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Properties, classification, genesis and agricultural suitability of soils in a semiarid pediplain of North Cameroon

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The aim of the study was to determine the morphological and physicochemical characteristics, classification, genesis and suitability of soils developed on pediplain around granitic hills in Minawao in the Far North region of Cameroon. The studied soil profile had 450 cm thick. It is composed of two subsections formed by erosion and cumulization. The upper subsection classified as typic ustifluvents clayey isohyperthermic is characterized by the high content of coarse elements showing stratifications in some part of the horizons. It recovers the below subsection classified as thapto typic haplustalfs clayey isohyperthermic. They are clayey, with clay contents ranging from 45 to 49%, and slightly acidic. Total nitrogen and organic carbon contents are very low ranging respectively from 0.05 to 0.11 and 0.25 to 0.63. Available phosphorous contents are below critical level. Calcium and Magnesium dominate the exchange complex of these soils. Their values range respectively from 12.96 to 15.04 cmol (+)/kg and 3.52 to 6.56 cmol (+)/kg. The CEC values are high, ranging from 44.64 to 57.84 cmol(+)/kg of soil. The CEC clay range from 89.92 to 117.02 cmol(+)/kg of clay. Base saturation percentage values are low, ranging from 37.05 to 42%, corresponding to a mean value of 39.74%. The studied soils are globally subjected to problems of low organic matter content, high coarse material content and low pH for the cultivation of *Sorghum*, *Cotton*, *Soya*, *Groundnut, Maize* and *Cowpea*. These problems could be solved through introduction of DMC systems, addition of available organic substrates, restoration of the cation balance and liming.

Key words: Soils, properties, genesis, suitability, North Cameroon.

INTRODUCTION

Arid and semiarid zones cover approximately 40% of the land surface, with a continuous increase in the area by desertification processes, induced mainly by human activities and/or climatic change (Moshki and Lamersdorf,

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2011; Vásquez-Méndez et al., 2011). The detachment of particles of soil, surficial sediments and rocks, is caused by raindrops and runoff, hydrological processes of sheet erosion, rill and gully erosion, and through mass wasting and wind action (Kim and Gilley, 2008; Vásquez-Méndez et al., 2011). In arid and semiarid areas, soils with little or no vegetation cover are exposed to torrential precipitation events, characterized by short durations and high intensities, and are prompt to the occurrence of physical and chemical processes that change the surface layer conditions (Vásquez-Méndez et al., 2011). Surface cover associated with vegetation and rocks is known to have an important influence on the generation of sediment in semiarid landscapes (Nearing et al., 2005; Bautista et al., 2007). It is well documented that soils of arid and semiarid zones are very susceptible to water erosion (Cornelis, 2006) mostly due to a scanty vegetation cover, low organic matter content and the little resistance to the erosion forces (Nearing et al., 2005; Vásquez-Méndez et al., 2011). Slope gradient is generally considered to be a factor that influences soil erosion in most environments (Wischmeier and Smith, 1978) along with wind speed, soil cover, and rainfall force. Erosion and salinity continues to be a primary cause of soil degradation throughout the world, and has become an issue of significant and severe societal and environmental concern (Wei et al., 2007; Vásquez-Méndez et al., 2011). About 80% of the world´s agricultural land suffers moderate to severe erosion, and 10% suffers slight to moderate erosion (Pimentel et al., 1995). Erosion by water and wind adversely affects soil quality and productivity by reducing infiltration rates, water-holding capacity, nutrients, infiltration rates, organic matter, soil biota and soil depth (Vásquez-Méndez et al., 2011; Li et al., 2014; Padidar et al., 2016). Cameroon is also experiencing significant problems with land degradation and declining soil fertility due to soil erosion (Boli, 1996). Farmers have responded to pressures of feeding a growing population by clearing new land (Markham and Fonjong, 2015). They have also reacted to the diminished availability of new land by abandoning traditional practices of crop rotation and leaving fields fallow (Tsozué et al., 2015). There are also problems with soil erosion and droping water tables resulting from overgrazing and poor agricultural practices (Boli, 1996; Markham and Fonjong, 2015). In the Far North region of Cameroon, high population pressure, poor soil management practices, tree cutting for firewood, and overgrazing, combined with climate change factors and recurrent and more extended droughts, are resulting in desertification (Tsozué et al., 2015; Markham and Fonjong, 2015). Facing problem of land degradation, all land formerly devoted to cattle rearing are now cultivated, even soils developed on pediplain or sheet-flood glacis (Tricart and Cailleux, 1969) around granitic hills or inselbergs, naturally sandy and infertile. In this work, three questions specifically addressed. Firstly, what are morphological and physicochemical characteristics of soils developed on pediplain around granitic hills in Minawao in the Far North region of Cameroon? Secondly, to which group of soil do they belong? Third, are they really suitable for the growth of *Sorghum*, *Cotton*, *Soya, Maize, Groundnut* and *Cowpea* which are crops generally cultivated in the area since typical soils of arid and semiarid environment are poor in fertility according to Vásquez-Méndez et al. (2011)? According to The United Nations Refugee Agency, Minawao area shelters fifty six thousand, eight hundred and thirty-eight (56838) Nigerian refugees in May 2016 who leave their country due to "Boko Haram" exactions. Their presence and activities greatly affect the behaviour of few habitants of this area and might create food insecurity in the near future.

MATERIALS AND METHODS

The study was carried out in Minawao in the Mayo Tsanaga Division (Far North region of Cameroon) (Figure 1). The studied site was located in a pediplain devoted mainly for *Sorghum*, *Cotton*, *Soya, Maize, Groundnut* and *Cowpea* cultivation (10°35'02.9" N, 13°52'16.3 E, 581 m a.s.l.). The climate is characterized by a total annual rainfall of 1074 mm and a mean annual temperature of 26°C. The aridity index of de Martonne (1926) showed five months of rainy season from May to September (Aridity index > 20) and seven dry months (aridity index < 20) (Table 1). Natural vegetation had disappeared apart from some rare trees recalling the ancient dry forest. The relief was constituted of two geomorphological units, hills/inselbergs and pediplains. The bedrock was deformed granite characterized by an orientation of minerals, composed of quartz, feldspars and abundant biotite.

Field work consisted of direct observations, description of environmental settings and soil survey trough boreholes. Boreholes were made manually along a dense network of 20 to 50 m wide. This helped to define one major group of soil in the pediplain on the basis of some morphological profile characteristics (colour, texture, structure, coarse elements, etc) and to identify the point of implantation of a representative soil pit for detailed study. This was followed by soil description and soil sampling according to Hinsch Mikkelson et al. (2009). The main search characters were colour, thickness of horizons, coarse elements, texture, structure, porosity, consistency and boundaries between horizons. After collection, soil samples were packaged in plastic bags, labelled and sent to the laboratory for soil analyses in the University of Dschang. In the laboratory, bulk soil samples were air-dried at room temperature and then sieved (2 mm) to discard coarse fragments. Analyses were carried out on the fine fraction, and include particle size distribution, pH, exchangeable bases, cation exchange capacity (CEC) at pH 7, organic carbon, total nitrogen and available phosphorus. For soil texture analysis, soil organic matter and carbonates were removed with hydrogen peroxide (30%) and diluted hydrochloric acid (10%), respectively. Then, soil samples were dispersed with sodium hexametaphosphate and particle size distribution was analysed by the Robinson's pipette method. Soil pH was measured potentiometrically in a 1:2.5 soil: solution ratio. Exchangeable bases and CEC were determined using atomic absorption spectrophotometry in a solution of ammonium acetate at pH 7. Total nitrogen was obtained after heat treatment of each sample in a mixture of concentrated sulfuric acid and salicylic acid. The mineralization was accelerated by a catalyst consisting of iron sulphate, selenium and potassium sulphate. The mineralization was

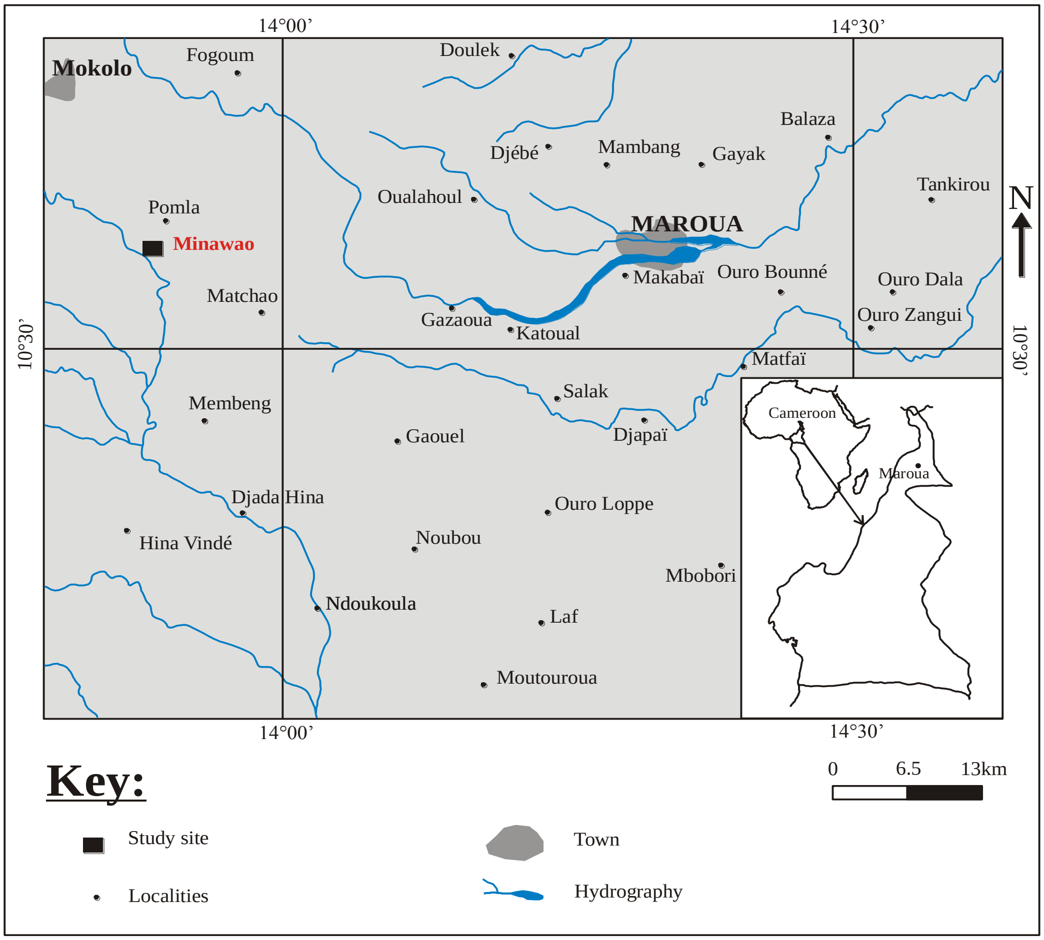

Figure 1. Location of the study site.

Table 1. Total annual rainfall, mean annual air temperature and Aridity index of De Martonne (1926).

Months	J	F	M	A	M	J	J	A	S	O	N	D	Total
Precipitations	0	0	0	28.9	80.8	118.4	259.4	335.1	198.1	51.5	2.6	0	1074.8 mm
Temperatures	22.7	21.8	29.24	31.05	28.64	26.81	24.98	24.25	25.38	26.36	26.71	24.19	/
Aridity index	0	0	0	8.44	25.1	38.6	88.98	117.4	67.2	16.99	0	0	/

followed by distillation via conversion of nitrogen into steam in the form of ammonia (NH_3), after alkalinisation of mineralized extract with NaOH. The distillate was fixed in boric acid (H_3BO_3) and then titrated with sulfuric acid or diluted hydrochloric acid (0.01 N). Organic carbon was determined by the Walkley–Black method (Walkley and Black, 1934). Soil organic matter (OM) content was obtained by multiplying soil organic carbon content by 1.724 (Walkley and Black, 1934). Available phosphorus was determined by Bray 2 method (Bray and Kurtz, 1945). In order to see if the studied soils were really suitable for *Sorghum*, *Cotton*, *Soya, Maize, Groundnut* and *Cowpea*, main crops cultivated in the area, soils were evaluated following the method of Sys et al. (1991a, b, 1993). Soils' suitability for *Sorghum*, *Cotton*, *Soya, Maize, groundnut* and *Cowpea* were classified as being highly suitable (S1), moderately suitable (S2), marginally suitable (S3), actually not, but potentially suitable (N1) and actually and potentially not suitable (N2), using simple limitation and parametric methods. The mean annual soil temperature (MAST) was calculated according to the following equation: MAST= 6.84 + (0.925*MAAT) - (0.0031*Precipitations) (Bai, 2009). In this equation, MAAT is the mean annual air temperature. The studied soils were classified according to Soil Survey Staff (2010). The data collected were analysed using descriptive statistics with XLSTAT 2008.6.03. Pearson correlation analysis was used to determine the relationship between soil parameters.

RESULTS

Morphology of soils

The studied soil profile was 450 cm thick (Figure 2). From the surface to the bottom of the profile, four horizons

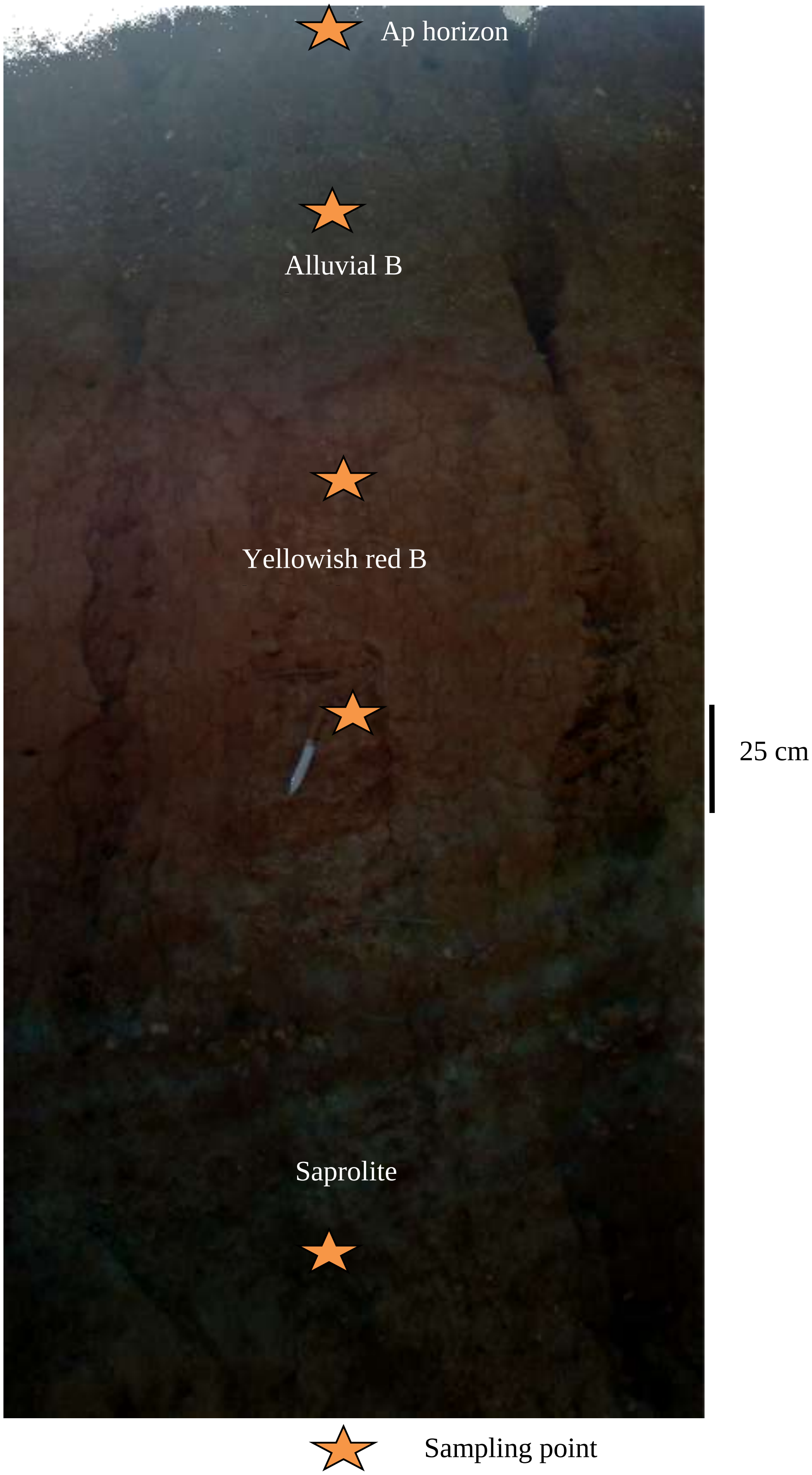

Figure 2. Typical profile of the semi-arid pediplain of Northern Cameroon.

Table 2. Physicochemical characteristics of soils.

Horizons	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Textural class	pH_{H2O}	pH_{KCl}	N (%)	OC (%)	OM (%)	C/N	Avail. P (mg/kg)	Ca^{2+}	Mg^{2+}	K^+	Na^+	S	CEC	CEC Clay	S/CEC (%)
													cmol(+)/kg							
Humiferous surface horizon	0-30	39	14	47	Clay	5.8	5.4	0.11	0.36	0.63	3.35	4.24	12.96	4.16	0.42	0.65	18.19	48.88	102.47	37.21
Alluvial B horizon	30-160	37	18	45	Clay	5.8	5.1	0.08	0.22	0.38	2.83	4.64	15.04	6.56	1.14	0.65	23.39	55.68	122.76	42.01
Yellowish red B horizon	160-240	19	32	49	Clay	5.7	4.8	0.07	0.15	0.25	2.21	2.40	12.96	6.24	0.78	0.65	20.63	49.28	99.96	41.86
	240-300	19	32	49	Clay	6.1	4.9	0.09	0.25	0.44	2.69	4.92	14.56	5.44	0.78	0.65	21.43	57.84	117.02	37.05
Saprolite	300-450	29	22	49	Clay	6.4	5.1	0.05	0.29	0.50	5.54	5.15	13.76	3.52	0.42	0.43	18.13	44.64	89.92	40.61

were distinguished and presented as follow:

Humiferous surface (Ap) horizon (0-30 cm): The colour was dark olive brown (2.5Y3/3) when dry. The horizon was characterized by a clayey texture (fine earth), poorly developed lumpy structure; the consistence is slightly hard when dry and non sticky and non plastic when wet; coarse elements are abundant (50%), irregularly shape with various sizes and composed mainly of quartz and feldspars particles; rootlets are rare; the boundary is irregular and gradual;

Alluvial (B) horizon (30-160 cm): The colour was dark brown (10YR3/3) when dry. The horizon was characterized by a clayey texture (fine earth), a particulate structure; the consistency was slightly hard when dry, non sticky and non plastic when wet; coarse elements were dominant (>80 %), irregularly shape, with various sizes and composed mainly of quartz and feldspars, showing stratification in some part of the horizon; there were very few rootlets; the boundary was regular and abrupt;

Yellowish red (B) horizon (160-300 cm): The colour was brownish yellow (10YR6/6) when dry. The horizon was characterized by a clayey texture, a very fine blocky structure; the consistency was hard when dry, and sticky and plastic when wet; coarse elements were very few to few, irregularly shape, with various sizes; dark brown typic coatings were observed on the walls of some voids; the boundary was regular and gradual;

Saprolite (300-450 cm): It was light olive brown (2.5Y5/4) when dry, with a clayey texture (fine earth) and a granular structure; the consistency was hard when dry, slightly sticky and slightly plastic when wet; coarse elements were very few to few, irregularly shape, with various sizes, composed mainly of quartz and feldspars; there was a quartz vein in the upper part of the horizon, containing angular to subangular fragments of quartz of various sizes.

Physicochemical characteristics of soils

Textural classes of the studied soil were clay. Clay contents ranged from 45 to 49% (Table 2). They were very slightly variable along the soil profile (CV= 3.3%), characterized by negative skewness and kurtosis (Table 3). This soil fraction was followed by sand, whose contents ranged from 19 to 39%. Sand contents were moderately variable (CV=29.8%), characterized by negative skewness and kurtosis (Table 3). They are most represented in the upper part of the soil profile (Table 2). Silt contents on contrary, were the lowest. They ranged from 14 to 32%, with a mean value of 23.6% (Tables 2 and 3). They were moderately variable (CV= 31%), characterized by positive skewness and negative kurtosis (Table 3). There was a significant negative correlation between sand and silt ($r=-0.99$, $p<0.05$) (Table 4), confirming the opposite evolution of their contents with depth (Figure 3).

Soil pH was slightly acid and very slightly variable (CV=4.3%). It ranged from 5.7 to 6.4, with a mean value of 5.96 (Tables 2 and 3). No significant correlation existed between soil pH and other soil parameters.

Total nitrogen and organic carbon contents were very low ranging respectively from 0.05 to 0.11 and 0.25 to 0.63 (Tables 2 and 3). Their contents were moderately variable along the soil profile (15<CV<35) (Table 3). C/N ratios were low. They ranged from 2.21 to 5.54 and were high variable along the soil profile (CV=35.10%) (Tables 2 and 3). Available phosphorous contents were below critical level. They ranged between 2.40 and 5.15 mg/kg (Tables 2 and 3). No significant correlation was noted, except a significant negative correlation between C/N and Na^+ ($r=-0.95$, $p<0.05$) (Table 4).

Table 3. Summary statistic of soil properties.

Soil properties	Minimum	Maximum	Mean	CV	SD	Skewness	Kurtosis
Sand (%)	19.000	39.000	28.600	0.298	8.523	-0.017	-1.724
Silt (%)	14.000	32.000	23.600	0.310	7.316	0.062	-1.639
Clay (%)	45.000	49.000	47.800	0.033	1.577	-0.844	-0.922
pH_{H2O}	5.700	6.400	5.960	0.043	0.256	0.727	-1.016
N (%)	0.050	0.110	0.080	0.250	0.02	0.000	-0.950
OC (%)	0.150	0.360	0.254	0.276	0.070	0.043	-0.952
C/N	2.210	5.540	3.324	0.351	1.167	1.151	-0.201
Avail. P (mg/kg)	2.400	5.150	4.270	0.230	0.982	-1.165	-0.210
Ca^{2+} (cmol (+)/kg)	12.960	15.040	13.856	0.060	0.831	0.193	-1.581
Mg^{2+} (cmol (+)/kg)	3.520	6.560	5.184	0.226	1.171	0.233	-1.568
K^{+} (cmol (+)/kg)	0.420	1.140	0.708	0.381	0.270	0.344	-1.153
Na^{+} (cmol (+)/kg)	0.430	0.650	0.606	0.145	0.088	-1.500	0.250
S (cmol (+)/kg)	18.130	23.390	20.354	0.098	1.995	0.202	-1.355
CEC (cmol (+)/kg)	44.640	57.840	51.264	0.094	4.819	0.104	-1.437
S/CEC (%)	37.050	42.010	39.748	0.055	2.186	-0.272	-1.779

Table 4. Correlation coefficient of soil properties

Soil properties	Sand	Silt	Clay	pH_{H2O}	N	OC	C/N	Avail. P	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	S	CEC	S/CEC
Sand	1														
Silt	**-0.991***	1													
Clay	-0.798	0.711	1												
pH_{H2O}	-0.153	0.076	0.466	1											
N	0.352	-0.328	-0.375	-0.543	1										
OC	0.626	-0.700	-0.136	0.341	0.443	1									
C/N	0.277	-0.369	0.206	0.833	-0.522	0.533	1								
Avail. P	0.355	-0.374	-0.181	0.719	-0.021	0.604	0.600	1							
Ca^{2+}	0.068	0.017	-0.439	0.225	-0.095	-0.165	-0.055	0.610	1						
Mg^{2+}	-0.247	0.368	-0.368	-0.679	0.095	-0.793	-0.837	-0.474	0.394	1					
K^{+}	-0.075	0.205	-0.535	-0.456	0.000	-0.672	-0.627	-0.131	0.694	**0.925***	1				
Na^{+}	-0.023	0.109	-0.375	-0.854	0.750	-0.257	**-0.950***	-0.448	0.057	0.709	0.535	1			
S	-0.127	0.255	-0.488	-0.402	0.049	-0.635	-0.640	-0.059	0.745	**0.906***	**0.990***	0.555	1		
CEC	-0.168	0.269	-0.334	-0.290	0.441	-0.273	-0.672	0.163	0.713	0.676	0.744	0.687	0.824	1	
S/CEC	-0.015	0.067	-0.226	-0.178	-0.685	-0.682	0.007	-0.374	0.117	0.452	0.480	-0.197	0.370	-0.219	1

* Significant at $p<0.05$

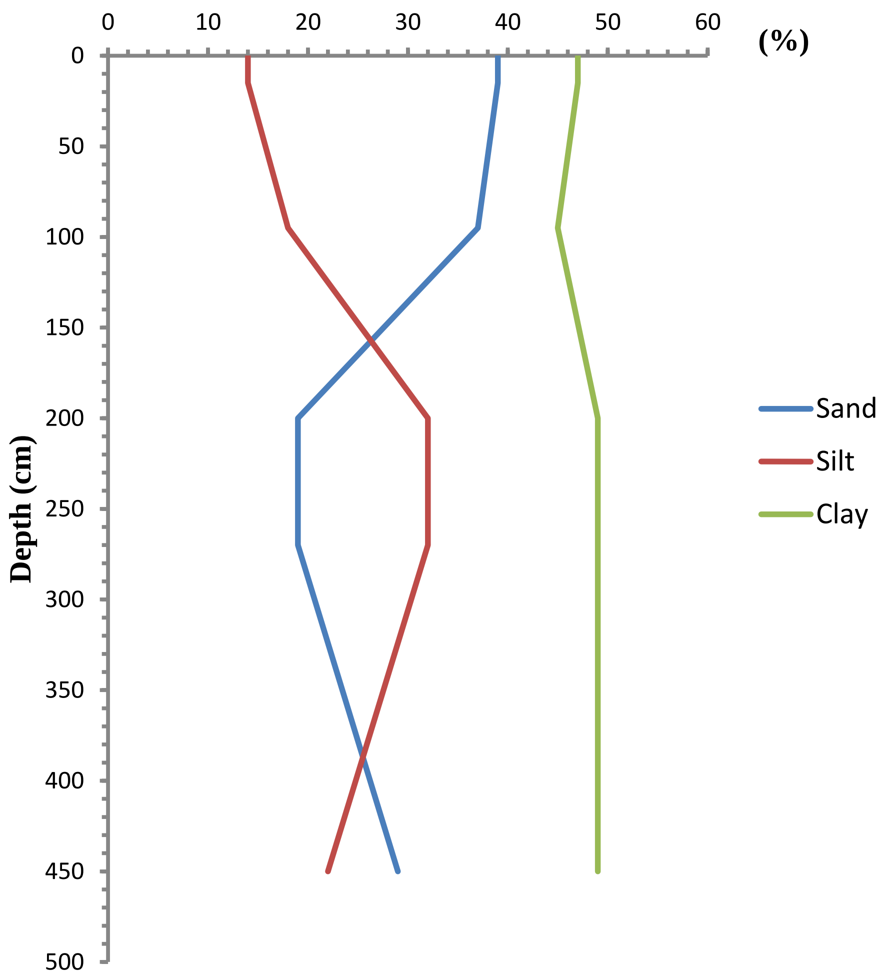

Figure 3. Distribution of soil particle size distribution fractions with depth.

Calcium and Magnesium dominate the exchange complex of these soils. Their values ranged respectively from 12.96 to 15.04 cmol(+)/kg and 3.52 to 6.56 cmol(+)/kg corresponding respectively to mean values of 13.85 cmol(+)/kg and 5.18 cmol(+)/kg (Tables 2 and 3).

The CEC values were high and ranged from 44.64 to 57.84 cmol(+)/kg of soil (Table 2). The CEC clay ranged from 89.92 to 117.02 cmol(+)/kg of clay (Table 2). Base saturation percentage values were low, ranging from 37.05 to 42%, corresponding to a mean value of 39.74% (Table 3). They were very slightly variable and showed a negative skewness and kurtosis (Table 3). Except the significant positive correlation between Mg^{2+} and K^{+} ($r=0.92$, $p<0.05$) and S ($r=0.90$, $p<0.05$) and between K^{+} and S ($r=0.99$, $p<0.05$), no significant correlation was noted on the exchange complex (Table 4).

Soil classification

The studied soil profile was composed of two subsections (Figure 2). The upper part was characterized by dominance of mineral soil materials (160 cm) and absence of distinct pedogenic horizons. Coarse elements were dominant (50-80 %), irregularly shape, with various sizes and composed mainly of quartz and feldspars, without any structural organization, globally characteristic of alluvial materials. These characteristics observed in the upper part of the soil profile were those of the Entisols order and fluvent suborder (Soil Survey Staff, 2010). These soils remain dry for more than 90 cumulative days but less than 180 days according to the aridity index (Table 1), characteristic of ustic moisture regime. This permitted to classify them in ustifluvents great group and typical ustifluvents subgroup. Although the coarse material was very abundant, the fine earth which composed the soil was clayey and the mean annual soil temperature > 22°C, allowing to classify the studied soil as clayey isohyperthermic family. The upper subsection of the studied soil is thus a typic ustifluvents clayey isohyperthermic.

This upper classified part of the soils overlaid an ancient soil developed on granite, from which it was separated by a regular and abrupt boundary. This ancient soil was constituted of yellowish red B horizon and saprolite. The B horizon showed dark brown typic coatings which represented marks of translocation processes of silicate clays, characteristic of argillic B horizons. There was globally high supply of bases in this part of the soil, with base saturation greater than 35%. This ancient soil composed solely of a saprolite and a B horizon was classified as an Alfisols. These soils experienced drought for more than 90 cumulative days but less than 180 days according to the aridity index (Table 1), characteristic of ustic moisture regime. This permitted to classify this part of the soil profile in ustalfs suborder and haplustalfs great group. The fact that this part of the soil profile was buried permitted to classify it as thapto typic haplustalfs subgroup. The texture was clayey and the mean annual soil temperature was higher than 22°C, leading to the classification of this part of the soil in the clayey isohyperthermic family. The coated soil was thus a thapto typic haplustalfs clayey isohyperthermic.

Suitability of the studied soil for sorghum, cotton, soya, maize, groundnut and cowpea cultivation

Sorghum, Cotton, Soya, Maize, Groundnut and *Cowpea* were main crops widely cultivated in the study area. Their high yields might permit to find solutions against food insecurity created by the installation of Nigerian refugees (56838 refugees) in this area. The studied soil were chemically fertile, but deficient in nitrogen, organic carbon and available phosphorous. Their contents were below the critical levels given by Tabi et al. (2013) and Euroconsult (1989).

On the climate characteristics view point, the mean temperature of the study area was highly suitable (S1) for the development of the six chosen crops. Precipitations were highly suitable (S1) for *Cotton*, *Soya*, *Maize* and *Groundnut*, but moderately suitable (S2) for *Sorghum* and *Cowpea*. Topography and wetness were highly suitable (S1) for the crops growth. On physical soil characteristics view point, texture/structure and soil depth were highly suitable for crop growth. Coarse fragments on contrary constituted a handicap. The studied soils were marginally suitable (S3) for *Sorghum*, *Cotton*, *Soya*, *Maize* and *Cowpea*, but actually and potentially not suitable (N2) for the production of *Groundnut* (Table 5). On soil fertility view point, the studied soils were highly suitable due to apparent CEC and base saturation, except for *Cotton* where soils were moderately suitable for their growth due to base saturation. Soil pH was highly suitable for *Sorghum*, *Soya*, *Maize* and *groundnut*, but moderately suitable for *Cowpea* and marginally suitable for *Cotton*. Organic carbon content might constitute a handicap for the production of all the chosen crops. It was moderately suitable for *Sorghum* and *Cotton* growth but marginally suitable for the four others (Table 5). On the salinity view point, the studied soils were highly suitable (S1) for the selected crops growth.

Globally, the studied soil was moderately suitable for *Sorghum*, *Cotton*, and *Cowpea* due respectively to low organic content, low organic content and base saturation, soil pH and precipitations during crop cycle (Table 5). It was marginally suitable for *Cotton*, *Soya* and *Maize* due to low organic carbon content and high coarse fragments, but marginally suitable for *Sorghum* and *Groundnut* due only for coarse fragments and low organic carbon content respectively. This soil was permanently not suitable for *Groundnut* due to high coarse fragments content (Table 5).

DISCUSSION

Morphological and physicochemical properties

The studied soil was morphologically characterized by two subsections. The first subsection on top showed stratifications which characterize poorly develop soils (Bourgeon, 1989), classified as typic ustifluvents. It overlaid the second subsection of the profile which was classified as thapto typic haplustalfs. This soil morphology is frequently observed in semi-arid pediplains (Bourgeon, 1989). The Ap horizon had high sand content (39%), high quantity of coarse fragments (>50%), average clay content and weak lumpy structure. These properties make the soil very vulnerable to erosion as much as the fragments are easily detached under the impact of rain-drops or running water (Kim and Gilley, 2008; Fasina et al., 2015). The particles tend to lie in close contact due to low contents of bridging materials like organic matter. The land on which most of the soils are situated should not be mechanically cleared as it is done now because this exposes the structurally imbalanced subsoil to erosion, leaching, degradation and compaction (Vásquez-Méndez et al., 2011; Fasina et al., 2015). Soil with higher clay particle content has more stable aggregates against wind erosion (Chen, 1991).

The low organic carbon content of the studied soil might be due to continuous cultivation and frequent burning of farm residues. It might also be due to the effect of high temperature and relative humidity which favour rapid mineralization of organic matter (Fasina et al., 2006; Van Leeuwen et al., 2015). The soils with low organic matter content are prone to wind erosion during the dry and windy fallow period (He et al., 2008). The studied soils have good levels of exchangeable bases, but nitrogen, phosphorous and organic contents are below the critical level. These low contents are due to the absence of vegetation, consequence of competition between farmers and breeders for much (Dongmo et al., 2007). In fact, soils under tree canopies in semiarid

Table 5. Land suitability evaluation of different studied soils for *Sorghum*, *Cotton, Soya, Maize, groundnut* and *Cowpea* using simple limitation and parametric methods.

Land, soil and climate characteristics	Sorghum	Cotton	Soya	Maize	Groundnut	Cowpea
Climate (c)						
Precipitation during crop cycle (mm)	S2	S1-0	S1-1	S1-1	S1-1	S2
Mean temperature during crop cycle (°C)	S1-0	S1-1	S1-1	S1-0	S1-0	S1-0
Topography (t)						
Slope (%)	S1-1	S1-1	S1-1	S1-1	S1-1	S1-1
Wetness (w)						
Flooding	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0
Drainage	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0
Physical soil characteristics (s)						
Texture /Structure	S1-0	S1-0	S1-0	S1-0	S1-1	S1-0
Coarse fragment (vol %)	S3	S3	S3	S3	N2	S3
Soil depth (cm)	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0
Soil fertility characteristics (f)						
Apparent CEC (cmol (+) kg^{-1} clay)	S1-0	S1-0	S1-0	S1-0	S1-0	S1-0
Base saturation (%)	S1-1	S2	S1-1	S1-1	S1-1	S1-1
pH_{H2O}	S1-1	S3	S1-1	S1-1	S-1-1	S2
Organic carbon (%)	S2	S2	S3	S3	S3	S3
Salinity (n)						
ESP (%)	S1-0	S1-0	S1-0	S-0	S1-0	S1-0
Suitability	S2cfS3s	S2fS3sf	S3sf	S3sf	S3fN2s	S2cfS3sf

environments are often more fertile than soils from the surrounding grasslands. Quantities of mineralizable nitrogen, phosphorous, potassium, calcium, organic matter, and the microbial biomass, are significantly higher in soils beneath the canopy than in the open area (Belsky et al., 1989; Vásquez-Méndez et al., 2011).

Soil genesis

Within most landscapes, there is movement of material from one soil to adjacent soils. Movement can take place both on the soil surface and beneath the surface (Buol et al., 2011). The upper subsection of the studied soil is the result of surficial erosion which corresponds to lateral removal of material from the surface of soil by raindrop splash and runoff waters. It also corresponds to transfer of material from hillslope to lower parts of the slope and the accumulation of mineral material by water on the surface of the soil. This accumulation, also called cumulization or accretion, may be considered as geogenic rather than a pedogenic process (Buol et al., 2011). It is well recognized through stratification noted in the upper subsection. Those characteristics, lead to the classification of this upper part of the studied soil in the Entisols order. Erosion and cumulization, commonly recognized as paired processes, are associated in the landscape of the study area. The major factors determining soil genesis, classification, morphological properties, and account of diagnostics horizons in this area appear to be the result of the topography causing erosion rather than climate and the nature of parent material affected by leaching regime and weathering rates (Ozaytekin and Uzun, 2012).

The below subsection classified as thapto typic haplustalfs may be an ancient weathering profile. This soil was formed under more humid climate different from the semi-arid climate which prevailed now in the studied area. This ancient climate leads to the differentiation of a thick soil profile (thickness > 3 m) with a yellowish brown clayey B horizon of 140 cm thick. The absence of an A horizon between the two subsections might be due to the fact that the upper part of the ancient soil profile was removed by erosion process which stops when climatic conditions change into others, favourable to cumulization process. It might also be due to the fact that the slope was eroded until the slope gradient and runoff slowdown, allowing much of the sediment in the runoff from the hillslopes to deposit (Nearing et al., 2005). This leads to peneplanation process which affected all the studied area leading to the formation of the upper part of the studied soils.

Soil suitability

For the cultivation of *Sorghum*, *Cotton*, *Soya*, *Groundnut, Maize* and *Cowpea*, the studied soils are globally subjected to problems of low organic matter content, high coarse material content and low pH for groundnut growth. The low organic matter content has to be substantially increased through effective crop residue management with increased use of leguminous plants as well as judicious use of organic fertilizers (Fasina et al., 2015). It might also been increased trough the introduction of direct-seeding mulch-based cropping (DMC) systems (Brown et al., 2002; Ndah et al., 2015, Tsozué et al., 2015). Soil organic matter was an essential component of soil quality, governing processes like carbon sequestration, nutrient cycling, water retention and soil aggregate turnover (Tsozué et al., 2015; Van Leeuwen et al., 2015). Addition of available organic substrates would promote the growth and activity of indigenous microorganisms (García-Orenes et al., 2010). The accumulation of biomass on the soil surface in the DMC systems, while increasing soil biological activity, intensified the mineralization process of OM, leading thus to rapid mineralization of soil OM, which would therefore improve soil structure (García-Orenes et al., 2009; Costa et al., 2015; Tsozué et al., 2015) and plant nutrition (Chabanne et al., 2001; Séguy et al., 2001). Postharvest incorporation of plant residue into the soil instead of the usual burning of crop residue to stimulate the emergence of new flushes for grazing will stabilize the soil aggregates (Fasina et al., 2015). The problem of acidic pH could be solved by restoration of the cation balance through appropriate use of chemical fertilizers and liming (Verdoodt and Van Ranst, 2003; Asio et al., 2006; Fasina et al., 2015). DMC system is recommended because of the high content of coarse elements in the studied soils. The soil with high coarse elements contents must always be under cover to prevent serious erosion (Fasina et al., 2015).

Conclusion

The studied soils are very thick, characterized by clayey texture. They are slightly acid. The total nitrogen and organic carbon contents are very low and the exchange complex is dominated by calcium and magnesium. These soils are composed of two subsections: the upper subsection, largely dominated by coarse elements is classified as typic ustifluvents clayey isohyperthermic and the below one as thapto typic haplustalfs clayey isohyperthermic. The upper subsection was form by stripping of ancient soil trough erosion and accumulation of coarse elements from hillslopes by cumulization processes. The studied soils are globally subjected to problems of low organic matter content, high coarse material content and low pH for the cultivation of *Sorghum*, *Cotton*, *Soya*, *Groundnut, Maize* and *Cowpea*. These problems could be solved through introduction of DMC systems, addition of available organic substrates, restoration of the cation balance and liming.

Conflict of Interests

The authors have not declared any conflict of interests.

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