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Genesis and Classification of Soils on a Toposequence in Guelendeng, Southwest Chad

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Abstract: A study was carried out in Guelendeng in the south west of Chad with the objective to determine the main process at the origin of soil formation and to classify the soils along a toposequence. Three pedological profiles have been dug with variable depths. The three soil profiles namely G1, G2 and G3 were dug respectively, in the upslope, midslope and the footslope; samples were collected from each horizon in each of the three profiles. The collected samples were labelled and sent to laboratories for mineralogical, geochemical and physicochemical analyses. The mineralogical analysis of the collected samples allowed to highlight the dominance of primary minerals, namely quartz and feldspar. The geochemical analysis of the samples collected in the different profiles shows that SiO_2 is by far the most abundant oxide. The physicochemical analysis shows very high sand contents ranging from 72.5 to 88.00% in profile G1; from 73.5 to 76.5% in profile G2 and from 75.0 to 79.5% in profile G3. In each profile, sand contents increase with depth. The pH-water varies from 5.1 to 6.5 in profile G1; in profile G2, it varies from 5.5 to 6.6; it is from 5.4 to 5.9 in profile G3. The pH values are highest in the surface horizons and decrease with increasing depth. For each sample, the change in pH (ΔpH) is negative. The sums of exchangeable bases are low as are the exchangeable cations. The cation exchange capacities are also low as shown by the values of the exchangeable cation sums. The other nutrients, namely calcium, magnesium, organic carbon, nitrogen, available phosphorus, potassium, sodium and organic matter are also very poorly represented and the C/N values are also very low. According to the WRB, all three soils in the site are Arenosols. The colors of the different pits induce some nuances in the designations. According to the CPCS, they are *sols ferrugineux tropicaux peu ou non lessivés.* The dominant process of pedogenesis is monosiallitisation. The bad drainage due to relatively less abundant rainfall is the factor responsible for the presence of 2/1 minerals like smectite.

Keywords: Chad, Arenosols, Sols Ferrugineux, Monosiallitisation

1. Introduction

In tropical regions with contrasting seasons, the dominant pedogenetic process is ferrugination, which often leads to the formation of acid ferruginous soils, rich in iron sesquioxides [1, 2]. Other types of soils such as lateritic soils, soils with little evolution and hydromorphic soils are also regularly encountered [3, 4, 5]. In these areas, Vertisols commonly occur in depressions where external drainage is poor [1, 6]. The main minerals found in these soils are quartz, feldspar, kaolinite, illite and smectite. These minerals often dominate in the soils of arid and semi-arid zones [7, 8]. Indeed, arid and semi-arid zones cover nearly 40% of the earth's surface [9]. The abundance of quartz and feldspar in these soils reflects incomplete weathering of primary minerals [9]. It indicate the poor nutrients status of these soils and makes them highly vulnerable to water erosion and leaching [10]. The poor nutrient status of soils in these areas can also be justified by the presence of 1:1 clays (especially kaolinite) and high temperatures that promote rapid mineralization of soil organic matter [10, 11]. The presence of smectite shows poor drainage in the horizons and less chemical weathering due to low rainfall [12, 13]. 1:1 type minerals (kaolinite) and 2:1 type minerals (smectite and others) very often coexist in these soils. In order to better understand the soils of Mayo-

Lemié, this study was conducted to determine the main pedogenic processes responsible for their formation and to classify them according to the CPCS and WRB.

2. Material and Methods

2.1. Study Area

The study area is located in South-Western Chad, in the middle of the sudano-sahelian environment [14]. It extends from 10° 31' to 11°06' North and 15°00' to 16°30' East (Figure 1). The climate is characterized by a long dry season from October to May and a short rainy season, from June to September. The mean annual rainfall is about 652 mm and the average temperature is 28°C. The main activities of the population are agriculture and animal breeding. *Sorghum* is the main crop [15]. The geological formations are fluvio-lacustrine or fluvial, deposited during the various transgressive or regressive phases of the Chad Lake, from the beginning of the Quaternary era to present [16]. The dominant soils are sandy tropical ferruginous soils, poor in organic matter. The vegetation consists of a shrub savannah dominated by Acacias and Balanites, depending on the type of soil, with a grassy carpet made up of Andropogonea.

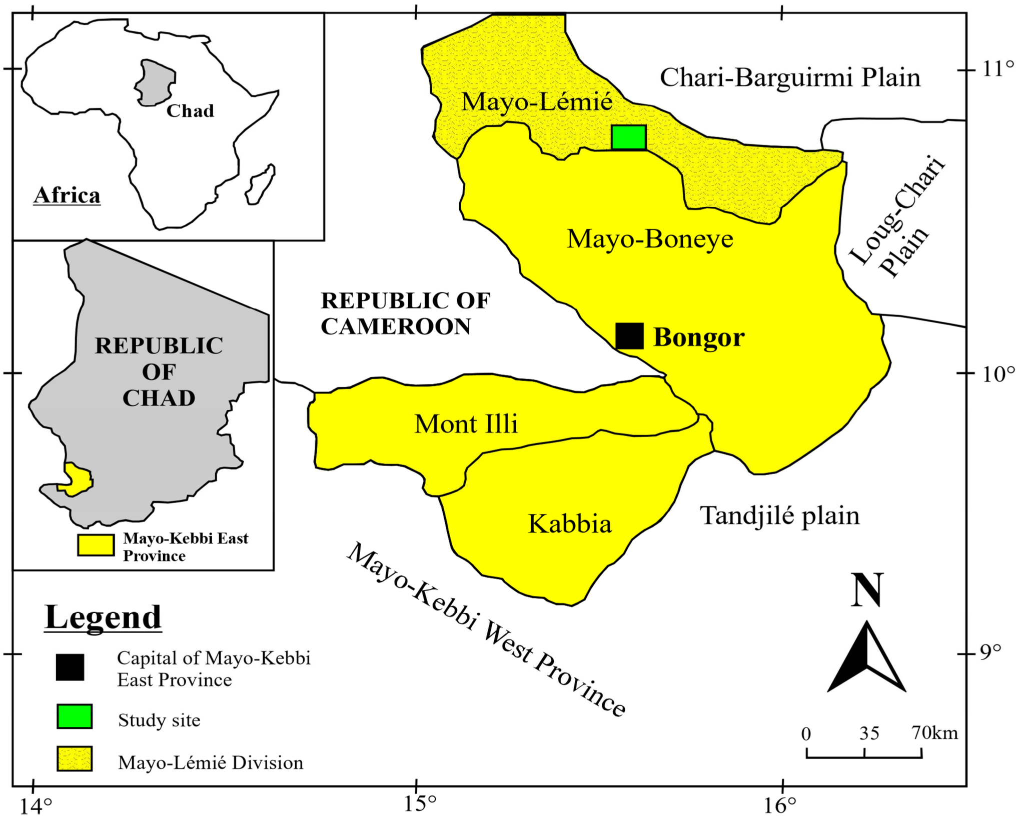


Figure 1. *Location of the study area.*

2.2. Methods

A field survey enabled to dig three soil profiles of variable depth along a toposequence. The three soil profiles namely G1, G2 and G3 were dug respectively, in the upslope, midslope and the footslope. They have been described in the field according to [17]. The characteristics considered in the description are colour, texture, consistency, structure, porosity and transition between different horizons. Samples were collected from each horizon in each of the three profiles. The collected samples were labelled and sent to laboratories for mineralogical, geochemical and physicochemical analyses. Soil colour was determined by the Munsell Colour Chart.

In the laboratory, physicochemical analyses were limited to the routine analyses. Soil samples were air-dried at room temperature and sieved (2 mm) to discard coarse fragments. The pipette method was used for particle size distribution analysis after dispersion with sodium hexametaphosphate $(NaPO_3)_6$ and organic matter destruction by hydrogen peroxide (H_2O_2). Soil pH was measured in water and KCl via pH meter equipped with a glass electrode in 1:2.5 soil-water suspensions. The soil organic carbon (OC) was determined by the wet oxidation method (Walkley and Black, 1934). The content in organic matter was calculated by multiplying the organic carbon values by the factor 1.72. The total nitrogen was measured by the Kjeldahl method. Available phosphorus was determined according to Bray II procedure. Exchangeable cations were dosed by ammonium acetate extraction method at pH 7 and Cation Exchange Capacity (CEC) was determined using the sodium saturation method.

X-ray diffraction was used to obtain total and clay fractions on both disoriented powders and oriented aggregates (measurements in 2θ range from 2° to 45° with a scan step size of 0.02° and time per step of 2s) according to the methodology of Moore Duane and Reynolds Robert (1989). Identification was done through air-drying (24 h), glycolation (22 h) and heating (500 °C for 4 h). A Bruker Advance D8 diffractometer (copper Kα1 radiations, λ = 1.5418 Å, V = 40 kV, I = 30 mA) of the Laboratory of Clays, Geochemistry and sedimentary Environment (University of Liège, Belgium) was used. Diffuse reflectance infrared spectra were recorded between 4000 and 400 cm^{-1}, using a FTIR Perkin Elmer 2000 spectrometer (Perkin Elmer, Waltam, MA, USA) equipped with deuterated triglycine sulfate (DTGS) detector. Air-dried samples were analysed at room temperature in the University of Yaoundé I using Diamond Attenuated Total Reflectance (ATR) accessories (Perkin Elmer). The spectrum resolution was 4 cm^{-1} and the accumulation time was 5 min. Geochemical analyses were obtained by atomic absorption spectroscopy. Loss on ignition (LOI) was measured from total weight after ignition at 1000˚C for 2h.

3. Results

3.1. Morphological Description of Soils

3.1.1. Morphological Description of Soils in Profile G1

Profile G1 is about 190 cm thick. It is located at an altitude of about 314 m at 10°54'631" N and 15°33'132" E. It presents from top to bottom the following succession of horizons (figure 2):

0 - 19 cm. Horizon reddish yellow (7.5YR7/8) in dry state, sandy texture, very weakly expressed polyhedral structure; friable and brittle in dry state and non-plastic in wet state; presence of numerous roots and rootlets; significant biological porosity, very strong matrix porosity. The boundary is continious and regular;

19 - 124 cm. Red colored horizon (10YR5/8) in dry state. Sub-foamed polyhedral structure, sandy-clay texture, crumbly when dry and not plastic when wet. Presence of minute roots and rootlets, low biological porosity, matrix porosity is high; the transition with the other horizon is continious and regular.

124 - 190 cm. Yellowish red horizon (5Y, 5/8) in dry state. Polyhedral structure weakly expressed; sandy-clay texture, friable when dry and not plastic when wet. Presence of tiny roots; extremely low biological porosity; high matrix porosity; presence mottles (about 5%) of millimeter size; continious and regular boundary.

190 - 200 cm. Yellowish-red horizon (7.5YR, 8/6) in dry state. Essentially sandy; absence of roots and rootlets.

3.1.2. Morphological Description of Profile G2

Profile G2 is about 170 cm thick. It is divided into four horizons (figure 2). It is located about 312 m above sea level. Its coordinates are 10°54'630"N and 15°33'07"E (Figure 2). From top to bottom it is composed of the following horizons:

0 - 30 cm. Pink colored horizon (2.5YR8/3) in dry state. Sandy texture, polyhedral structure, friable consistency when dry and not sticky when wet. Presence of roots and rootlets; high matrix porosity, medium biological porosity; irregular boundary.

30 - 95 cm. Light red horizon (10R7/8) when dry. Polyhedral structure, sandy-clay texture, friable and fragile consistency in dry state; presence of roots and rootlets; presence of roughness of indurated nature; continious and regular transition.

95 - 170 cm. Yellowish red horizon (5YR7/8) in dry state. Sandy texture; low biological porosity; low matrix porosity; presence of roots and rootlets; continious and regular transition, friable consistency in dry state and not sticky in wet state;

3.1.3. Morphological Organization of Soils in Profile G3

Profile G3 is approximately 208 cm thick at 10°54'452" N and 15°33'01" E (Figure 2). It is located at the base of the toposequence at an elevation of about 311 m. From top to bottom the horizons succeed each other as follows:

0 - 52 cm. Horizon of light gray color (7.5YR6/4) in the dry state; sandy-silt texture, very weakly expressed prismatic structure; friable and fragile in the dry state and not plastic in the wet state; presence of numerous roots and rootlets. High biological porosity; medium matrix porosity; boundary is diffuse.

52 - 118 cm. Yellow (2.5Y7/6) horizon in dry state. Polyhedral structure, sandy-silty and friable texture when dry, not plastic when wet, roots and rootlets present; friable consistency not very brittle; biological porosity not significant; matrix porosity strong; transition gradual and diffuse.

118 - 208 cm. Dry yellow (2.5Y5/8) horizon, weakly expressed polyhedral structure; sandy texture. Friable when dry and not plastic when wet. Presence of tiny roots; extremely low biological porosity; high matrix porosity.

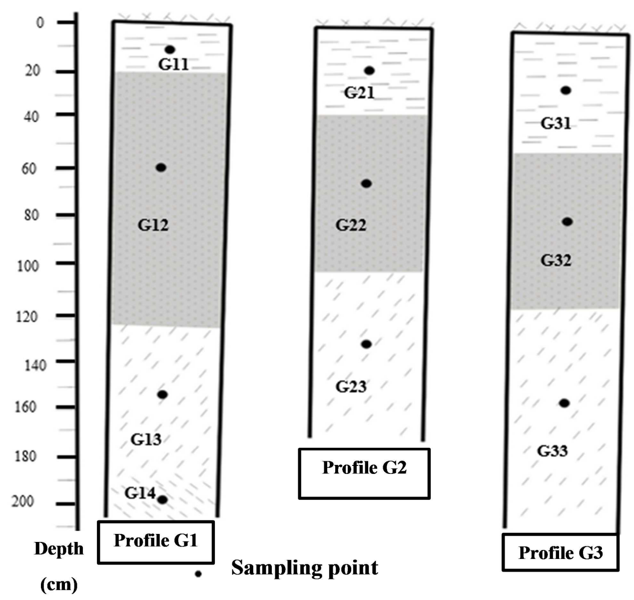


Figure 2. Morphological organisation of the studied soils.

3.2. Characterization by X-ray Diffraction

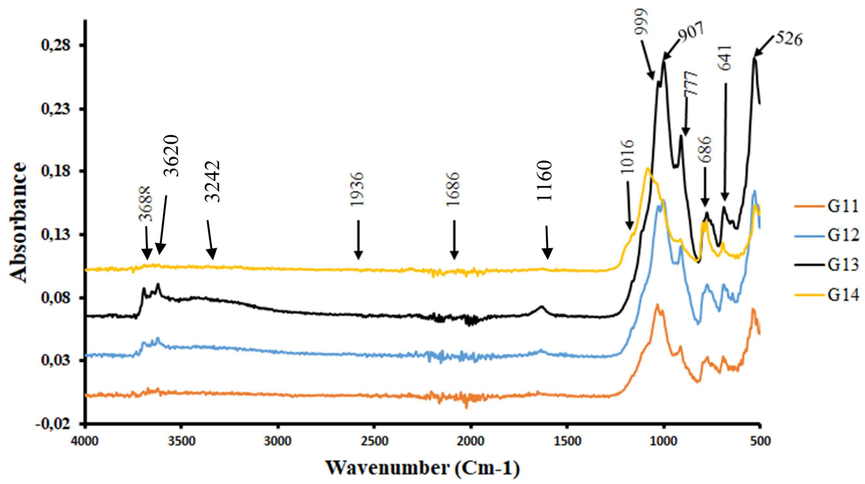
The mineralogical analysis (table 1) of the collected samples allowed to highlight the dominance of primary minerals, namely quartz and feldspar. Moreover, kaolinite, 1/1 clay type mineral is the most represented clay mineral quantitatively. In addition to kaolinite, 2/1 phyllosilicates such as smectite and 1litre are also observed. In all three profiles, the minerals encountered are the same. Several quartz peaks can be observed at: 4.25 Å; 3.34 Å; 2.45 Å; 2.28 Å; 2.24 Å; 2.12 Å and 1.98 Å. As for the other minerals, they are revealed by the following peaks: kaolinite, (d= reflection 7.07 Å); feldspar (d= reflection 3.24 Å); illite (d= reflection 10 Å).

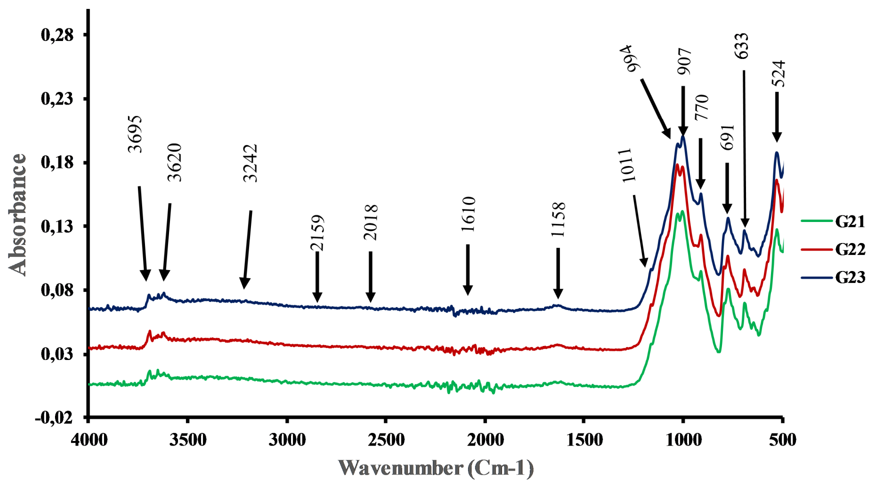
Table 1. *Mineralogical composition of the studied soils.*

Samples	Quartz %	F. K %	Plagioclase %	Micas %	Hematite %	Calcite %	Dolomite %	Kaolinite %	Illite %	Smectite %	Total %
G1-1	78,21	9,41	5,00	0,36	0,16	0,40	0,57	3,68	1,80	0,42	100
G1-2	71,93	18,87	0,00	0,00	0,13	0,40	0,38	5,18	2,53	0,59	100
G1-3	63,80	25,22	6,33	0,95	0,00	0,00	0,52	1,99	0,97	0,22	100
G2-1	52,41	31,78	4,85	0,45	0,00	6,99	0,54	1,86	0,91	0,21	100
G2-2	69,52	21,69	2,11	0,44	0,09	0,52	0,57	4,06	0,74	0,28	100
G3-1	78,73	10,47	4,79	0,40	0,00	0,24	0,00	4,29	0,78	0,29	100
G3-2	49,66	16,71	0,00	0,42	0,00	0,35	0,61	25,92	4,07	1,72	100
G3-3	79,32	7,83	1,41	0,33	0,00	2,88	0,25	6,52	1,02	0,43	100

3.3. Characterization of Minerals by Infrared Spectroscopy (IR)

The infrared spectra confirm the presence of most of the minerals revealed by mineralogical analysis (figure 3). In total, four minerals were identified. These are quartz, kaolinite, smectite and sepiolite. Quartz is identified by its peaks located at 777cm^{-1}, 1160 cm^{-1}, 999 cm^{-1} and 800 cm^{-1}. The band centered at 910 cm^{-1} reveals the presence of kaolinite. The peak 526 cm^{-1} indicates the presence of sepiolite, a mineral characteristic of dry environments. Finally, the peak observed at 1630 cm^{-1} indicates the presence of smectite, a type 2/1 mineral. Feldspar was not reported by the infrared absorption spectrum.





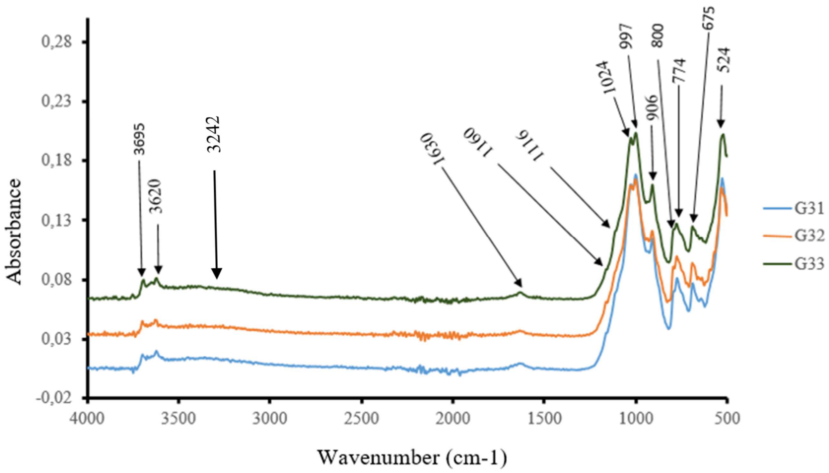


Figure 3. *Infrared spectra of the studied soils.*

3.4. Geochemical Characterization of Soils

The geochemical analysis of the samples collected in the different profiles (Table 2) shows that SiO_2 is by far the most abundant oxide. It is followed in order of importance by Al_2O_3, Fe_2O_3 and K_2O_3. The other elements on the other hand are in very negligible proportions. However, an increase in CaO content can be noted in the third horizon of profile G1. Placing the three most abundant elements in a triangle, there is an accumulation of all points towards the silicon-aluminum pole. This confirms the sandy texture described in the field and then demonstrated by the granulometry in the laboratory and the abundance of quartz mentioned by the mineralogical and geochemical analyses.

Table 2. *Chemical composition of the studied soils.*

Profile	Depth (cm)	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	K_2O %	Na_2O %	CaO %	MgO %	P_2O_5 %	SO_3 %	LOI %	Total %	$\frac{Si}{Al}$	$\frac{K2O}{Al2O3}$
G3	0-26	76.07	6.27	2.64	3.05	0.47	0.83	0.20	0.03	0.05	10.37	99.98	9.83	0.49
	26-156	58.45	7.76	5.73	4.24	1.10	9.40	0.62	0.00	0.22	10.68	98.20	6.10	0.55
	156-186	63.94	12.22	6.01	1.60	0.21	0.83	0.14	0.02	0.07	14.46	99.50	4.24	0.13
G2	0-10	79.80	7.86	3.18	2.75	0.43	0.54	0.21	0.01	0.06	4.06	98.90	8.22	0.35
	10-30	57.77	8.18	5.87	4.10	0.82	4.46	0.44	0.03	0.10	17.98	99.75	5.72	0.50
	30-75	66.37	11.65	5.33	2.70	0.53	0.72	0.35	0.02	0.06	11.31	99.05	4.61	0.23
	75-175	64.29	11.90	5.97	3.02	0.69	1.09	0.55	0.07	0.29	11.85	99.72	4.38	0.25
	175-215	74.72	8.06	4.44	2.50	0.44	0.78	0.41	0.02	0.05	7.69	99.09	7.51	0.31
G1	0-11	68.82	8.20	6.16	3.49	0.56	1.55	0.34	0.05	0.12	9.20	98.50	6.80	0.43
	11-80	54.97	15.42	8.22	2.74	0.39	0.39	0.48	0.03	0.06	16.64	99.33	2.89	0.18
	80-154	75.89	7.47	2.97	2.65	0.34	0.60	0.21	0.02	0.05	8.69	98.89	8.23	0.35
	154-205	69.43	6.72	4.72	3.03	0.62	0.50	0.31	0.00	0.09	14.02	99.45	8.38	0.49

3.5. Physicochemical Characteristics of Soils

In all three profiles, the physicochemical analysis (table 3) shows very high sand contents ranging from 72.5 to 88.00% in profile G1; from 73.5 to 76.5% in profile G2 and from 75.0 to 79.5% in profile G3. In each profile, sand contents increase with depth. The sand contents are followed quantitatively by the clay contents and then by the silt contents. The clay fraction varies from 10.5 to 21.5% in the first profile; it varies from 16.5 to 22% in the second profile and from 4.5 to 9.0% in the third profile. As for the silty fraction, the variation is from 2 to 16% in the three profiles; the highest contents are found in profile G3. The pH-water varies from 5.1 to 6.5 in profile G1; in profile G2, it varies from 5.5 to 6.6; it is from 5.4 to 5.9 in profile G3. The pH values are highest in the surface horizons and decrease with increasing depth. For each sample, the change in pH (ΔpH) is negative. The sums of exchangeable bases are low as are the exchangeable cations (Table 3). The cation exchange capacities are also low as shown by the values of the exchangeable cation sums. The other nutrients, namely calcium, magnesium, organic carbon, nitrogen, available phosphorus, potassium, sodium and organic matter are also very poorly represented and the C/N values are very low.

Table 3. *Physicochemical characteristics of the studied soils.*

Profiles	**G1**				**G2**			**G3**		
Depth (cm)	**0- 19**	**19-124**	**124-190**	**190-200**	**0- 30**	**30-95**	**95-170**	**0- 52**	**52-118**	**118-208**
Texture (%)										
Clay	10,5	18,5	21,5	10,00	19,00	16,5	22,00	9,00	6,5	4,50
Silt	5,0	4,0	6,0	02,00	7,5	7,0	3,5	16,00	15,00	16,00

Profiles	G1				G2			G3		
Depth (cm)	0- 19	19-124	124-190	190-200	0- 30	30-95	95-170	0- 52	52-118	118-208
Sand	84,5	77,5	72,5	88,00	73,5	76,5	74,5	75,0	78,5	79,5
Organic carbon (%)	2,13	2,00	1,45	1,08	1,6	0,15	0,76	1,20	0,28	0,30
Organic matter (%)	3,66	3,44	2,49	1,85	2,76	0,26	1,31	2,28	0,65	0,53
Total nitrogen (%)	0,37	0,33	0,31	0,22	0,37	0,33	0,31	0,12	0,07	0,11
C/N	5,75	6,06	4,67	4,90	0,07	0,15	0,08	10,00	4,00	2,72
pH H_2O (1/2,5)	6,5	5,7	5,1	5,1	6,6	6,5	5,5	5,9	5,7	5,4
pH KCl(1/2,5)	5,6	4,4	4,1	4,2	5,2	5,5	4,3	4,8	4,8	4,8
P Olsen (ppm)	0,5	0,5	0,5	0,5	0,4	0,5	0,4	0,34	0,19	0,30
Exchangeable bases (meq/100 g of soil)										
K^+	0,31	0,30	0,12	0,01	0,32	0,75	0,51	0,37	0,27	0,19
Na^+	0,32	0,32	0,32	0,32	0,12	0,12	0,12	0,52	0,52	0,32
Ca^{++}	2,64	2,00	1,64	1,32	4,72	3,92	4,4	4,44	3,40	4,32
Mg^{++}	1,04	1,08	1,36	0,90	1,16	1,36	1,12	1,68	1,48	1,92
Sum of bases	4,32	3,62	3,44	2,64	4,32	6,32	6,15	2,93	5,67	6,75
Base saturation (%)	37,11	16,71	25,59	20,88	37,11	29,17	45,75	16,42	26,39	38,26
CEC7 (meq/100g de sol)	11,64	21,66	13,44	12,64	11,64	21,66	13,44	17,84	21,84	17,64
CEC (meq/100g d'argile)	110,85	117,08	159,97	126,4	61,26	131,27	61,00	111,5	140,90	110,25
CE (ms/Cm)	0,016	0,01	0,01	0,02	0,016	0,01	0,01	0,01	0,01	0,01
ESP (%)	2,71	1,47	2,38	2,53	1,03	0,55	0,89	2,90	2,30	1,81

3.6. Soil Classification

3.6.1. Classification According to [18]

The study takes place in a semi-arid climate (De Martone aridity index of 17.54). The three sunken profiles are deep. The profiles are rich in SiO_2 (quartz) and are characterized by high sand content from the surface to more than 100 cm depth. There are no coarse elements (<40 vol%) in all horizons up to ≤ 100 cm from the mineral soil surface. The effective saturation rate of exchangeable bases and exchangeable aluminum are less than 50%. The characteristics listed above correspond to Arenosols according to [18]. By definition, Arenosols from the Latin word (sand) are deep, sandy soils. They include soils on residual sands from quartz-rich rocks that have undergone in situ weathering as well as soils on recent sandy sediments such as desert dunes and maritime beaches.

Base saturation of Profile G1 stands at 20.58%. The color of the surface horizon up to 10 cm is pale. There is neither a mollic horizon nor an umbric horizon. This allows the classification as Ochric. According to WRB, the final classification of G1 is an Ochric Arenosols.

The G2 profile from 30 to 95 cm depth is characterized by soil color greater than 10YR. When wet, the color is 10R 4/6. The Rubic qualifier can be applied to it. According to [18], the final name of G2 can be: Arenosols Rubic.

The G3 profile is characterized by a wet soil color (10R5/6) that is redder than 7.5YR with a chroma greater than 4. This characteristic gives it the chromic designation. Its final name according to WRB (2014) may be Arenosols Chromic.

All three soils in the Guelendeng site are Arenosols. The colors of the different pits induce some nuances in the designations.

3.6.2. Classification According to [19]

In the Guelendeng site, according to the morphological description made in the field, the three profiles present type A B C profiles. Physicochemical analyses showed low levels of organic matter in all horizons of the three profiles (table 3). These soils are located in a climate where annual rainfall varies from 600 to 1000 mm with an average of 652 mm. The average annual temperature is 27.9°C. This high temperature implies rapid mineralization of organic matter. According to the CPCS, these descriptions refer to sesquioxidic (*la classe des sols à sesquioxydes*). This class of sesquioxide (*la classe des sols à sesquioxydes)* soils includes two subclasses (*sous-classes*) in the intertropical zone, namely tropical ferruginous soils (*sols ferrugineux tropicaux*) in the Sahelo-Sudanese climate (rainfall of 900 to 500 mm/year) and ferrallitic soils (*sols ferrallitiques*) in the Sudano-Guinean climate (rainfall 900 to 1350 mm).

The tropical ferruginous soil subclass (*sols ferrugineux tropicaux*) is the one that characterizes the site soils given the amount of rainfall recorded annually. The B horizons of the three profiles have a color range between 10YR and 7.5YR according to the morphological description made in the field. The results of the mineralogical analyses show a total absence of alumina hydroxides (gibbsite, boehmite) in all three profiles (table 1). The clay fractions are represented by kaolinite, illite and smectite (montmorillonite). The Si/Al atomic ratios are well above 2. These details confirm that these soils belong to the tropical ferruginous soil subclass. Within the subclass of tropical ferruginous soils, two groups of soils can be distinguished, one with little or no leaching and the other with leaching (*sols peu ou non lessivés et les sols lessivés*).

The soils at the Guelendeng site meet the criteria for low or non-leached tropical ferruginous (*sols ferrugineux tropicaux peu ou non lessivés)* soils because they are sandy in texture (tables 3); the B horizons are darker than the A horizons; the A horizons are thinner (tables 3); clay contents are low on the surface; organic carbon contents are low; pH varies between 5 and 7 and decreases with depth; exchangeable base sums are around 3; and mineralogically, these soils are dominated by kaolinite.

Thus, according to the [19], the soils of the Guelendeng site are "*sols ferrugineux tropicaux peu ou non lessivés"*.

4. Discussion

Mineralogical, Geochemical and Physicochemical Characteristics

All the soils studied are dominated by high sand content. They are yellowish at the surface and red in the deep horizons (10YR, 5/8 to 5Y, 5/8). The red color reflects the individualization of iron sesquioxides, as indicated by many authors [19, 20]. The high sand contents suggest the effects of aeolian inputs [21]. In addition, the high sand contents could also refer to an allochthonous origin of the deposits that are at the origin of the formation of these soils and suggests that the process that prevailed during their formation is legacy [22-25]. Minerals identified by mineralogical analysis are primarily quartz, feldspar, kaolinite, illite, smectite, sepiolite, lepidocrosite, and some traces of anatase. The mineralogy observed is similar to that described by different authors in the dry tropical zone [8, 26-29]. The presence of quartz, kaolinite and illite is consistent with the acidic character of the surrounding rocks [30]. The acidity of the soil is characteristic of ferruginous soils [1, 2, 30-32]. The presence of smectite would result from the sediments by neogenes or by transformation [22, 33] and would show poor drainage in the horizons and less chemical alteration [8, 12]. The presence of kaolinite, a 1:1 mineral demonstrates that monosiallitization is the primary process driving pedogenesis [22, 34].

5. Conclusion

All soils have been subject to study are characterized by strong sandy levels. The high sandy levels show that these soils are formed on site by wind deposits. The dominance of kaolinite on other minerals reflects that the dominant process of pedogenesis is monosiallitisation. The bad drainage due to relatively less abundant rainfall is the factor responsible for the presence of 2/1 minerals like smectite. According to the CPCS, only one type of soil has been identified; these are "*les sols ferrugineux tropicaux peu ou non lessivés*". According to the WRB, the identified soils are Arenosols.

Conflicts of Interest

The authors declare no conflicts of interest.

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