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Distribution of Soil Micronutrients of Bakalori Irrigation Project, Zamfara State, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

The study was carried out to assess the distribution of soil micronutrients at Bakalori Irrigation Project, Zamfara State. Three local government areas; Maradun (Upper slope), Talata Mafara (Middle slope) and Bakura (Lower slope) were purposively sampled along Sokoto River. Three soil profile pits were dug, one in each local government of the study site, soil samples were collected from each horizon. Results showed that the soils were slightly acid to neutral with mean pH of 6.29, 6.60 and 6.62 for upper, middle and lower slope respectively. Organic carbon was low with mean values of 5.67 gkg^{-1}, 2.79 gkg^{-1} and 4.72 gkg^{-1}. CEC values were medium with the mean value of 10.76, 10.92 and 10.60 $cmolkg^{-1}$. The results of available micronutrients showed that Fe was low with the mean values of 1.55 $mgkg^{-1}$, 1.8 $mgkg^{-1}$, and 1.83 $mgkg^{-1}$, Mn was low to medium with the mean values of 0.70 $mgkg^{-1}$, 0.85 $mgkg^{-1}$ and 1.08 $mgkg^{-1}$, Zn was medium with the mean values of 1.05 $mgkg^{-1}$, 0.85^{-1} and 1.0 $mgkg^{-1}$ and Cu was high with the mean values of 2.30 $mgkg^{-1}$, 1.5 $mgkg^{-1}$ and 2.58 $mgkg^{-1}$ in all the three sites (upper, middle and lower slope). According to the USDA soil Taxonomy Classification System, soils of profile 1 (upper slope) were classified as

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Typic Endoaqualfs, soils profile 2 (middle slope) were classified as *Aquic Haplustalfs* and soils profile 3 (lower slope) were classified as *Aquic Hapludalfs* and the soils were locally named as Dosara, Matusgi and Birnin Tudu series for Maradun, Talata Mafara and Bakura soils respectively.

Keywords: Distribution; micronutrients; Bakalori Irrigation Project.

1. INTRODUCTION

There is an increasing demand for information on soils as a means to produce food [1]. Soil plays a major role in determining the sustainable productivity of an agro-ecosystem. The sustainable productivity of a soil mainly depends upon its ability to supply essential nutrients to the growing plants [2].

There are 16 natural elements (nutrients) that are essential for plant growth. Three elements (carbon, hydrogen and oxygen) make up 94% of the plant tissues and are obtained from air and water. The other 13 elements are obtained from the soil and are divided into two broad categories - 'macro' and 'micro'. These terms do not refer to the importance of the elements; macronutrients are required in greater amounts than micronutrients for normal plant growth [3].

Micronutrients are elements required in small quantities for higher plant growth and reproduction. The exact quantity needed varies with plant species and the specific element. Seven elements are generally considered as plant micronutrients, these include boron (B), copper (Cu), chlorine (Cl), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn) (Soil Survey Staff, 2010) [4].

Generally, studies on micronutrients status of Nigerian soils have been neglected in the past due to non- prevalence of their deficiency symptoms. This has made the information on soil micronutrient status of Nigeria savanna soils scanty. Lombin [5] Kparmwang et al. [6] and Adeboye [7] reported that limited studies have been conducted on the micronutrients status of soils within the savanna zone of Nigeria. However, the few investigations carried out so far have revealed micronutrient deficiency in some Nigerian savanna soils [5,8,9]. Depletion of micronutrients in Nigerian savanna soils has resulted from intensively cultivated soil with high nutrient-demanding crops, highly weathered rocks and leaching. Mustapha and Loks [10] reported that the use of new high yielding crop varieties which are nutrient demanding have unraveled micronutrient deficiencies in some Nigeria Savanna soils.

The deficiency of micronutrients has become a major constraint to productivity, stability and sustainability of soils [11]. In order to realize the full potentials of these soils, there is need to take the inventory of their nutrient status including their distribution. A good knowledge of the variation of soil profile characteristics as it relates to micronutrient status is essential for good land evaluation which is a pre-requisite for sound land use and planning. Moreover, information on the profile distribution of these elements in rice growing soils will provide the basis for making informed decision with respect to fertilization and other soil management practices (Ahukaemere et al. [12]. The need to understand the importance of micronutrients is highly imperative for improved productivity of both the soil and crops (Mustapha et al. [13]). The objective of this research therefore, is to assess the distribution of Fe, Mn, Cu and Zn in soil profile as well as to classify the soils under Bakalori Irrigation Project, Zamfara State, Nigeria.

2. MATERIALS AND METHODS

2.1 Study Area

The study area was selected from three local government (Maradun, Talata Mafara and Bakura) under Bakalori Irrigation Project in Zamfara State, The area lies between latitude 12° 34’- 12° 42’N and longitudes 6° 14’-5° 52’ E [14]. The climate of the area is characterized by a hot-dry season lasting from October to May and a rainy season that usually starts in mid-May and ends in September. Long-term mean annual rainfall ranges from 500 mm-900 mm, with considerable inter annual variations. The annual temperature averages 27℃ with a minimum of 17℃ (December/January) and maximum of 40 ^{0}C in April/May [14].

2.2 Soil Sampling and Handling

One profile pit was sunk from soils of each local government sampled area selected for the study to characterize and classify the soils. The soils from the profile were sampled according to natural horizons, giving a total of 13 profile soil samples. The soil samples collected were properly labeled and stored in polythene bags prior to laboratory analysis. In the laboratory, each sample was separately air dried and crushed gently using pestle and mortar. The crushed soil samples were sieved with 2 mm sieve and the fine earth fractions (<2 mm separates) were used for all the laboratory analyses.

2.3 Laboratory Analyses

The particle size distribution was determined using the hydrometer method after dispersing with sodium hexametaphosphate [15]. The soil pH was determined in 1:1 soil/water suspension using a glass electrode pH meter while Organic Carbon was determined using wet oxidation method of Walkley and Black [16] method. Cation exchange capacity was determined using the NH_4OAc saturation at pH 7, while the leachate was used to determine the exchangeable bases. Total and available micronutrients (Zn, Cu, Fe and Mn) were determined using $HClO_4/HNO_3$ and 0.1M HCI solution (Osiname et al. [17]) respectively, and were read using atomic absorption spectrophotometer at appropriate wave lengths.

3. RESULTS AND DISCUSSION

3.1 Morphological and Physical Characteristics of the Soils

The morphological and physical properties, of the soils from the profiles are presented in Table 1.

Pedon 1, is located in Maradun local government (Upper slope) around Dosara village (12° 34'N and 6° 14' E). The soils were light yellowish brown (10YR 6/4) in colour at the surface and changed to reddish brown (2.5YR 4/4) in the subsurface horizon. Texturally, the soils were sandy loamy at the surface changing to sandy clay loam in the subsurface horizons. Structurally the soils were angular blocky at the surface changing to subangular blocky at the subsurface horizon and the soils were well drained.

Pedon 2, is located in Talata Mafara local government (Middle slope) around Matusgi village (12° 34'N and 6° 04' E). The soils were very pale brown (10YR 7/3) in colour at the surface, and changing to strong brown (7.5YR 5/6), at the subsurface with brownish yellow mottles (10YR 6/8) to yellow colour mottles (10YR 7/6). The soils were generally deep and well drained. Textually, the soils were sandy clay loam in almost all the horizons with subangular blocky structure at the surface and changes to weak angular blocky structure at the subsurface horizons.

Pedon 3, is located in Bakura local government (Lower slope) around Birin Tudu village (12° 42' N and 5° 52' E). The soils were dark brown (10YR 3/3) at the surface changing to very dark brown (10YR 2/2) and the subsurface. The soils were deep and poorly drained. Textually, the soils were loamy in the surface changing to loamy and loamy in the subsurface horizons. The structure of the soils was weak angular blocky in the surface and changes to sub angular blocky in the subsurface.

3.2 Chemical Characteristics of the Soils

The chemical properties of the soils are presented in Table 2.

The average pH values of the soils were 6.62, 6.60 and 6.29 for pedon 1, 2, and 3 respectively. The pH was observed to increase or decrease irregularly with increasing depth. Similar trends were observed and reported by Ojanuga et al. [18]. This could be attributed to the removal of basic cations from the soil to the lower depth and/or the use of some acid forming fertilizers such as urea for agricultural purposes. Organic matter was generally very low in the soils going by Esu [19] rating in which value < 10 gkg^{-1} were rated very low while > 15 gkg^{-1} was rated high. Wadatau et al. [20] reported a mean value of 3.0 gkg^{-1} for soils of flood plain of Rima River. The low organic carbon content of the soils of the studied area may be attributed to the continuous cultivation of the land by the farmers for both rainy and dry season farming. The CEC of the soils were medium, according to Esu [19] rating of CEC <6 low, 6-12 medium and > 12 high. Singh et al. [21] reported a mean CEC value of 15.7cmolkg in Kandoli Shela Stream valley at Dundaye, Sokoto. Total nitrogen was high with average value 0.33, 0.34 and 0.34%. The high level of total nitrogen of the study area may be attributed to application of nitrogenous fertilizers while P was low with average value of 2.89, 3.68 and 2.44 $mgkg^{-1}$ for pedon 1, 2, and 3 respectively. The values of the exchangeable bases vary greatly in the soils of the 3 pedons. Ca was low with average value of 0.32, 0.35 and 0.53 cmolkg^{-1}, Mg was medium with average value of 0.52, 0.41 and 0.20 cmolkg^{-1}, K was low to high with average value of 0.26, 0.23 and 0.45 cmolkg^{-1} and Na was high with average value of 0.82, 0.86 and 0.92 cmolkg^{-1} for pedon 1, 2, and 3 respectively.

3.3 Total and Available Soil Micronutrients in the Soils Collected from the Pedons

Total and available soil micronutrients of the soil are presented in Table 3.

The average total Fe values in the soils were 3.98 mgkg^{-1}, 3.67 mgkg^{-1} and 3.67 mgkg^{-1} while average available Fe values of the soils were 1.55 mgkg^{-1}, 1.8 mgkg^{-1}, and 1.83 mgkg^{-1} for pedon 1, 2 and 3 respectively. The values were highest in Ap horizon and decreased in the immediate underlying horizon and increase thereafter, suggesting that Fe were held by inorganic colloids in the subsoil as reported by [6]. Esu [19] gave a range of <4.5 mgkg^{-1}, 4.5-10 mgkg^{-1} and > 10 mgkg^{-1} as low, medium and high iron content of the soils respectively. This indicates that the soils of the study area were low in iron content. Iron deficiency may be expected on sandy soils, organic soils or acid soils having high levels of copper [22].

The average total Mn in the soils were 2.11 mg kg^{-1}, 2.62 mgkg^{-1} and 1.92 mgkg^{-1}, while average available Mn in the soils were 0.70 mgkg^{-1}, 0.85 mgkg^{-1} and 1.08 mgkg^{-1} for pedon 1, 2 and 3 respectively. Esu [19] gave the critical limits of manganese in soils as < 5 mgkg^{-1} (low), 5-10 mgkg^{-1} (medium) and > 10 mgkg^{-1} (high). This indicates that all the soils of the study area were low in manganese content. Both the available and total Mn were irregularly distributed within the profile suggesting that it was not tied to any single soil property or a particular pedogenic process [23].

Average total Zn in the soils were 2.20 mgkg^{-1}, 1.99 mgkg^{-1} and 2.62 mgkg^{-1} while average available Zn in the soil studied were 1.05 mgkg^{-1}, 0.85^{-1} and 1.00 mgkg^{-1} for pedon 1,2 and 3 respectively. Iyaka and Kakulu [24] reported a zinc range value of 2.8 mgkg^{-1} to 7.5 mgkg^{-1} in soils of Niger State. The soils of the studied area were rated medium to high in zinc content as the values were in range of 0.8-2.20 mgkg^{-1}.

Esu [19] rated < 0.8 mgkg^{-1} as low and > 2.0 mgkg^{-1} as high. Average total Cu in the soils of the 3 pedons were 3.88 mgkg^{-1}, 2.94 mgkg^{-1} and 3.59 mgkg^{-1}, while average available Cu in the soil studied were 2.30 mgkg^{-1}, 1.50 mgkg^{-1} and 2.58 mgkg^{-1} for pedon 1,2 and 3 respectively. According to Esu [19], copper content of < 0.2 mgkg^{-1} are low, 0.2-1.0 mgkg^{-1} medium and> 1.0 mgkg^{-1} as high going by this rating the soils of the area were rated high in copper content. Chude and Obigbesan [25] reported ranges of 1.6-14 mgkg^{-1} for soils of South Western Nigeria.

3.4 Classification of the Soils of the Study Area

The soils have been classified according to the USDA Soil Taxonomy (Soil Survey Staff, 2010) [4] and correlated with the World Reference Base (WRB) for Soil Resources (FAO, 1999) [2].

3.5 USDA Soil Taxonomy

Soils of pedon 1, are classified as Alfisols at order level because of the presence of an argillic horizon. It is *Aqualfs* at the suborder level because of the redoximorphic features in almost all layers (evidenced by mottle colours in the subsurface horizons). It is classified as *Endoaqualfs* at the greatgroup level because it has saturation layer below 50cm (*Epiaqualfs* have episaturation). At the subgroup level it is further classified as *Typic Endoaqualfs* because it does not fit into the other subgroup. It was further classified as *Dosara series* because it was first identified near *Dosara* settlement.

Soils of pedon 2, are classified as Alfisols at order level because of the presence of an argillic horizon. It is *Ustalfs* at the suborder level because it has ustic moisture regime. It is classified as *Haplustalfs* at the greatgroup level because it does not fit into other great group. At the subgroup level it is further classified as *Aquic Haplustalfs* because it has aquic conditions for some time in normal years (or artificial drainage). It was further classified as *Matusgi series* because it was first identified near *Matusgi* settlement.

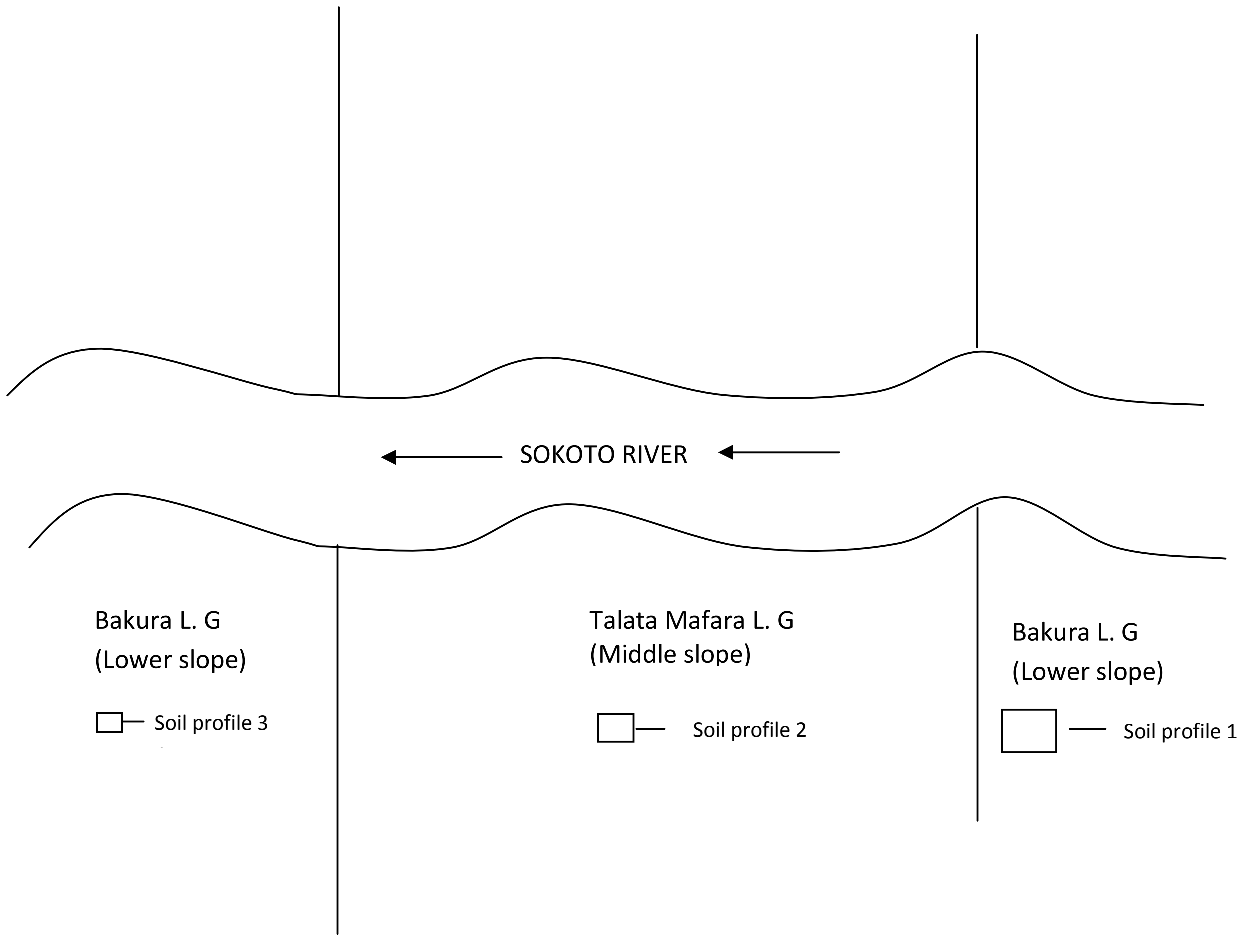

Fig. 1. Simple sketch of the studied area

Table 1. Morphological and physical properties of soils from the profiles of the study sites

	Depth (cm)	Munsell Colour Matrix	Mottle	Structure	Consistence	Boundary	Particle size dist.			Textural class
							Sand	Silt (gkg^{-1})	Clay	
Upper slope pedon 1		***Typic Endoaqualfs***								
Ap	0-9	10YR 6/4	-	1fabk	Fr	DS	707	134	158	SL
AB	9-31	10YR 7/4	10YR 5/8	2fabk	Lo	DW	727	138	158	SL
Bt	31-65	2.5 YR 4/4	10YR 5/8	2msbk	Fr	CS	382	312	311	SC
2C1	65-91	5 YR 4/6	-	3msbk	Fr	CG	454	373	231	SC
2C3	91-181	5 YR 6/8	-	2fsbk	Fr		650	139	335	SCL
Middle slope pedon 2		***Aquic Haplustalfs***								
Ap	0-40	10YR7/3	10YR 6/8	1csbk	Fr	DS	560	103	345	SCL
Bt	40-62	10YR 8/6	10YR 7/6	2fabk	Lo	DW	712	232	161	SL
2B2	62-114	10YR 5/6	10YR 6/8	2mabk	Fr	DW	454	288	256	SCL
2B3	114-143	7.5 YR 5/8	-	2fabk	Lo	AW	650	376	153	SCL
2B4	143-180	7.5YR 5/6	-	1fabk	Fr		635	113	268	SCL
Lower slope pedon 3		***Aquic Hapludalfs***								
Ap	0-14	10YR 3/3	-	1fabk	Fr	CS	270	327	402	L
AC	14-35	10YR 2/2	-	2mabk	Fr	DW	368	249	383	LS
C	35-90	10YR 7/8	-	2fsbk	Lo		466	249	285	L

**Determined at wet condition, Note: Symbols or codes are according to FAO, 2006. Structure: 0 = Structureless, 1= Weak, 2= Moderate, 3= Strong, f= Fine, m= Medium, c= Coarse abk = Subangular blocky, Consistence: Lo= loose, Fr= Friable. Texture: LS= Loamy sand, SCL= Silt clay loam, SC= Sand clay SL= Sandy loam and L= Loam Boundary: AW = Abrupt and wavy, CS= Clear and smooth, CG= Gradual, DS= Diffuse and smooth, DW= Diffuse and wavy*

Table 2. Chemical properties of the soils of the study sites

Profile no.	Horizon	Depth (cm)	pH 1:1(H_2O)	Org. C gkg^{-1}	N (%)	P (mg/kg)	Ca	Mg	K	Na	CEC
							← cmolkg^{-1} →				
Upper slope pedon 1	***Typic Endoaqualfs***										
	Ap	0-09	7.45	5.99	0.33	2.32	0.25	0.20	0.15	0.91	9.12
	AB	9-31	5.86	2.99	0.40	2.45	0.25	0.55	0.15	0.69	11.60
	B_1	31-65	5.76	5.59	0.35	2.37	0.55	0.15	0.38	0.86	10.20
	$2C_1$	65-91	6.07	7.79	0.34	2.95	0.30	1.45	0.48	0.95	9.60
	$2C_3$	91-181	6.35	5.99	0.24	2.47	0.25	0.25	0.12	0.69	10.40
		Mean	6.29	5.67	0.33	2.89	0.32	0.52	0.26	0.82	10.76
Middle slope pedon 2	***Aquic Haplustalfs***										
	Ap	0- 40	6.49	5.59	0.28	2.67	0.40	0.60	0.35	0.86	11.60
	B_1	40-62	5.82	0.39	0.26	3.56	0.20	0.60	0.15	0.78	11.00
	$2B_2$	62-114	6.66	0.99	0.39	2.86	0.60	0.40	0.33	0.95	10.00
	$2B_3$	114-143	6.72	2.99	0.34	2.11	0.40	0.35	0.17	0.82	9.00
	$2B_4$	143-180	7.32	3.99	0.44	2.33	0.15	0.10	0.15	0.91	10.10
		Mean	6.60	2.79	0.34	3.68	0.35	0.41	0.23	0.86	10.92
Lower slope pedon 3	***Aquic Hapludalfs***										
	Ap	0-14	6.58	4.39	0.34	2.49	0.75	0.05	0.64	0.91	9.00
	AC	14-35	6.65	2.79	0.30	2.56	0.4	0.30	0.38	0.95	10.40
	C	35-90	6.63	6.99	0.38	2.32	0.45	0.25	0.33	0.91	10.20
		Mean	6.62	4.72	0.34	2.44	0.53	0.20	0.45	0.92	10.60

Table 3. Total and available micronutrients of the soils in profiles of the soil study sites

Profile no.	Horizon	Depth (cm)	Total				Available			
			Fe	Mn	Zn	Cu	Fe	Mn	Zn	Cu
			mgkg^{-1}							
Upper slope pedon 1	***Typic Endoaqualfs***									
	Ap	0 – 9	2.10	3.15	2.62	4.72	1.25	0.75	1.00	2.50
	AB	9 – 31	4.72	2.10	2.10	5.25	2.00	0.25	1.50	3.00
	B1	31 – 65	5.25	1.57	1.57	3.67	1.75	0.75	0.75	1.75
	2C1	65 – 91	3.67	1.57	2.10	3.15	1.50	0.50	1.00	1.25
	2C3	91 – 181	4.20	2.20	2.62	2.62	1.25	1.25	1.00	1.00
		Mean	3.98	2.11	2.20	3.88	1.55	0.70	1.05	2.30
Middle slope pedon 2	***Aquic Haplustalfs***									
	Ap	0-40	5.25	5.25	1.57	5.77	2.00	0.75	0.50	2.00
	B1	40-62	3.67	1.57	2.10	2.62	1.50	1.00	0.75	1.25
	2B2	62-114	3.67	1.57	2.10	2.62	1.75	0.75	1.00	1.75
	2B3	114-143	2.62	2.10	2.62	2.10	1.75	1.00	1.25	1.00
	2B4	143-180	3.15	2.62	1.57	1.57	2.00	0.75	0.75	1.50
		Mean	3.67	2.62	1.99	2.94	1.80	0.85	0.85	1.50
Lower slope pedon 3	***Aquic Hapludalfs***									
	Ap	0-14	3.67	1.57	3.15	3.15	2.00	1.00	1.25	3.00
	AC	14-35	2.62	2.10	2.10	5.25	1.25	0.75	1.00	3.75
	C	35-90	4.72	2.10	2.62	2.62	2.25	1.50	0.75	1.00
		Mean	3.67	1.92	2.62	3.59	1.83	1.08	1.00	2.58

Soils of pedon 3, are classified as Alfisols at order level because of the presence of an argillic horizon. It is *Udalfs* at the suborder level because it does not fit into other suborders. It is classified *Haplusdalfs* at the greatgroup level because it does not fit into other greatgroup. At the subgroup level it is further classified as *Aquic Hapludalfs* because it has Within 75 cm of the mineral soil surface if the upper boundary of the argillic horizon is 50 cm or more below the mineral soil surface. It was further classified as *Birnin Tudu series* because it was first identified near *Birnin Tudu* settlement.

3.6 World Reference Base

Soils of pedon 1, are classified as Luvisols at the major soil group level for having an argic horizon overlain by sandy loam. At the soil unit level, soils of profile 1, are classified as Arg*ic Luvisols* for having a texture of sandy loam.

Soils of pedon 2, are classified as Lixisols for having an argic horizon within one hundred centimeter of the soil surface overlain by loamy sand. At the soil unit level it was classified as *Areniclixisols* for having subsurface horizon with distinct high clay content.

Soils of pedon 3, are classified as Fluvisols because the soil is developed in alluvial deposits. At the soil unit level they are classified as *umbricfluvisols* for having soil structure sufficiently strong that the horizon is not both massive and hard.

4. CONCLUSION

The findings presented and discussed so far inferred that the soils of the study area were classified as Alfisols for pedon 1, 2 and 3. The areas were moderately to slightly acid. Total nitrogen was high, organic carbon and phosphorus was generally low in the soils of the study area which will impact negatively on the overall fertility status of the soils under investigation. The results obtained from this study have shown that out of the four soil micronutrients investigated namely: Fe, Mn, Zn, and Cu from the profiles, Cu had high concentrations, Zn was medium in concentration and Fe was deficient in the area. The distribution of these micronutrients in the study area suggests that supplementary application of Fe and Mn will be required for sustainable crop production in the soils, while Zn and Cu were not deficient in the soils. Annual check-up of the soil condition is required to ascertain the status of the soil.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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