ecological characteristics (Kowal and Kassam, 1978). Rainfall is erratic in the savanna region (Owonubi *et al*., 1991). Thus sustainable production on these soils is threatened under continuous cultivation with little consideration for soils to recover (Abdulkadir and Habu, 2013). These Soils are very intensively utilized for agricultural production. They include Alfisols, Ultisols, Entisols and Inceptisols (Jagtap, 1995).

The savanna region's soils are physically fragile because the surface contains a large proportion of sand and low organic matter contents, thus weak aggregation. The physical constraints are further compounded in gravelly soils or soils with shallow depth overlying plinthite or hardpan layers (Salako, 2003). Knowledge of soil properties is essential, as it influences potential soil management for sustainable production, provides a guide for policy formulation on land use and enhances their management to increase productivity (Ibanga, 2003). Thus, it is of paramount importance to have an in-depth knowledge of soils' characteristics to manage and use the resources based on their potentials and limitations. This will also maximize crop production to their allowable genetic potential limits and conserve the soils for future use. It will also be equally essential to classify the soils using their inherent characteristics and in a manner that will ease communication and transfer of knowledge about such soils to farmers, stakeholders and soil scientists (Alemayehu *et al*., 2014).

Detailed information on soil characteristics is required to decide management practices for sustainable agricultural production, rehabilitation of degraded land (Dinku et al., 2014), and sound research on soil fertility. Therefore, it is advantageous to study and understand the properties of soils and their distribution over an area to develop management plans for efficient soil resources utilization (Shi *et al.*, 2005). This study aims to determine soil properties, characterize and classify soils of the study areas.

3.1 Description of The Study Sites

The study was conducted in Three locations: Kano State, Bauchi State and Abuja (FCT).

Kano State lies within latitude 10^{0}48'N and 12^{0}030'N and longitude 7^{0}59'E and 9^{0}11'E and falls within the Sudan Savanna type of vegetation (Figure 1). Kano state is bordered to the south by Bauchi State, to the east by Jigawa State, and the west by Kaduna and Katsina States. It has a total population of about 9,401,288 (Census, 2006). The study areas were Tudun wada, located in the southern part of the state. Kano State's climate is the tropical wet and dry type symbolized as AW by Koppen (Adamu and Aliyu, 2012). Temperature is averagely warm to hot throughout the year at about 25± 7^{0}C (Olofin and Tanko, 2002). The study area is located in the Northern Guinea savanna ecological zone (Shehu *et al.,* 2015) and positioned on a basement complex. The soil types are predominantly Alfisols, Ultisols and Entisols. The crops grown are sorghum, millet, late millet, maize, rice, cassava, potatoes, groundnuts, onions, pepper, okra and cowpeas as the major crops (KSLGRB, 1991/1992).

Kafin Madaki in Bauchi state, northeastern Nigeria is located between latitude 10^{0}31' and 11^{0}00'N and longitude 9^{0}30, and 10^{0}00'E. The area is under tropical wet and dry climate, coded as Aw by Koppen 1912. Rainfall in the area is up to 1000 mm though varied slightly from year to year. The mean maximum temperature is high, ranging between 26-39^{0}C throughout the year though slight decline occurs around December and February due to harmattan winds. The natural vegetation of the area is Sudan Savanna type though significantly altered by human activities. The geology comprises Precambrian basement complex rocks made up of igneous, gneisses, and granites. The soil is Alfisols (Soil survey staff, 1999). Crops grown include sorghum, maize and groundnut (Faruk, 2010).

Kubwa is located on the windward side of Jos-Plateau, which made it possible to receive an average of 1200mm of rainfall annually. Kubwa is characterized by tempera-

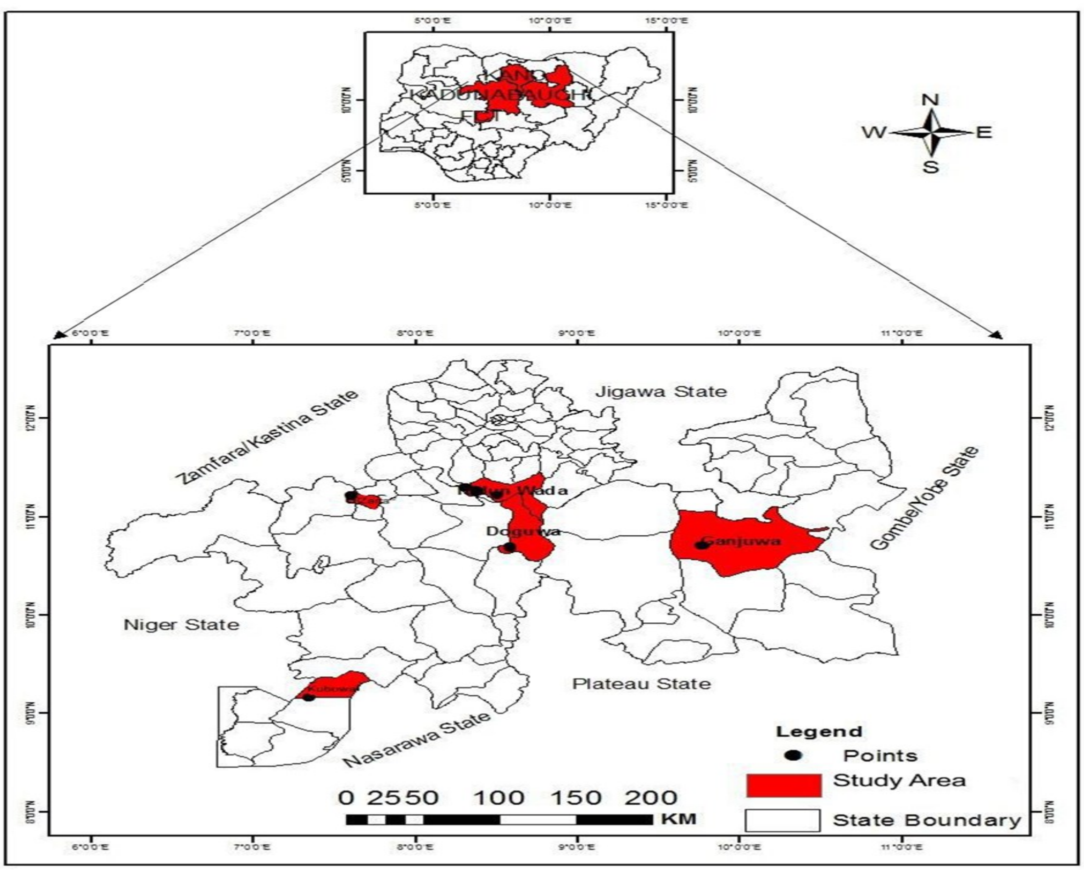

Figure 1: Map of Nigeria showing the study areas

ture changes, with a mean minimum temperature of 20^0c and a mean maximum temperature of 37^0c in the dry season. The area is situated in the Southern Guinea Savanna (Ade, 2015). The area is predominantly underlain by a high grade metamorphic and igneous rock of Precambrian age consisting of Gneiss, migmatite and granite and the soil type is predominantly Typic Plinthusalfs (Kogbe, 1978).

2.2 Field studies

Three locations within the Northern Nigeria savanna were selected namely Tudun wada, in Kano state (Northern Guinea savanna), Kafin Madaki in Ganjuwa Local Government Area of Bauchi state (Sudan Savanna), and Kubwa in Bwari Local Government Area of Federal Capital Territory in the Southern Guinea Savanna Agroecological zones (Fig. 1). A total of 6 profiles, 2 in each agro-ecologies were georeferenced, sunk and described. The profiles were dug to a depth of 200cm or to an impenetrable layer, whichever came first. Profile locations were described, sunk and soil morphological characteristics such as depth, colour, textures, structures, consistence, clay films, concretions, boundary, pores and roots were described according to USDA Soil Survey Manual (Soil Survey Staff, 1981). Undisturbed core samples were collected from pedogenic horizons by manually forcing the core samplers into the soil for bulk density determination. A soil sample collected was packed in polythene bags and labelled adequately for analysis.

2.3 Laboratory Analysis

Bulk density was determined using undisturbed core samples. (Campbell and Henshall, 1991). Particle Density was determined using the Pycnometer method as described by Blake and Hartage (1986). Total porosity was determined from the values of bulk density (BD) and particle density (PD) as described by Brady and Weil (2002). Particle size distribution was determined using Bouycous Hydrometer method (Gee and Or, 2002).

Soil pH was determined both in water using 1:2.5 soil to water ratio (IITA, 1979). The soil pH was read with a glass electrode on a pH meter (JENWEY 3520 MODEL). Soil organic carbon was determined by the wet oxidation method of Walkley and Black (1934) as described by Nelson and Summer (1982). Total Nitrogen content was determined using the Micro-Kjeldahl technique as described by Bremmer (1996). Available Phosphorous was extracted using the Bray 1 method (Bray and Kurtz 1945). The exchangeable bases (Ca, Mg, K, and Na) were extracted with 1M ammonium acetate solution (1M NH_4OAC), buffered at pH 7.0 as described by Anderson and Ingram, (1998). Cation exchange capacity (CEC) of the soil was determined with 1M ammonium acetate solution (NH_4OAC), buffered at pH 7.0 (Chapman, 1965; Rhodes, 1982). Percent base saturation was calculated by dividing the total exchangeable cations (Ca, Mg, K and Na) by the cation exchange capacity (CEC), obtained from 1M NH_4AOC (pH 7.0).

2.4 Soil Classification

Field and laboratory data were used to classify soils using the USDA soil taxonomy Soil survey staff, 2010) and world reference base (WRB) 2006 classification systems.

3.0 Results And Discussions

3.1. Morphological Properties of Soils in the Study Sites

The summary of the morphological properties of the soils in the study sites is presented in Table 1. The colour of the surface soils in the study sites varied between locations. The brownish colour, which dominates the epipedons of the entire study sites, could be attributed to the presence of organic matter which is the primary colouring agent in the topsoils. Atofarati *et al.*; (2012) also attributed brown colour as an indication of well-drained condition.

The soil texture of the study sites varied with location. Tudun wada and Kafin Madaki Ganjuwa study sites had clay texture overlain by Gravelly clay to Gravelly sandy clay. This increase in clay content with depth could be attributed to clay lessivation process in this study area. Kubwa pedons were dominated by sandy loam to loam texture underlain by clay and gravelly clay texture. The dominance of this fine soil material could be attributed to the deposition of fine colluvial materials from high elevation due to erosion processes. Similarly, the dominance of clay in the subsurface horizon could be attributed to illuviation of clay.

The soils' surface horizons structures were weak, fine sub angular blocky changing to strong, medium to coarse angular blocky structure across the study sites. Generally, the weak fine subangular blocky structure of the surface horizons indicates structural deterioration attributed to prolonged cultivation that fragments soil aggregate. According to Samndi and Jibrin (2012), the structural development from weak to subangular/angular blocky (to massive in some horizons) indicates alteration of the original soil property by pedogenic processes.

3.2 Physical Properties of Soils of Northern Nigeria Savanna

3.2.1 Particle size distribution

Table 2 shows the respective soil physical characteristics of the study sites. The sand content of the surface and underlying horizons of the study location varied from 37.89 to 45.89% and 29.89% to 47.89%, 39.07 to 49.07% and 31.07% to 49.07 %, 49.07% to 57.07% and 17.07% to 47.07% for Tudun wada (NGS), Kafin Madaki (SS) and Kubwa (SGS) respectively. The distribution of sand content decreased with depth. The distribution of the silt content of surface and underlying horizons of the various profiles of study location (Table 2) varied from 10.70% to 12.70% and6.70% to 12.70%, in Tudun wada (NGS) 10.0 to 20.0% and 10.00 to 36.93% in Kafin Madaki (SS) 32.93 to 34.93% and 32.93 to 38.93% in Kubwa (SGS).

Similarly, the clay contents of Tudun Wada study sites' surface horizons ranged from 43.41 to 49.41% and 45.41 to 57.41%, for the underlying horizons. In Kafin Madaki Ganjuwa study site, the clay content of the surface horizons for both profiles was 40.93%. In the underlying horizons, values of the clay contents ranged from 14.00% to 54.93%. While in Kubwa study sites, the clay content of the surface horizon ranged from 10- 16% and 18.00 to 50.0% for the underlying horizon. Across the three study sites, clay content increased with depth while sand and silts decreased with profile depth. The increase in clay with depth may be due to clay eluviation- illuviation Processes in the soil as observed by Atofarati *et al*., (2012) and Samndi *et al.,* (2012).

Across all the study sites' entire profiles, clay contents were observed to increase irregularly with profile depth. The dominance of sand in these profiles could be attributed to the parent material being granite and a high weathering rate. Sand particles are made of quartz mineral, which

Table1. Morphological Properties of Soils of Northern Nigeria Savanna

Horizon	Depth (cm)	Munsell Colour Dry	Moist	Texture	Structure	Consistency Wet	Moist	Dry	Boundary	Other features
TD P1 Typic Haplustalfs/Haplic Lixisols										
Ap	0-15	7.5 YR4/3	7.5YR3/3	Gsc	1fsbk	sssp	l	l	Cs	Common tabular very fine to fine pores, many very fine to fine roots with many fine to medium Quartz minerals
Bt1	15-39	7.5YR4/6	7.5YR3/4	Gc	1-2f-msbk	sp	fm	s	Ds	Few irregular fine pores, few very fine roots with few medium to coarse iron and manganese concretion
Bt2	39-93	7.5YR6/4	7.5YR4/6	Gc	1-2f-mabk	sssp	fm	sh	Ds	Common irregular fine pores with few medium to coarse iron and manganese concretion
C	93-155	7.5YR5/4	7.5YR4/4	Gc	tending massive	sp	fr	sh	Ne	Many coarse manganese concretions, partially weathered parent materials with few fine mica flakes
TD P2 Typic Haplustalfs/Haplic Lixisols										
Ap	0-14		7.5YR3/2	C	1f-mabk	sssp	l-f	sh	Cs	Many fine tabular pores, many fine roots with many fine to coarse Quartz minerals
Bt	14-55	7.5YR5/6	7.5YR5/3	C	1-2fabk	sssp	l-f	sh	Dw	Many fine tabular pores, few fine roots, many medium to coarse iron and manganese concretions with many medium to coarse partially decomposed parent materials
BC	55-107	7.5YR5/4	7.5YR4/4	C	1-2f-mabk	Sp	fm	h	Dw	Many fine tabular pores with many medium to coarse iron and manganese concretions
C	107-150		7.5YR5/4	Sc	tending massive	sssp	fm	h	Ne	Many medium to coarse iron and manganese concretions with partially decomposed parent material.
Ap	0-16	7.5YR4/2	7.5YR3/2	C	1-2f-mabk	sssp	fr	sh	cs	Many fine tabular pores and few coarse pores with many fine roots.
B	16-73		5YR3/4	Gc	1-2f-mabk	sp	fm	sh	dw	Few to many fine to coarse tabular pores, very few fine roots with many fine to medium iron and manganese concretions and many medium weathered quartz minerals.
C1	73-113		7.5YR5/8	Gc	tending massive	sp	fm	h	dw	Few fine tabular pores, many medium to coarse iron and manganese concretions with many medium to coarse quartz minerals and decomposed granitic materials.
C2	113-170		7.5YR6/8	C	massive					Many coarse iron and manganese concretions with partially weathered parent material.
KMG P2 Typic Haplustepts/Haplic Regosols										
Ap	0-19	7.5YR4/4	7.5YR3/2	Sc	1-2fabk	sssp	fr	l	ds	Many fine to medium tabular pores with many fine roots
AB	19-44	7.5YR4/6	7.5YR3/3	C	1m-cabk	sssp	fr	l	dw	Many fine tabular pores, many fine roots with many medium to coarse iron and manganese concretions and many medium weathered quartz materials.
B	44-79		5YR4/4	L	Structureless	nsnp	fr	l	cs	Many fine with few coarse tabular pores, few very fine to fine roots and many fine to medium iron and manganese concretions with many weathered quartz minerals
C	79-180		5YR6/6	L	massive	nsnp				Many medium to coarse iron and manganese concretion.
KBW P1 Typic Plinthustalfs/Plinthic Lixisols										
Ap	0-20	7.5YR5/4	7.5YR3/3	L	1-2f-msbk	nsnp	l	l	Cs	Many fine tabular pores with many fine to medium roots
Bt1	20-50		7.5YR5/6	c	2-3m-cabk	Sp	Fm	sh	Ds	Many fine tabular pores, few fine roots with few Ant nest
Bt2	50-85		7.5YR5/8	c	2-3m-cabk	Sp	vfm	vh	Ds	few fine to medium tabular pores
Bt3	85-130		5YR4/6	c	1f-mabk	Sp	fm	h	Dw	Few fine tabular pores with many fine to medium iron concretions
Btv	130-190		5YR4/6	c	tending massive	Sp	vfm	vh	Ne	Many medium to coarse iron concretions with few medium to coarse quartz grains
KBW P3 Typic Plinthustalfs/Lixic Plinthosols										
Ap	0-20	7.5YR5/2	7.5YR4/3	sl	1fsbk	nsnp	l	l	cs	Many fine tabular pores, many fine to medium ironstones with few fine to medium quartz minerals
			7.5YR4/3	gl					cs	
B	20-48	7.5YR4/6			single grained	nsnp	l	l		Many fine tabular pores with few fine roots and many fine to medium ironstones with few fine to medium quartz minerals
Btv1	48-89		5YR5/8	gc	1tending massive	sp	fm	h	ds	Few fine to medium tabular pores, very few fine roots with many medium to coarse iron and manganese concretions and few fine to medium quartz mineral and Ant nest.
Btv2	89-138		2.5YR4/8	gc	1tending massive	sp	vfm	vh	ne	Few coarse tabular pores with many medium to coarse iron and manganese concretions.

Table 2. Physical Properties of Soils of Northern Nigeria Savanna

Horizon	Depth (cm)	Sand	Silt	Clay	Gravel	Textural Class	Silt/Clay	BD	PD	TP
		-----------------	%	----------------			----%---	-----g cm^{-3}	------	--%---
TD P1 Typic Haplustalfs/Haplic Regosols										
Ap	0-15	45.89	10.70	43.41	40.74	Sandy clay	0.247	1.12	2.31	51.65
Bt1	15-39	35.89	10.70	53.41	67.74	clay	0.200	1.12	2.57	56.42
Bt2	39-93	35.89	8.70	55.41	71.42	clay	0.157	1.31	2.07	36.68
BC	93-155	41.89	6.70	51.41	66.00	clay	0.130	1.51	2.31	34.51
Mean		39.89	9.20	50.91	61.48		0.184	1.27	2.32	45.35
TD P2 Typic Haplustalfs/Haplic Regosols										
AP	0-14	37.89	12.70	49.41	62.20	Clay	0.257	1.24	2.51	50.37
Bt	14-55	29.89	12.70	57.41	61.53	clay	0.221	1.44	2.00	28.13
BC	55-107	33.89	12.70	53.41	64.52	clay	0.238	1.65	2.31	28.66
C	107-150	47.89	6.70	45.41	68.00	sandy clay	0.148	1.57	2.19	28.35
Mean		37.39	11.20	51.41	64.06		0.216	1.47	2.25	34.51
KMG P1 Typic Haplustepts/Haplic Regosols										
Ap	0-16	39.07	20.00	40.93	13.04	Clay	0.489	1.23	2.66	53.71
B	16-73	31.07	14.00	54.93	50.00	Clay	0.255	1.36	2.55	46.78
C1	73-113	33.07	14.00	52.93	59.67	Clay	0.265	1.51	2.45	38.47
C2	113-170	39.07	12.00	48.93	55.55	Clay	0.245	1.48	2.45	39.74
Mean		35.57	15.00	49.43	44.57		0.313	1.39	2.53	44.88
KMG P2 Typic Haplustepts/Haplic Regosols										
Ap	0-19	49.07	10.00	40.93	16.60	Sandy clay	0.244	1.55	2.52	38.38
AB	19-44	39.07	10.00	50.98	66.18	Clay	0.196	1.33	2.75	51.81
B	44-79	39.07	36.93	24.00	62.50	Loam	1.539	1.33	2.66	50.03
C	79-180	49.07	36.93	14.00	53.73	Loam	2.638	ND	2.31	ND
Mean		44.07	23.46	32.48	49.75		1.154	1.40	2.56	45.19
KBW P1 Typic Plinthustalfs/Plinthic Lixisols										
Ap	0-20	49.07	34.93	16.00	4.09	Loam	2.183	1.53	2.47	38.04
Bt1	20-50	25.07	32.93	42.00	2.63	Clay	0.784	1.45	2.64	45.16
Bt2	50-85	17.07	32.93	50.00	2.63	Clay	0.659	1.50	2.10	28.79
Bt3	85-130	17.07	34.93	48.00	6.06	Clay	0.728	1.39	2.75	49.45
Btv	130-190	25.07	34.93	40.00	16.00		0.873	1.57	2.56	38.64
Mean		26.67	34.13	39.20	6.28		1.045	1.49	2.50	40.62
KBW P2 Typic Plinthustalfs/Lixic Plinthosols										
Ap	0-20	57.07	32.93	10.00	30.00	SL	3.293	1.53	2.69	43.03
B	20-48	47.07	34.93	18.00	65.71	Loam	1.940	ND	2.58	ND
Btv1	48-89	23.07	34.93	42.00	41.67	Clay	0.832	1.39	2.58	46.04
Btv2	89-138	19.07	38.93	42.00	11.76	Clay	0.927	1.52	2.48	38.95
Mean		36.57	35.43	28.00	37.29		1.748	1.48	2.59	42.68

ND = Not determine. TD= Tudun wada, KMG= Kafin madaki Ganjuwa, KBW= Kubwa Silt/clay = Silt clay ratio, BD= Bulk density, PD=Particle density, TP = Total porosity,

is an essential component in granites. According to Wilson (2010) and Lawal *et al.* (2012), quartz is resistant to weathering. Similarly, Fitz Patrick (1986) and Haruna *et al.* (2014) reported that basement complex rocks are made of granitic gneisses, which usually produce coarse materials with high quartz proportions.

3.2.2. Bulk density

Across the whole study site, most of the profiles indicated bulk density increase with profile depth. Other profiles showed irregular increased with profile depth as in Table 2. Bulk density values for surface horizons of soils in Tudun wada study site ranged from 1.12 to 1.24gcm^{-3}. For the subsurface horizons, bulk density values ranged from 1.12 to 1.57gcm^{-3}. Kafin Madaki Ganjuwa study site varied between 1.23 to 1.55gcm^{-3} and 1.33gcm^{-3} to 1.51gcm^{-3} for the surface and underlying horizons respectively while Kubwa study location had values 1.53gcm^{-3} in the surface horizons and 1.39 to 1.57gcm^{-3} in the underlying horizons.

As indicated, values of bulk density in all the study sites ranged from medium to high (1.12-1.67 g cm^{-3}) according to Esu (1991) ratings. High bulk density values were obtained in the surface horizon of profile KMG P2, KBW P1, and P2. The values were between 1.53 to 1.67gcm^{-3} while the remaining profiles were rated as a medium as values were below 1.5gcm^{-3}. Most underlying horizons recorded higher values than the overlying horizon, Kubwa pedons had the highest bulk density (1.53 to 1.67 g cm^{-3}) probably due to compaction due to continuous and intensive cultivation with heavy farm machinery for many years. The medium to high values of the bulk density observed in most study areas could be attributed to tillage which generally decreases pore spaces and increases bulk density. The bulk density of the entire study site generally increased with profile depth. The reason for the increment with depth could be related to reducing organic matter. Hailu *et al.*, (2015) attributed the increment to compacting weight of the soils.

3.2.3. Particle density

Particle density values for the surface and underlying horizons in the study location varied from 2.31 to 2.51gcm^{-3} and 2.00 to 2.57gcm^{-3} in Tudun wada, 2.52 to 2.66gcm^{-3} and2.31 to 2.75gcm^{-3} in Kafin Madaki and 2.47 to 2.69gcm^{-3} and 2.10 to 2.75gcm^{-3} in Kubwa study site respectively.

Generally, the particle density distribution was observed to increase with depth across the whole study area irregularly. The surface horizons in most of the pedons had high particle density values that could be attributed to the surface's sandy nature. The surface horizons' high values could probably be attributed to coarse (sands) materials present in the surface soil (Magaji 2015).

3.2.4. Total porosity

The total porosity value for surface and underlying horizons of pedons in Tudun wada study site ranged from 50.37 to 51.65% and 28.13 to 56.42%. Kafin Madaki Ganjuwa study site, had total porosity values ranged of the surface and underlying horizons from 38.38 to 53.71% .and 38.47 to 51.81%. In Kubwa study, the values ranged from 38.04 to 43.03% for surface horizons and 28.79 to 49.45% for the underlying horizons. The entire study sites' total porosity values were generally higher in the surface than in the subsurface horizons, except for Kafin madaki profile P2 and Kubwa profile P1. The porosity of most pedons across the study sites falls below the ideal porosity value (>50%) for healthy roots growth (Lawrence, 1977). The decrease in the total porosity values with profile depth is in line with Pravin et al. (2013) 's findings who reported a decrease in total porosity with soil depth and attributed it to the weight of the overlying soils, and the increase in bulk density with the profile depth.

According to Hailu et al., (2015), the decrease in total porosity with profile depth as observed in most pedons could be due to effects of management, penetration of crop roots that loosen the soil, and comparatively higher organ-

Table 3. Chemical Properties of Soils of Northern Nigeria Savanna

Horizon	Depth (cm)	pH H_2O 1:2.5	OC ---(gkg^{-1})-----	TN	Av.P (mgkg^{-1})	TEA	Ca	Mg	K	Na	CEC	BS(%)
						----------------------CmolKg^{-1}--------------------						
TD P1 Typic Haplustalfs/Haplic Lixisols												
Ap	0-15	5.92	4.60	1.05	6.96	0.60	7.02	0.12	0.50	0.08	9.20	83.88
Bt1	15-39	5.95	2.11	0.70	3.48	0.60	5.68	0.17	0.20	0.11	9.40	65.48
Bt2	39-93	6.24	1.92	0.70	2.83	0.50	6.48	0.18	0.16	0.15	9.85	70.83
BC	93-155	5.67	1.92	0.35	3.70	0.44	12.51	0.24	0.23	0.18	15.10	87.16
	Mean	5.95	2.63	0.70	4.24	0.53	7.92	0.18	0.27	0.13	10.89	78.09
TD P2 Typic Haplustalfs/Haplic Lixisols												
Ap	0-14	5.60	4.40	1.40	10.43	0.50	6.51	0.16	0.26	0.09	8.00	87.66
Bt	14-55	5.71	2.91	1.05	3.48	0.50	1.78	0.17	0.34	0.10	8.71	27.44
BC	55-107	5.23	2.87	0.70	2.61	0.50	7.94	0.20	0.24	0.11	10.20	83.21
C	107-150	6.39	1.92	0.35	2.83	0.40	2.51	0.21	0.56	0.19	5.22	66.53
	Mean	5.73	3.03	0.88	4.84	0.48	4.68	0.18	0.35	0.12	8.03	66.49
KMG P1 Typic Haplustepts/Haplic Regosols												
Ap	0-16	5.88	3.57	1.05	4.57	0.50	5.86	0.19	0.37	0.07	7.40	87.88
B	16-73	5.39	1.00	0.70	2.61	0.67	7.09	0.21	0.73	0.13	14.00	58.21
C1	73-113	5.71	0.55	0.35	1.09	0.50	7.76	0.22	0.65	0.12	12.15	72.02
C2	113-170	5.97	0.57	0.35	2.68	0.50	7.76	0.22	0.65	0.13	11.50	76.14
	Mean	5.74	1.42	0.61	2.73	0.54	7.12	0.21	0.60	0.11	11.26	71.38
KMG P2 Typic Haplustepts/Haplic Regosols												
Ap	0-19	5.74	4.15	1.05	1.09	0.50	5.74	0.19	0.23	0.08	8.30	75.15
AB	19-44	6.08	2.87	0.70	2.68	0.33	6.72	0.19	0.16	0.11	7.90	90.85
B	44-79	6.06	1.34	0.70	1.30	0.33	5.71	0.24	0.22	0.13	7.10	88.82
C	79-180	6.49	1.53	0.35	1.30	0.33	12.84	0.33	0.14	0.28	15.00	90.56
	Mean	6.09	2.47	0.70	1.59	0.33	7.75	0.24	0.19	0.15	9.58	86.96
KBW P1 Typic Plinthustalfs/Plinthic Lixisols												
Ap	0-20	4.99	7.51	1.40	4.78	0.70	10.42	0.03	0.13	0.10	12.85	83.21
Bt1	20-50	4.79	3.55	0.70	1.52	0.80	12.03	0.06	0.13	0.08	13.98	88.02
Bt2	50-85	4.66	1.53	0.70	0.87	0.80	12.41	0.01	0.12	0.08	14.50	87.05
Bt3	85-130	4.85	0.77	0.35	0.65	0.80	13.96	0.09	0.14	0.20	15.30	94.04
Btv	130-190	4.70	0.96	0.35	0.22	1.00	11.31	0.04	0.08	0.08	14.60	78.88
	Mean	4.80	2.86	0.70	1.61	0.82	12.03	0.05	0.12	0.11	14.25	86.37
KBW P3 Typic Plinthustalfs/Lixic Plinthosols												
Ap	0-20	5.05	7.55	1.40	4.46	0.60	12.76	0.06	0.07	0.08	13.00	99.78
B	20-48	5.16	2.49	0.70	1.79	0.50	12.51	0.06	0.11	0.09	13.00	98.22
Btv1	48-89	5.25	2.11	0.70	2.68	0.50	12.73	0.07	0.13	0.07	14.85	87.54
Btv2	89-138	5.07	0.77	0.35	0.89	0.83	14.25	0.10	0.11	0.12	15.00	97.20
	Mean	5.13	3.23	0.79	2.46	0.61	13.06	0.07	0.11	0.09	13.96	95.47

Table:TD= Tudun wada, KMG= Kafin Madaki Ganjuwa, ,KBW= Kubwa,TEB=Total Exchangeable Bases,EA= Exchangeable Acidity,CEC= Cation Exchange Capacity,ECEC=Effective Cation Exchange Capacity,BS= Base Saturation,ESP= Exchangeable Sodium Percentage,SAR= Sodium Absorption Ratio ic matter in the surface horizons. The lowest mean value of 34.51 % was observed across the entire study sites in Tudun wada profile P2 while the highest mean value of 45.35% was obtained in Tudun wada profile P1.

3.3. Chemical Properties of Soils in the Study Sites.

3.3.1. Soil pH

The results shown in Table 3 indicated that soil pH (H2O) of the surface horizon of the Tudun wada study area varied from 5.60 to 5.92, which are considered to be strongly acidic to slightly acidic. Slightly higher pH values were observed in the underlying horizons. Most horizons had pH values above 5.20. Kafin Madaki Ganjuwa study area had pH (H_2O) values of surface horizons varying from 5.74 to 5.88. The values for the subsurface horizons varied from 5.39 to 6.49. Kubwa study area had pH (H_2O) values which ranged from 4.99 to 5.05 and 4.66 and 5.25 for the surface and underlying horizons, respectively.

The pH is considered as being very strongly acidic to strongly acidic. There was a slight increase in pH with increasing profile depths; however, the distribution was irregular. The pH values were within the range reported on soils over basement complexes in different parts of Nigeria (Fasina *et al.,* 2007). Frossard *et al.* (2000) reported that soils' acidic nature could be attributed to the fact that soils were derived from weathering of acidic igneous granites and leaching of basic cations such as K Ca and Mg from the surface soil. According to Landon (1991), a pH range of 5.5 to 7.0 is the preferred range for most crops, while Friday *et al*., (2014) suggested a pH of 6.0 to 6.8 for most crops at which nutrients availability is highest.

The patterns of pH distribution with soil depth were not regular. Samndi and Jibrin, (2012) reported a slight decrease with soil depth and attributed it to the decrease in organic matter, basic cation uptake and leaching. The pH values varied across the study sites, and this could probably be ascribed to the differences in the soil type and vegetation and different agricultural management practice in the study sites.

3.3.2. Organic carbon

The organic carbon values for the surface horizons in the entire study sites were rated as low (Esu, 1991) as values were below 10gkg-1 critical limit. Organic carbon values for the surface horizons in Tudun wada profiles varied from 4.40 to 4.61 gkg^{-1}. For the underlying horizons, values ranged from 1.92 to 2.91gkg^{-1}. Kafin Madaki Ganjuwa study site the values varied from 3.57 to 4.15gkg^{-1} in the surface horizons and 0.55$gkg^{-1}$to 2.87gkg^{-1} for the underlying horizons, while in Kubwa it ranged from 7.51 to 7.55gkg^{-1} in the surface and 0.77 and 3.55 gkg^{-1} for the underlying horizons. Generally, there was a slight decrease in the OC content with increasing depth, which could be attributed to the higher quantity of plant residues in the surface horizon. This conforms with Samndi and Jibrin 2012) who attributed the increase in the surface horizon to organic matter inputs and subsequent decomposition. Kubwa study site had the highest organic carbon values (6.83-7.55 gkg^{-1}) This could be due to high vegetative growth in the Southern Guinea savanna than the northern guinea the Sudan savanna. Organic carbon's low content was generally attributed to continuous cultivation, bush burning, high rate of mineralization, crop removal for livestock feeding, fuelwood, fencing, and building purposes without incorporation (Odunze, 2006).

According to Essiet (2001), low organic carbon and nitrogen contents in most tropical soils are attributed to continuous cultivation with little or no fertilizer usage. Similarly, Jibrin *et al.* (2008) attributed the low level of organic carbon to continuous intensive cropping without much organic matter additions in the form of manures and crop residues.

3.3.3. Total nitrogen

The total nitrogen (TN) values for the study sites are presented in Table 3. Tudun wada study site's total nitrogen contents ranged from 1.05 to 1.40gkg^{-1}, and 0.35 to 0.70 gkg^{-1} for the surface and underlying horizon. That Kafin Madaki Ganjuwa study site was 1.05gkg^{-1} for the surface and 0.35 to 0.70gkg^{-1} for the underlying horizons while Kubwa had 1.40gkg^{-1} 0.35 to 0.70gkg^{-1} for the underlying horizons.

The total nitrogen (TN) in the surface and subsurface horizons in the study sites were rated as low based on Landon's ranking (1991). Generally, the TN values in the surface horizon in the entire study site ranged from 0.70 to 1.40gkg^{-1} while the subsurface horizon values ranged from 0.35 to 0.70 gkg^{-1}. Kubwa study site had slightly higher TN values with a mean value of 0.81gkg^{-1}. These higher values could be attributed to a higher amount of organic matter than organic carbon values. The values generally were lower than 1.5gkg^{-1} critical limit (Esu 1991) ratings. The nitrogen status is generally considered as being low in all the study sites. The similar result was obtained by Mustapha (2007) in Bauchi. The low level of TN values across the study site could be due to harvest losses. This is in agreement with Yifru and Taye (2011), who attributed the low level of total nitrogen to harvest losses due to total crop removal, leaching and humus losses associated with cultivation. Jibrin *et al.* (2008) attributed this low level of total nitrogen partly to low soil organic matter levels. The total nitrogen values generally decreased with depth following the trend of organic matter.

3.3.4. Available P

The available P (Av P) values for the surface and subsurface horizons of the study site were low except for profile TD P2, which had value slightly above 10$mgkg^{-1}$ critical limits. The values ranged from 6.96 to 10.43$mgkg^{-1}$. and 2.61 to 3.70$mgkg^{-1}$, 1.09 to 4.57$mgkg^{-1}$ and 1.09 to 2.68$mgkg^{-1}$, 4.46 to 4.78 mg kg^{-1} and 0.22 to 2.68$mgkg^{-1}$ for Tudun wada,(NGS), Kafin Madaki (SS) and Kubwa (SGS) respectively. Available Phosphorus values in the study areas were rated low, according to Landon's ranking (1991). The pattern of distribution generally decreased with depth following the trend of Organic carbon and TN. A Similar trend was observed and reported by Samndi and Jibrin (2012). The higher P values in the surface horizon could probably be attributed to phosphorus's continuous application containing fertilizer in the study area. According to Esu rating (1991), the available P content of the study soils could generally be rated as being low (<11$mgkg^{-1}$).

Similarly these values fell below the critical limit for Nigerian soils (15$mgkg^{-1}$) (Enwezor *et al.*, 1990; Adepetu *et al.*, 2000). The low available phosphorus in the study sites could also be attributed to low soil pH observed. Phosphorus could react with iron (Fe) and aluminium (Al) to produce insoluble Fe and Al phosphates that are not readily available for plant uptake(Karuma *et al.* 2015), under acidic conditions.

3.3.5. Exchangeable calcium

The exchangeable calcium values in the surface horizons of all pedons in the study area were rated as high with values higher than 5cmol (+) /kg. (Table 3). The values for exchangeable calcium in the surface horizon were high according to Esu's (1990) rating, and Landon, (1991) in most pedons within the study sites. Higher values of exchangeable Ca were observed in the subsurface horizons of the study sites. Lawal *et al.*, (2012) reported similar results and attributed the dominance of calcium and a higher amount in the subsurface horizon not only to leaching per se but to *in situ* weathering of parent materials rich in Ca bearing minerals.

3.3.6. Exchangeable magnesium

As shown in Table 3, exchangeable magnesium values of the entire study site's surface and subsurface horizons were rated as low to medium as values were below 1cmol(+) / kg. The magnesium rating in the surface horizon of the study sites was considered low as values are below $0.3 cmolkg^{-1}$. However, the subsurface horizons had higher values than the surface horizons. This could be attributed to leaching. The exchangeable potassium values in the surface horizons of Tudun wada, and kafin Madaki Ganjuwa study sites were rated as high(>0.30 $cmolkg^{-1}$) while that of Kubwa study sites were low (<0.15$cmolkg^{-1}$). The values of exchangeable Mg for the subsurface horizons were higher than those of the overlying horizon.

3.3.7 Exchangeable sodium

The exchangeable sodium values in the study sites' surface horizons ranged from 0.08 to 0.18 $cmolkg^{-1}$ and were rated low to medium, according to Landon (1991). Tudun wada, Kafin Madaki Ganjuwa and Kubwa values were rated low to medium (0-0.3 $cmolkg^{-1}$). Na's values for the subsurface horizons in the study sites were greater than those of overlying horizons (0.10 to 0.30 $cmolkg^{-1}$). Generally, there was an increase in the exchangeable cations with depth in all profile across the study sites. This increment could be attributed to the loss of cations suggesting illuvial accumulation of cations due to eluviation and illuviation processes. This result agrees with the findings of Ashenafi et al., (2010) who attributed the increment of cations with depth to the illuviation process.

3.3.8 Cation exchange capacity

The CEC values of the surface horizons for the entire study sites ranged from 7.40 to 13.00 cmol (+) kg^{-1} while that of the subsurface horizons ranged from 5.22 to 15.30 cmol (+) kg^{-1}. The CEC values for surface horizons were lower than those of the subsurface horizons in the entire study site. The low CEC levels observed in the surface soil could also be attributed to leaching of the bases down the profile and the low clay content in the surface soils. This is in agreement with the findings of Msanya *et al.* (2003). Ebouh (2013) reported lower CEC values as observed in most of the study sites and ascribed it to the amount of organic matter, and the type of clay mineral present in the soil. The Pattern of CEC distribution across the entire study sites followed the exchangeable basic cations' trend, reflecting that basic cations are the main ion contributors in the exchange complexes. Mulugeta, (2010) made similar observations; Alameyehu *et al.* (2014).

The mean CEC values of the study sites were between 5.88 and 11.29 $cmolkg^{-1}$ and rated as medium (Esu, 1991; Landon, 1991) except for Kubwa study site rated as high with mean values of 13.96 and 14.25$cmolkg^{-1}$. High CEC values indicate that soil has a greater capacity to hold cations and requires higher rates of fertilizer that can increase its cation level to provide adequate crop nutrition. Whereas, low CEC soils hold fewer nutrients, and are liable to leaching of mobile "anion" nutrients, leading to the requirement for split applications of several nutrients (Hamza, 2008). Similar results were reported by Achalu *et al*., (2012) suggesting that the CEC of the soil is expected to increase through the improvement of the soil organic matter.

3.3.9 Base saturation

The base saturation values for the surface and subsurface horizons were rated as high across the study sites (Table 4). The mean value for all the sites indicates a high base saturation as their respective mean values were above 50%. The highest mean values were obtained in Kubwa study sites (91.74%) while the least mean values (66.49%) were obtained in Tudun Wada profile 2. The higher base saturation in Kubwa study sites may be attributed to the high amount of exchangeable cations and CEC in this study area. Similarly, Atofarati *et al.,* (2012) attributed the high base saturation observed in the Study areas to the dominance of basic cations in the exchange complex.

The profile had high base saturation values for both the surface and subsurface horizons, reflecting the high amount of weatherable minerals (Engdawork, 2002). Esu (1991) and FAO (1999) stated that soils with base saturation greater than 50% are regarded as fertile soils, while those with less than 50% were regarded as not fertile soils.

3.4 Soil Classification

3.4.1 Classification according to USDA soil taxonomy

All the pedons across the respective study sites had an Ochric epipedons as the surface horizons were either too light in colour, too low in organic carbon, too shallow to be classified as mollic, umbric, histic or plaggen epipedon. All the profiles had argillic horizons. All the profiles had % base saturation greater than 50 % by NH_4OAC and greater than 35 % (ECEC). For USDA Soil Taxonomy (Soil Survey Staff 1999) criteria for soil classification, most of the soils were classified as Alfisols and Pedons KMG P1and P2 as Inceptisols due to few diagnostic horizons that form rapidly and absence of rock structure (Table 6). At the suborder level, Pedons TD P1, P2, KBW P1, P2 and were classified as Ustalfs due to the Ustic soil moisture regime of the study sites.

Profile TD P1, P2, were classified as Haplusalfs at the great group level; they had no plinthite that constituted one half or more of the horizon within 150cm of the mineral surface, and do not meet the condition required for classification into other great groups of Ustalfs They were classified as Typic Haplustalfs at the subgroup level. Kafin Madaki profiles P1 and P2 were classified as Inceptisols at the order level, Ustepts at suborder as a result of its ustic moisture regime, at the great group; they were classified as Haplustepts as they did not meet the requirement of any of the Ustepts, at subgroup level as Typic Haplustepts due to their failure to meet the requirement of other Haplustepts.

3.4.2 Classification according to world reference base for soil resources (WRB)

At the World Reference Base for Soil Resources (WRB) most the profiles had an Argic horizon, Tudun Wada pedons P1, P2, were classified as Haplic Lixisols due to the presence of an Argic horizon, high % base saturation and low CEC (<24$cmolkg^{-1}$) and did not meet any of the reference group and preceding prefixes. Kafin Madaki Profiles P1 and P2 were classified as Haplic Regosols due to shallow profiles above unconsolidated materials with A, B and

C horizons or absence of diagnostic horizons, minimal clay and organic carbon as a consequence of young age with base saturation (NH_4OAc) greater than 50%.

Kubwa Profile P1 were classified as Plinthic Lixisols, and these pedons had CEC of <24 cmolkg^{-1}, base saturation (NH_4OAc) greater than 50% and also meet the requirement of plinthic Prefix due to the occurrence of the plinthic layer at a depth of 185cm. Kubwa Profile P2 were classified as Lixic plinthosols due to the occurrence of Plinthic horizon within 138cm of the surface and with CEC of <24cmolkg^{-1} and base saturation (NH_4OAc) greater than 50%, (WRB, 2006).

4.0 Conclusion

The study results showed that the soils of the study area (Tudun wada, Kafin Madaki Ganjuwa and Kubwa) were moderately deep to very deep. Two taxonomy groups were identified (Alfisols and Inceptisols) of varying morphological and physicochemical properties. The soils were generally low in organic carbon, total nitrogen and available phosphorus, and the CEC were low to medium (<6-12 cmol(+)Kg) whereas Zaria and Kubwa had high CEC (>12 cmol(+)Kg), Base saturation values were rated Medium to high (50->80%) across the study sites.

The application of site-specific soil fertility management practices and researching to improve soil nutritional quality of crops is essential. The results from soil characterization and classification reveal that the soils across the study site were fragile, which needs careful management. The low pH coupled with low organic carbon, TN and Available P signified that sustainable crop production could only be achieved through integrated soil fertility management. Necessary management practices that will increase organic matter are required by incorporating farmyard manure and non-acidifying chemical fertilizers. Split application of fertilizers is recommended due to the occurrence of illuviation and eluviation and leaching process in all the study sites coupled with low to medium CEC.

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