Characterization, Classification and Agricultural Potentials of Soils on a Toposequence in Southern Guinea Savanna of Nigeria

B. A. Lawal, A. G. Ojanuga, P. A. Tsado, A. Mohammed

Abstract**—**This work assessed some properties of three pedons on a toposequence in Ijah-Gbagyi district in Niger State, Nigeria. The pedons were designated as JG1, JG2 and JG3 representing the upper, middle and lower slopes respectively. The surface soil was characterized by dark yellowish brown (10YR3/4) color at the JG1 and JG2 and very dark grayish brown (10YR3/2) color at JG3. Sand dominated the mineral fraction and its content in the surface horizon decreased down the slope, whereas silt content increased down the slope due to sorting by geological and pedogenic processes. Although organic carbon (OC), total nitrogen (TN) and available phosphorus (P) were rated high, TN and available P decreased down the slope. High cation exchange capacity (CEC) was an indication that the soils have high potential for plant nutrients retention. The pedons were classified as Typic Haplustepts/ Haplic Cambisols (Eutric), Plinthic Petraquepts/ Petric Plinthosols (Abruptic) and Typic Endoaquepts/ Endogleyic Cambisols (Endoclayic).

Keywords**—**Ecological region, landscape positions, soil characterization, soil classification.

I. INTRODUCTION

SOIL is an important component in human's total stock of natural resources and it underpins food production [1]. Soil was described as a product of its environmental factors of climate, vegetation/ organic material, geology, local relief and time [2]. Furthermore, soil exhibits the signatures of the afore-stated factors and as well as certain processes which combined to produce that specific characteristic [3]. Topography is a major factor which control most surface processes taking place on earth, i.e. soil formation and soil development. Topography has influence on soil chemical and physical properties and also on pattern of soil distribution over landscape [4], [5]. For instance, the impact of rainfall is great where landscape is sloppy with regards to erosion and deposition. Soils on hill slopes differ from those at summits or valleys in terms of moisture distribution, soil depth, cations distribution, organic matter contents [3].

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In Nigeria, many works on relationship between landscape positions and soil properties were documented. For instance, [6] deduced that nutrient status and soil properties are related to topography of the land area. Also, [7] reported differences in quantity and forms of sesquioxides as influenced by geomorphic positions. They also observed that the soils of the profiles at higher slopes were dominated by the crystalline forms of iron (Fe) and aluminum (Al) -oxides while the soils of the valley bottom were dominated by the amorphous forms of Fe and Al. Elsewhere, [8] observed a wide variation in phosphorus (P) distribution along a toposequence in southeastern Nigeria; where total P was found to be highest at the upper slope and lowest at the middle slope. Similarly, [9] observed plinthites in soils on different landscape positions except in adjacent valley floors in a location in northern Guinea savanna of Nigeria.

With emphasis being shifted to precision farming in Nigeria to meet up food requirement of rapidly growing population, investigations on properties of soils on different landscape positions is absolutely necessary. Potentials of soils can readily be tapped when information on its physical, chemical and biological properties are available. Niger State Nigeria is an agrarian state where data on soils are limited. Objectively, this study was conducted mainly to characterize, classify and assess the agricultural potentials of soils along a toposequence in Ijah Gbagyi in Tafa Local Government Area of Niger State, Nigeria.

II. MATERIALS AND METHOD

A. The Study Site

The study site lies at 4-kilometres along Sabon Wuse – Ijah Gbagyi road lies on 09° 16.246′ North and latitude 07° 15.327′ East in the southern Guinea savanna of Nigeria. The study area consists of gently undulating high plains developed on basement complex rocks comprising of granites, migmatites, gneisses and schists [10]. Climate of the area was designated by Koppen Aw, sub-humid with mean annual rainfall greater than 1016mm with distinct dry season of about 5 months occurring from November to March. Average temperature is 33ºC. Dominant soil parent materials are the weathered remains of the varied basement complex rocks. The soils derived from the weathered rocks are deep, weakly to moderately structured sand to sandy clay with gravelly and concretionary layers in the upper layer or beneath the surface layer. The dominant soils are broadly categorized as Ferric Luvisols, Ferric Acrisols and Ferric Cambisols [10]. A wide range of crops such as grains, roots and tubers, legumes and vegetables are grown within the study area, among them are maize, sorghum, upland rice, soy beans and yams.

B. Field Work

This study formed part of detailed soil survey of a 16ha of land lying north of Suleja Water Reservoir. Three pedons designated as JG1, JG2 and JG3 representing the identified geomorphic positions, the upper, middle and lower slopes were described according to guidelines in [11]. Soil colors were described using Munsell Soil Color Charts [12]. Soil samples were collected from the identified genetic horizons and taken to the laboratory for analysis.

C. Soil Analysis and Data Interpretation

The soil samples collected were air-dried, gently crushed using a mortar and pestle, and passed through a 2mm-sieve to obtain fine earth separates. The processed soil samples were analyzed for some physical and chemical properties following the procedures outlined by the International Soil Reference and Information Centre and Food and Agricultural Organization [13] as briefly highlighted herein. Particle size analysis was determined by the Bouyocous hydrometer method while soil pH H_2O suspension was determined with pH meter. Organic carbon (OC) was by Walkley-Black method. Available P was determined by the Bray P 1 method and total nitrogen (TN) by Kjeldahl method. Exchangeable bases, calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+) and sodium (Na^+) were extracted with neutral ammonium acetate (1N NH_4OAc) solution and amounts in solution measured by atomic absorption spectrophotometry. Cation exchange capacity (CEC) was determined by the neutral 1 N NH_4OAc saturation method, while percent base saturation was by calculation. The exchangeable acidity, that is, hydrogen (H^+) and aluminum (Al^{3+}) was determined by titrimetric method.

Data were interpreted based on [14] and [15] (Appendix I). The pedons were classified using Soil Taxonomy System [16] and correlated with World Reference Base for Resources (WRB) [11].

III. Results and Discussion

A. Morphological and Physical Characteristics

Data on some morphological and physical properties of soils are shown on Table I. The site was arbitrarily partitioned into upper, middle and lower slope positions and designated as JG1, JG2 and JG3 respectively. The surface of JG1 and JG2 was characterized by a dark yellowish brown (10YR3/4) color which graded to various shades of light yellowish brown in the subsurface, whereas JG3 had very dark grayish brown (10YR3/2) color at the surface over gray (10YR5/1), grayish brown (10YR5/2) and strong brown (7.5YR5/8) subsurface. The grayish coloration was an indication that JG3 was imperfectly or poorly drained [17]. Also, yellowish color in JG1 and JG2 may be attributed to presence of sesquioxides in hydrated form, especially the goethite. The surface horizon of all the pedons was mottle-free, an indication of good surface drainage. However, strong brown (7.5YR4/6) mottles was common at the subsurface of JG1 and JG3 which changed to red (2.5YR4/8) at lower horizon. The surface soil was weak and crumb-structured. Absence of cracks on the surfaces of the pedons probably inferred that the soils have nonexpanding caly minerals e.g. kaolinite in them [10]-[18]. Stones of quartz origin and gravels made of Fe and manganese (Mn) concretions were common in surface horizon of JG1 whereas plinthites cemented with clay dominated the subsurface of JG2 which contributed to its poor subsurface drainage. The texture was gravelly sandy loam at the surfaces of JG and sandy loam (JG2 and JG3) overlaying the subsurface sandy clay loam or sandy loam with some Fe and Mn nodules and concretions or plinthites.

Sand dominated the mineral fraction in all the landscape positions studied which may be partly attributed to parent material rich in quartz mineral, an essential component in granite [19], and partly to geological processes involving sorting of soil materials by biological activities, clay migration through eluviation and illuviation, or surface erosion by run-off or their combinations [20], [21]. Sand content of the surface horizons was in the order of JG1 > JG2 > JG3. The silt content increased with soil depth irrespective of landscape positions, probably because these soils were developed *in situ*. It was also observed that JG3 had the highest amount of silt with average value of 81g kg^{-1} which may be linked to the depositional effect of the seasonal stream and Suleja Water Reservoir inundating the JG3 in addition to receiving colluvial material from upper slopes (JG1 and JG). The trend of silt content in the surface horizon was JG1 < JG2 < JG3. Clay fraction was next to sand in dominance. Clay was higher in the subsurface than surface horizons. Its distribution within the subsoil of the three pedons was irregular, characteristic of a cambic horizon. The average silt/clay ratio was 0.30, 0.26 and 0.52 respectively for JG1, JG2 and JG3 was an indication that the soils studied are relatively young. Silt/clay ratio of < 1.00 could mean that these soils had undergone ferralitic pedogenesis [22], or the low silt/clay ratio probably implied that these soils still have weatherable minerals in them. Young parent materials usually have silt/clay ratio above 0.25 [23].

B. Chemical Properties of the Soils

Data for some chemical properties are shown in Table II The soil reaction, especially for the surface, was rated strongly acid to slightly acid with pH values 5.5, 6.2 and 5.4 for JG1, JG2 and JG3 respectively. Brady and Weil [24] had established pH range of 5.5-7.0 as optimal for overall satisfactory availability of plant nutrients. The exchangeable acidity was low inferring that acidity may not be a threat in these soils studied. The OC content of the soils decreased with soil depth was rated high irrespective of soil depth and landscape positions. The high values of OC inferred that the studied site might have been under fallow for a long period or probably suggests that the land was not intensively cultivated High intensity agricultural activities deplete soil organic matter content [25]. Total N was moderately high in upper and middle slopes and low in lower slope position. Although, pedon JG3 has the advantage of receiving soluble nutrients from the upper slopes, its lower N content may be linked to the higher water-table which might contributed immensely to leaching of N especially the nitrate form. Available P was rated medium in JG2 and JG3 to high in JG1. High level of available P at the JG1 may be due to its low solubility/ mobility in soil. However, high available P content is the subsoil of JG3 could be due to deposition of P as also reported in a study elsewhere in south-eastern Nigeria [8].

Calcium (Ca) and Mg are the principal cations in the soils investigated. Calcium was rated medium in surface soil of JG1 and high in JG2 and JG3. The trend of distribution of Ca within the surface horizon was in the order of JG1 < JG2 < JG < JG3 signifying the possibility of lateral movement of the nutrient element from upper to lower slope. On the other hand, Mg irrespective of soil depth and landscape position was rated high. Accumulation of Mg^{+2} on the exchange complex of these soils is worrisome. According to [26], [27] accumulation of Mg in soil may cause deterioration of soil structure, lower water intake rates and affects its chemical and biological properties. Potassium was rated medium at the surface horizon of JG1 and low in JG2 and JG3. However, of K increased just below the surface especially in JG1 and JG3 where its concentration was rated high. Sodium was rated low in JG2 and high in JG1 and JG3 making them to be potentially sodic. CEC of the surface soils was high probably due to reasons earlier stated for organic carbon. Base saturation was moderate and was a reflection of basic cations in the exchange complex [28].

TABLE I
SOME MORPHOLOGICAL AND PHYSICAL PROPERTIES OF THE SOILS

Pedon	Soil Depth (cm)	Color (moist)		Structure†	Texture (g kg^{-1})			Texture*	Silt/clay ratio
		Matrix	Mottling		Sand	Silt	Clay		
JG1	0-22	10YR3/4	-	1cr	808	51	141	GSL	0.36
	22-36	10YR5/6	7.5YR4/6	2sbk	720	60	220	SCL	0.27
	36-87	10YR6/8	7.5YR4/6	2sbk	725	60	215	SCL	0.28
	87-108	10YR6/4	Mottled	1sbk	705	65	230	SCL	0.28
JG2	0-14	10YR4/4	-	1cr	800	60	140	SL	0.43
	14-86	10YR5/6	-	2sbk	713	52	235	SCL	0.22
	86-164	10YR6/6	Mottled	3ms	721	51	228	GSCL	0.22
JG3	0-16	10YR3/2	-	1cr	787	81	132	SL	0.61
	16-104	10YR5/2	7.5YR4/6	2sbk	705	78	217	SCL	0.36
	104-139	7.5YR5/8	2.5YR4/8	2sbk	741	82	177	SL	0.46
	139+	10YR5/1	-	2sbk	785	83	132	SL	0.63

*GSL= gravelly sandy loam; SL= sandy loam; SCL= sandy clay loam; GSCL= gravely sandy clay loam

TABLE II
SOME CHEMICAL PROPERTIES OF THE SOILS

Pedon	Soil Depth(cm)	pH (H_2O)	OC (g kg^{-1})	TN	Av.P (mg kg^{-1})	Exchangeable Bases				Exch. Acid	CEC	BS (%)
						Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}			
						← (cmol kg^{-1}) →						
JG1	0-22	5.5	24	2.10	25	3.36	4.63	0.20	0.57	0.02	13.17	66.51
	22-36	6.0	21	0.55	20	4.08	4.51	0.48	0.32	0.01	14.10	66.60
	36-87	5.1	17	1.70	21	2.64	1.00	0.26	0.39	0.02	6.44	66.61
	87-108	4.9	14	1.10	15	4.08	5.04	0.13	0.22	0.01	14.22	66.60
JG2	0-14	6.2	21	0.55	18	14.32	1.68	0.38	0.17	0.02	24.86	66.57
	14-86	5.4	27	1.10	14	2.80	2.91	0.41	0.26	0.04	9.63	66.25
	86-164	5.2	21	0.95	3	4.24	4.59	0.38	0.57	0.02	14.70	66.53
JG3	0-16	5.4	28	0.80	14	7.08	1.00	0.10	0.39	0.06	12.95	66.18
	16-104	5.1	25	0.70	14	4.12	2.29	0.36	0.22	0.02	10.52	66.44
	104-139	5.8	24	0.60	11	6.48	4.02	0.10	0.30	0.03	16.40	66.46
	139+	5.4	16	1.25	35	7.68	2.20	0.38	0.39	0.01	15.99	66.60

*OC= organic carbon; TN=total nitrogen; Av.P= available phosphorus; Exch. Acid. = exchangeable acidity; CEC=cation exchange capacity; BS=base saturation

C. Classification of Soils

The soils on the three landscape positions represented by pedons JG1, JG2 and JG3 were classified [16] and correlated [11]. The JG1, JG2 and JG3 all have cambic horizons and hence classified at order level as Inceptisols. The ustic moisture regime qualified JG1 as Ustepts at suborder level and absence of other diagnostic properties placed it as Haplustepts at Great group level and Typic Haplustepts at Sub-group level under USDA Soil Taxonomy and which correlated Haplic Cambisols (Eutric) under WRB classification system.

Whereas, JG2 was classified as Aquepts at Sub-order level due to presence an aquic moisture conditions which do prevails for some time in normal years. At Great group level JG2 fitted into Petraquepts because of the occurrence within 100cm of the mineral soil surface a plinthite horizon which forms a continuous phase, and at Subgroup level as Plinthic Petraquepts which correlated with Petric Plinthosols (Abruptic).

Also, JG3 was classified as Aquepts at Sub-order level due to presence in a layer at a depth between 40 and 50cm from the mineral soil surface an aquic moisture conditions for some time in normal years (or artificial drainage). It was further classified at Great group level as Endoaquepts due to endosaturation and Typic Endoaquepts at sub-group level which correlated with Endogleyic Cambisols (Endoclayic).

IV. Conclusion

The subsurface horizons of the soils studied were imperfectly drained due to occurrence of indurated (petroplinthite) layer especially in JG2 and influence of water-table in JG3. Their poor internal drainage properties may affect choice of deep rooted crops except measures to correct drainage problem are introduced. Cultural practices that would prevent erosion are essential, especially at JG2 in order not to expose the plinthite layer. It is important to monitor pH of JG1 and JG3 to avoid fixing of phosphorus which at the time of this study was adequate for arable crops production. Further decrease in pH value of these soils may accelerate iron solubility/ activity which may advance the plinthization in JG1 and JG2. Thus, measures suggested include maintaining high organic matter level in the soil to improve the structure of soils. High CEC status made the soils potentially good agricultural land for arable and tree crops production.

Appendix 1

Critical Limits for Interpreting Fertility Levels of Analytical Parameters for Nigeria Soils

Parameter	Low	Medium	High	Source
Ca^{2+} (cmol kg^{-1})	< 2	2 – 5	> 5	[14]
Mg^{2+} (cmol kg^{-1})	< 0.3	0.3 – 1	> 1	”
K^{+} (cmol kg^{-1})	< 0.15	0.15 – 0.3	> 0.3	”
Na^{+} (cmol kg^{-1})	< 0.1	0.1 – 0.3	> 0.3	”
CEC (cmol kg^{-1})	< 6	6 – 12	> 12	”
Org. C (g kg^{-1})	< 10	10 – 15	> 15	”
Avail. P (mg kg^{-1})	< 10	10 – 20	> 20	”
B.S (%)	< 50	50 – 80	> 80	”
pH:				
Strongly Acid -	5.0 – 5.5			[15]
Moderately Acid -	5.6 – 6.0			”
Slightly Acid -	6.1 – 6.5			”
Neutral -	6.6 – 7.2			”
Slightly Alkaline -	7.3 – 7.8			”

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