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CHARACTERIZATION AND CLASSIFICATION OF THREE MAJOR SOILS AT THE COLLEGE OF AGRICULTURE, JALINGO, TARABA STATE, NIGERIA

***[1]Kefas P.K., [2]Ofem K.I., [1]Hammanjoda A. and [3]Garjila Y.A.**

[1]Department of Soil Science & Land Resource Management, Taraba State University, Jalingo, Nigeria
[2]Department of Soil Science, University of Calabar, Calabar, Nigeria
[3]Federal University of Kashere, Gombe State, Nigeria

*Corresponding author: pkefas@yahoo.com

ABSTRACT

Adequate information on land resources have been identified as a pre-requisite for sustainable land management. The present study was carried out to characterize and classify the soils of College of Agriculture, Jalingo, Taraba State, and to suggest soil management recommendations for optimum crop yield. Digital elevation model (DEM) of the study location was obtained and the slope map of the area generated using ArcGIS (ESRI, US) software. This was used to identify the major soils (MU1, MU2 and MU3). Two soil profile pits were sited in each of MU1 and MU2, and one pit was sited in MU3. The soils were described and sampled for laboratory analyses. The results revealed the dominance of transitional horizons namely; AB, BC and CB which also showed raised proportions of clay. The soils were shallow to bedrock and dominated by brown, dark yellowish brown and gray colours (moist) in the surface soils and reddish to yellowish brown in the subsurface horizons. Sand size fraction dominated the particle size distribution and resulted in sandy loam and sandy clay loam textural classes. All the soils had bulk density < 1.50 g cm^{-3}. Soil pH was slightly acid to neutral and values in water were higher than those in $CaCl_2$ in all horizons. Organic carbon, total N, available P and exchangeable bases were low in most of the soils, while base saturation was high. Two of the soils (MU1 and MU2) were classified as Alfisols while MU3 was classified as an Entisol according to the USDA system. According to the World Reference Base for Soil Resources system of classification, MU1 and MU2 were classified as Lixisols and MU3 as a Gleysol. The incorporation of organic manure, cropping across slopes, and practicing afforestation are recommended for soil nutrient management.

Key words: basement complex, soil classification, soil characteristics, Jalingo, land use

INTRODUCTION

Proper land evaluation procedures emphasize adequate soil resource base obtained through field and laboratory studies (Ukaegbu *et al.*, 2023). The combination of field and laboratory studies results in soil characterization and involves morphological, physical, chemical and mineralogical properties. During soil characterization, properties of soils rather than their genesis are emphasized. This is probably due to the assumption that soil properties result from soil forming processes and are more readily quantifiable than the processes (Arnold, 1983). Adequate data on land resources have been identified as a pre-requisite for sustainable land management. Ofem *et al.* (2016) and Esu (2005) advocated detailed study of soil resources via soil characterization and land evaluation. Soil properties are more readily remembered and predictions more easily made about the behaviour of soils when they are classified. Soil classifications begin with the examination of soil profiles, and proceed with the determination of physical, chemical and mineralogical properties. During soil examination, subsoil horizons are given greater emphasis than surface horizons which are more often easily influenced by human activities (Kang and Tribathi, 2000). Although modal profiles of two adjacent soil series may be distinctly different, there is usually a gradual transition in the field, between one series and another (Peterson and Calvin, 1986).

Agriculture is the most dominant occupation of the people of Taraba State, with over 75% of its population directly or indirectly involved in the vocation. Farming activities range from rainfed to irrigated agriculture, livestock rearing to tree and arable crop production. Intensive farming activities without management remedies deplete soils of nutrients. The soils also could become vulnerable to leaching and erosion. Land use is not determined scientifically as most of the farmers use management practices inherited from their forebears. Consequently, yields are generally, poor irrespective of the level of inputs such as improved seeds, fertilizer and irrigation used. This research would provide baseline information on the soils of the area for general agricultural production. The objectives

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of this study were to characterize and classify three major soils at the College of Agriculture, Jalingo, Taraba State based on the requirements of United States Department of Agriculture and correlate with the World Reference Base for Soil Resources System. Recommendations on best soil management practices for optimum crop yield will also be suggested.

MATERIALS AND METHODS

Description of the Study Area

The study was located at the College of Agriculture Farm Area, Jalingo, northeastern Nigeria. The farm occupies an area of about 85 ha. The study area lies between latitude 8˚ 53′ 37.20″ N and longitude 11˚ 21' 34.60″ E is characterized by the northern guinea savanna. Bauchi and Gombe States are located in the northern axis of the study area, while Adamawa State and Cameroun Republic are in the East and South, respectively. Benue, Nassarawa, and Plateau States are located in the West of Taraba State (Figure 1). The area is tropical with distinct wet and dry seasons. The wet season lasts for 7 months, while the dry season lasts for 5 months with a mean annual rainfall which ranges from 800 mm in the northern part of the state to over 2000 mm in the southern part (Adebayo, 2012). Precipitation is lowest in January with an average of 217 mm. Mean annual temperature is 34˚C and varies in mean monthly values between 28.4˚C in the coolest month of December and 37˚C in the hottest month of March (NIMET, 2009). The soils are predominantly underlain by basement complex rocks with the outcrops of Precambrian granitic, and migmatite - gneisses occurring at intervals (Ogezi, 2002).

Field and Laboratory Studies

The digital elevation model (DEM) of the study location was obtained and the slope map of the area generated using the ArcGIS (ESRI, US) software. The elevation ranges created in the slope maps were used to delineate slope transition from high to low elevations (Figure 1). This was in turn used to identify the three different soils, which include MU1 (MUIP1, MUIP2), MU2 (MU2P1, MU2P2) and MU3 (MU3P1). Two profile pits were randomly sited and dug in each of the major soil units to represent the soils, however, only one pit was dug in MU3. Auger soil samples were obtained from depths of 0-20 and 20-40 cm in each soil unit transiting to the next to check transition zones between elevation ranges. The soil profiles were described according to the criteria of Schoeneberger *et al.* (2012). Sixteen soil samples were obtained from the genetic horizons of the five profile pits and used for the determination of physical and chemical analyses. Soil samples meant for bulk density determination were obtained with the use of 5 cm (diameter) core samplers. The soil samples were transported in labelled polythene bags to the laboratory. Particle size distribution was determined following the Bouyoucous hydrometer method using sodium hexametaphosphate as dispersant and the textural classes were determined with the USDA textural triangle. The soil cores were oven dried at a temperature of 105˚C for 24 h, and the bulk density calculated as the weight of oven dry soil divided by the volume of the soil (i.e., volume of core sampler). Soil pH was determined potentiometrically using a glass electrode pH meter in water and $CaCl_2$ in a ratio of 1:2:5 (soil:water), while the soil electrical conductivity (EC) was determined in a 1:1 soil to water ratio. Soil organic carbon was determined by the Walkley-Black wet oxidation method, while total N was by the macro-Kjeldahl digestion procedure. Exchangeable bases were extracted using 1 N ammonium acetate (NH_4OA_c) solution at pH 7. The exchangeable Ca and Mg were read on the atomic absorption spectrophotometer, while K and Na were read using flame photometer. Exchangeable acidity (Al^{3+} + H^+) was determined by leaching the soil samples with 1 M KCl solution and titrating with 0.01 M NaOH. The cation exchange capacity of the soils was determined with the neutral 1 N NH_4OAc solution of saturated extract. The Bray 1 method was used to determine available phosphorus. All laboratory analyses were performed as outlined by Soil Survey Staff (2014b).

RESULTS AND DISCUSSION

Morpho-Physical Properties of the Soils

The morpho-physical properties of the soils are presented in Table 1. Apart from the Ap horizon, the soils had transitional AB, BC or CB horizons in the horizon sequence of each soil profile. The presence of these transitional horizons in MU1 and MU2 somewhat characterizes the slow movement of fine clay from either the Ap, AB or BC horizons, hence the absence of a clear Bt horizon and indicates the absence of clear argillic horizons. Formation of an argillic horizon takes place over time and indicates soil maturity. Therefore, the soils may be adjudged as relatively young. The soils were either shallow or moderately deep with depth of less than 100 cm, and

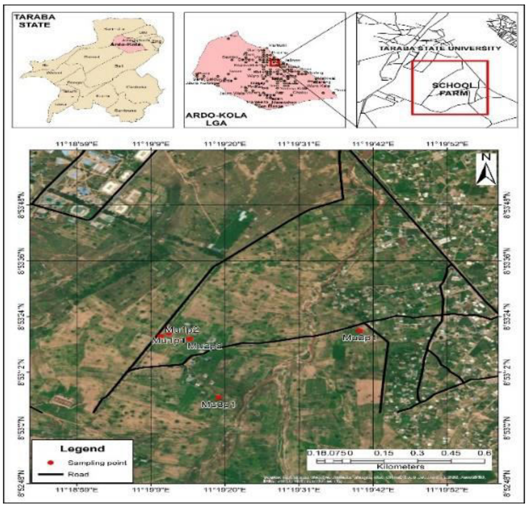

Figure 1: Map showing the sampling points and study location

Table 1: Morpho-physical properties of soils of the study area

Profile number	Soil horizon	Horizon depth (cm)	Colour matrix				Mottle colour	Particle size distribution (%)			Texture	Bulk density (g cm^{-3})
			Notation (moist)	Name (moist)	Notation (dry)	Name (dry)		Sand	Silt	Clay		
MU1P1	Ap	0-25	7.5YR 4/4	Brown	10YR 7/3	Very pale brown		60	35	5	Sandy loam	1.17
	BA	25-35	5YR 5/4	Reddish brown	10YR 6/3	Pale brown		65	30	5	Sandy loam	0.97
	BC	35-60	2.5YR 3/3	Dark reddish brown	10YR 6/6	Brownish yellow		65	27	8	Sandy loam	0.89
MU1P2	Ap	0-20	10YR4/3	Brown	10YR 6/2	Light brownish grey		55	25	20	Sandy clay loam	1.13
	AB	20-45	10YR5/4	Yellowish brown	10YR 7/3	Very pale brown		54	25	21	Sandy clay loam	0.95
	BA	45-60	10YR6/6	Brownish yellow	10YR 8/4	Very pale brown		53	20	27	Sandy clay loam	0.82
	BC	60-85	10YR5/8	Yellowish brown	10YR 7/6	Yellow		66	14	20	Sandy clay loam	1.05
MU2P1	Ap	0-24	10YR3/6	Dark yellowish brown	10YR 7/3	Very pale brown		55	25	20	Sandy clay loam	1.15
	BA	24-40	10YR5/6	Yellowish brown	10YR 6/3	Pale brown		53	20	27	Sandy clay loam	1.17
	BC	40-60	7.5YR5/6	Strong brown	7.5YR 7/6	Reddish yellow		58	18	24	Sandy clay loam	1.21
	CB	60-75	7.5YR5/6	Strong brown	10YR 7/4	Very pale brown		55	25	20	Sandy clay loam	1.30
MU2P2	Ap	0-26	10YR3/3	Dark brown	10YR 7/3	Very pale brown		62	20	17	Sandy loam	1.22
	BC	26-35	10YR3/6	Dark yellowish brown	10YR 6/3	Pale brown		65	15	20	Sandy clay loam	1.35
	CB	35-55	7.5YR4/6	Strong brown	10YR 5/6	Yellowish brown		56	18	26	Sandy clay loam	1.40
MU3P1	Ap	0-20	10YR5/1	Gray	10YR 6/2	Light brownish gray		55	20	25	Sandy clay loam	1.23
	AB	20-40	10YR4/2	Dark greyish brown	7.5YR 6/1	Gray	Light brownish gray (10YR 6/2)	48	27	25	Sandy clay loam	1.04

having water table encountered at < 50 cm in MU3. The soil was rated as shallow on the scale described by Esu (2010). Generally, such shallow depths are limitations to the establishment of most tree crops. In addition, trees may have their tap roots affected by the excess underground water in MU3 or their proliferation hindered by root limiting layers in MU1 and MU2. The similarity in the thickness of the Ap horizons (20-26 cm) of the soils indicates a near uniform plough layer, organic matter deposition or mineralization, or uniform removal of soil by water or wind erosion. Also, the slope factor difference between the major soil units is not significant to influence differential surficial removal of soil materials. A previous study by Kefas *et al.* (2020a) adjudged soils in the study area as deep, well-drained A, B, C soils with extensive B horizons, while Kefas *et al.* (2020b) described them as having depths greater than 125 cm. A dominant hue of 10YR was obtained under both moist and dry conditions of the soils with values of 3, 4 and 5 (moist), and 6, 7 and 8 (dry). Surface soil colours (moist) were either dark yellowish brown, brown, strong brown, dark brown, and gray with yellowish, reddish or grayish colours in the subsurface horizons. The dark to brown colours indicate the presence of decayed organic materials, while yellowish brown may indicate the presence of Fe-organic matter complexes. Similar matrix colours of brown (7.5YR 3/4) and dark brown (10YR 3/3), and dark yellowish brown (10YR 4/6) were reported by Kefas *et al.* (2020a) for similar soils in the area. Similarly, Kefas *et al.* (2020b) identified the soils as dark greyish brown to brown in matrix colour. Particle size distribution of the soils indicates the dominance of sand over silt and clay. Silt and clay were relatively similar in distribution except in MU1P1 where there was more silt than clay resulting in sandy loam texture. Sand dominated textural classes encourage soil water holding capacity, particularly in the surface soils, and when combined with limited fertility properties, it is rare for such soils to be suitable for production of most crops (Ofem *et al.,* 2022). Kefas *et al.* (2020b) reported loamy sand and sandy loam textures for similar soils in Jalingo. Furthermore, comparing the clay content in the transition B horizons to the adjoining horizons (except in MU3P1) is indicative of active process of arg. illuviation. The dominance of sand in these soils reflects the granitic origin of the parent materials from which the soils are formed (Kefas *et al.,* 2020a; Kefas, 2021). Bulk density of the soils was less than 1.50 g cm^{-3}, and the values in MU1 and MU3 decreased with soil depth. Kefas *et al.* (2020a, b) reported bulk density of less than 1.50 g cm^{-3} for similar soils. The bulk density of the two profiles of MU2 increased steadily with depth. The relatively higher values in the subsurface horizons could be attributed to compaction caused by traction of farm animals and machines. This may restrict the growth of plant roots and reduce productivity.

Chemical Properties of the Soils

Chemical properties of the soils are presented in Table 2. Soil pH (H_2O) was less than 7 with a range of 5.8-6.9 and tended to increase with depth. In the all the soils, pH (H_2O) values were higher than those of pH ($CaCl_2$). This indicates that significant amounts of exchangeable Al and the dominance of their exchange complex by negative charges (Esu, 2010). Such range of values indicate that the soils were moderately to slightly acid and neutral, and near the optimal range of values (5.5-6.5) for microbial activities and plant growth (Holland *et al.,* 1989). Kefas *et al.* (2020a, b) reported a similar range of pH for comparable soils in Jalingo. The values of electrical conductivity (EC) were less than 1.00 dS m^{-1} in the studied soils. This indicates that the soils were not saline and could not be Aridisols (Esu, 2010). According to FAO (1988), soils are regarded as saline if EC is greater than 4.00 dS m^{-1}. Such low EC values of the soils would not affect plant root establishment and proliferation. Soil organic carbon ranged from 0.08 in MU3P1 to 0.21 g kg^{-1} in MU1P1 for the surface soils with values that decreased regularly with soil depth. The values were generally rated low on the scale of Holland *et al.* (1989). The relatively low organic carbon in the poorly drained MU3P1 is a reflection of the slow rate of decomposition due to poor aeration compared to the well-drained MU1P1. Udo *et al.* (2009) opined that the rate of decomposition of organic matter is a major factor controlling its accumulation in soils, while Igwe *et al.* (2007) and Obalum *et al.* (2012) attributed such low values to mineralization of organic matter due to high temperatures in the tropics. Kefas *et al.* (2020a) reported low values of organic carbon for similar well-drained soils, and comparatively higher values for soils at the foot slope position. Organic carbon content of less than 15 g kg^{-1} is low on the scale reported by Landon (1991), and indicates the absence of histic and mollic epipedons (Udo *et al.*, 2009). The low organic carbon could be attributed to crop removal as a result of continuous cultivation over the years without recourse to replenishing lost nutrients via organic amendment. Total N in the soils ranged from 0.012 in MU3P1 to 0.03 g kg^{-1} in MU1P1 for the surface soils and had similar distribution as organic carbon as values decreased with increasing soil depth. The values were rated very low on the scale described by Holland *et al.* (1989). The values aligned with those of organic carbon mainly because much of soil nitrogen is present in organic form (Udo *et al.*, 2009; Ukabiala *et al.*, 2021). Available P content of the soils ranged from 2.06 to 3.60 g kg^{-1} in the surface soils and from 0.99 to 3.08 g kg^{-1} in the subsurface soils. The levels of available P generally decreased with increasing soil depth, and were rated as low on the scale described by Holland *et al.* (1989). The MU2 soil had relatively higher values of available P, mainly as a result of higher leaf fall in the location.

Table 2: Chemical properties of the study area

Pedon	HD	Soil pH		EC	OC	OM	TN	Ca	Mg	K	Na	EA	ECEC	Av. P	PBS	ESP
	(cm)	H_2O	$CaCl_2$	dS m^{-1}	g kg^{-1}			cmol kg^{-1}						g kg^{-1}	(%)	
MU1P1																
Ap	0-25	5.80	4.80	0.65	0.21	0.36	0.030	1.50	0.30	0.05	0.07	0.80	2.72	2.06	52.20	2.57
BA	25-35	6.00	5.70	0.09	0.20	0.34	0.028	2.00	0.54	0.06	0.05	0.80	3.45	1.57	76.81	1.45
BC	35-60	6.00	5.50	0.09	0.18	0.31	0.026	2.80	0.80	0.07	0.04	0.80	4.51	1.36	86.07	0.88
MU1P2																
Ap	0-20	6.00	4.70	0.10	0.18	0.31	0.025	1.60	0.40	0.05	0.05	0.60	2.70	2.06	77.49	1.85
AB	20-45	6.10	5.40	0.07	0.21	0.36	0.032	2.20	0.59	0.06	0.04	0.60	3.49	1.83	82.80	1.14
BA	45-60	6.00	5.10	0.08	0.17	0.29	0.024	3.20	0.90	0.08	0.07	0.60	4.85	1.52	67.01	1.44
BC	60-85	5.80	4.80	0.08	0.08	0.14	0.022	3.00	0.78	0.14	0.12	0.60	4.64	0.99	86.63	2.59
MU2P1																
Ap	0-24	6.00	5.30	0.06	0.14	0.25	0.021	2.80	0.76	0.07	0.07	0.60	4.30	3.60	85..81	1.63
BA	24-40	6.30	5.70	0.07	0.04	0.06	0.012	2.80	0.81	0.08	0.14	0.60	4.43	2.86	86.45	3.16
BC	40-60	6.50	5.70	0.08	0.03	0.05	0.004	2.20	0.59	0.08	0.09	0.60	3.56	1.78	83.14	2.53
CB	60-75	6.90	6.10	0.12	0.02	0.03	0.003	2.60	0.70	0.07	0.08	0.60	4.05	1.73	85.18	1.98
MU2P2																
Ap	0-26	6.50	5.70	0.09	0.10	0.17	0.014	1.80	0.49	0.06	0.05	0.80	3.20	3.60	74.99	1.56
BC	26-35	6.30	5.50	0.08	0.04	0.19	0.012	2.80	0.80	0.09	0.05	0.60	4.34	3.08	65.43	1.15
CB	35-55	6.60	5.70	0.05	0.03	0.05	0.003	3.00	0.82	0.10	0.14	0.60	4.66	2.87	87.12	3.00
MU3P1																
Ap	0-20	6.80	5.90	0.10	0.08	0.14	0.012	4.80	1.30	0.10	0.09	0.80	7.09	2.06	74.47	1.27
AB	20-40	6.90	6.00	0.09	0.06	0.11	0.012	4.60	1.20	0.12	0.07	0.80	6.79	2.06	73.49	1.03

HD - horizon depth, EC - electrical conductivity, OC - organic carbon, OM - organic matter, TN - total nitrogen, Ca - calcium, Mg - magnesium, K - potassium, Na - sodium, EA - exchangeable acidity, ECEC - effective cation exchange capacity, Av. P - available phosphorus, PBS - percentage base saturation, ESP - exchangeable sodium percent

Organic carbon, total N and available P often have similar and related distribution. They are similarly sourced from organic matter and often have similar rating. Kefas *et al.* (2020b, 2021) reported low levels of organic carbon, total N and available P in similar soils in Jalingo. Exchangeable Ca ranged from 1.50 in MU1P1 to 4.80 cmol kg^{-1} in MU3P1 with higher values in the subsurface soils. The percent contribution of exchangeable Ca to the soils exchange complex was 55, 59, 65, 56 and 68% in the surface soils of MU1P1, MU1P2, MU2P1, MU2P2 and MU3P1, respectively. Similarly, exchangeable Mg ranged from 0.30 in MU1P1 to 1.30 cmol kg^{-1} in MU3P1 with values that increased with soil depth. The values of exchangeable K and Na were less than 0.20 cmol kg^{-1} in the soils with irregular variation in values with soil depth. The levels of exchangeable Ca and Mg were rated moderate to low, while K and Na were rated low on the scale reported by Holland *et al.* (1989). Irrespective of the soil units, the soil exchange complex was dominated by basic cations in the order of Ca > Mg > K > Na, except in MU2P1 where the order Ca > Mg > Na > K, was obtained. The exchangeable cations (Ca, Mg, K, Na) were comparatively higher in MU2P1 and MU3P1, and the soils regarded as more fertile and most likely to be more productive. In a related study, Kefas *et al.* (2020a) reported similar levels for all the exchangeable basic cations in some Jalingo soils. Ofem *et al.* (2020) intimated that high precipitation and mobility during chemical weathering are factors responsible for low exchangeable K in tropical soils. The levels of exchangeable acidity in the soils were less than 1.00 cmol kg^{-1} and ranged from 0.60 to 0.80 cmol kg^{-1}. The similarity in the values reflects the uniformity of the influence of rainfall in the location and similarity in sand size distribution which have similar influence on the soils. Such low values of exchangeable acidity may not have any significant negative influence on plant growth. Effective cation exchange capacity (ECEC) ranged from 2.70 in MU1P2 to 7.09 cmol kg^{-1} in MU3P1 for the surface soils with values that increased regularly as soil depth increased except in MU3P1. Increasing values of ECEC with increasing clay amount and soil depth is indicative of the probable contribution of clay colloids to the exchange capacity of the soils. The decrease in ECEC with soil depth in MU3P1 may be due to the higher levels of exchangeable Ca and Mg in the Ap horizon. On the scale reported by Holland *et al.* (1989), the ECEC of the soils was rated low, except in MU3P1 where values were rated as moderate. Moderately high values have been reported for ECEC in similar soils in Jalingo (Kefas *et al.*, 2020a), while Kefas *et al.* (2020b, 2021) reported low values for ECEC in similar soils. The percent base saturation (PBS) of all the soils was more than 50%, and in the majority of them the levels tended to increase erratically with depth. The levels of PBS in the soils were moderate to high on the scale reported by Holland *et al.* (1989) and Landon (1991). At these levels of PBS, the basic cations would be available for plant uptake (Akpan-Idiok and Ofem, 2014). Previous studies reported low values (< 50%) for base saturation in similar soils (Kefas *et al.,* 2020b, 2021). The exchangeable sodium percentage (ESP) of the soils ranged from 0.88 to 3.16%. Thus, the soils were non-sodic because their ESP was < 15% and their EC < 4.00 dS m^{-1}. Consequently, sodium and soluble salts would not pose threats to crops.

Classification of the Soils

The studied soils showed increase in clay in the B-horizons within 50 cm of soil depth from the soil surface (except MU3P1) with base saturation that exceeds 50% at this depth. The soils meet the requirement for Alfisols in the USDA Soil Taxonomy (Soil Survey Staff, 2014a). Ustic soil moisture regime characterized MU1P1, MU1P2, MU2P1, and MU2P2, and qualified the soils as Ustalfs in the suborder category and as Haplustalfs in the great group as no preceding qualifier applies. The soils have sandy loam or sandy clay loam textural classes in a layer extending from the mineral soil surface to the top of an argillic horizon at 50 cm and thus qualified as Typic Haplustalfs. The presence of cambic subsurface horizon and ochric epipedons in MU3P1 qualifies it as an Entisol, and Aquent by virtue of its gray matrix colour and shallow depth to soil water table. MU3P1 has less than 35% rock fragments and sandy clay loam textures, and qualifies as Psammaquent, and Typic Psammaquent in the subgroup category as it failed to meet the requirements for other subgroups. The soils (MU1P1, MU1P2, MU2P1, and MU2P2) had an argic horizon overlain by loamy sand, sandy loam or sandy textural classes and thus qualified as Lixisols at the first level of the World Reference Base for Soil Resources System. At the second level, the MU1 and MU2 soils were classified as Haplic Lixisols while MU3P1 qualified as a Fluvic Gleysol.

CONCLUSION

Three soils at the College of Agriculture, Jalingo, Taraba State were characterized and classified. All the soils had Ap and transitional horizons. In addition, two of the soils, MU1 and MU2 had an argillic horizon. The soils were shallow, while MU1 and MU2 were dominated by brown and dark yellowish brown, MU3 was gray (moist) in the surface soils and reddish to yellowish brown in the subsurface horizons. Sand size fraction dominated the particle size distribution and resulted in sandy loam and sandy clay loam textural classes. Bulk density of all the soils was < 1.50 Mg m^{-3} and their pH were slightly acid to neutral. The soils contained low levels of organic carbon, total N, available P and exchangeable bases, while base saturation was greater than 50% throughout the soil profiles. Under Soil Taxonomy, the MU1 and MU2 soils were classified as Typic Haplustalfs, while MU3 was classified as a Typic Psammaquent. Under the World Reference Base for Soil Resources, the MU1 and MU2 soils were classified as Haplic Lixisols, whereas MU3 was classified as a Fluvic Gleysol.

RECOMMENDATIONS

Incorporation of manure to improve nutrient levels and water-holding capacity of the soils is recommended. Furthermore, cropping across slopes is recommended to minimize nutrient loss through run-off. Also, afforestation is recommended to serve as wind breaks to reduce wind erosion and for nutrient management.

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