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Suitability of lateritic soils from Garoua (North Cameroon) in Compressed Stabilized Earth Blocks production for low-cost housing construction

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Abstract
The study focuses on the sustainability of lateritic soils from Garoua in Compressed Stabilized Earth Blocks production. The collected samples were subjected to particle-size analysis, Atterberg limits and organic matter content determination and geochemical analyses. Technological behaviors (water absorption and compressive strength) of some stabilized specimens with cement were determined according appropriated requirements. Results show that the studied lateritic soils contain sand (46.2-75.2%) and clay particles (10.2-34.3%) as major grain size, followed by gravels (5.7-14.7%) and silt (1.5-10%). All samples show medium plasticity with the plasticity index ranging from 7.4 to 18.3%. Those soils are more siliceous (SiO_2, 56.61-66.18 wt%) with significant amount of aluminum and iron oxides (Al_2O_3,14.87-20.48 wt% and Fe_2O_3, 4.47-6.96wt%). Other oxides (K_2O, MgO, TiO_2, Na_2O, MnO, and P_2O_5) are in relatively lower proportion (<1%) except CaO, whose content varies between 1.5 and 3%. Compressive strength and water absorption showed positive correlation when the cement content increases. Based on the test results, the studied lateritic soils were suitable in Compressed Stabilized Earth Blocks production.

1. Introduction

Currently, in a context of sustainable development, the economic and environmental challenges incite the valorization of local materials such as lateritic soils, largely representative of engineering soil all around the tropical African Countries. These soils are usually the product of an in-situ weathering process of a basement rock, under tropical climate conditions [1-2]. They are reddish brown residual soils formed after weathering, from pre-existing rocks such as granite, shale, limestone, schist sandstone and gneiss [3-4]. During weathering most of the parent materials chemically break down, mobile components like Mg, Ca, Na, K and SiO_2 try to leach out while less mobile elements like Fe, Al, Ti and Mn are retained as insoluble residues of oxides and hydroxides [5]. The residual product is variable both physically and chemically. Over 85% of major oxides constituents of laterite are made up of SiO_2, Al_2O_3 and Fe_2O_3 [6-7]. The reddish brown coloration of these soils is due to their Fe_2O_3 contents [8]. The physical properties of lateritic soil vary according to their mineralogical composition and their particle size distribution. The particle size distribution can vary from very fine to gravel with respect to its origin, thus it impacts greatly geotechnical properties [1]. They are also constituted of mixtures of crystalline minerals such as quartz, gibbsite, kaolinite, hematite, goethite [9-10]. Lateritic soils are extensively used as building material, for embankment dams, fill materials for foundations, and roads [11-12-13-14 -15].

Civil engineering studies of these materials are now in progress, with focus on their use is the production of Compressed Stabilized Earth Blocks (CSEB). Stulz and Mukerji [16] defined CSEB as "masonry elements, which are small in size with regular and verified characteristics obtained by the static or dynamic compression of earth in a humid state followed by immediate demoulding". The prime advantage of utilizing CSEB is that it utilizes local materials and reduces transportation costs since the production is in situ [17]. Other advantages include faster production, easier construction method that generally requires less skilled labor, and local economy generation rather than spending for imported materials [18-19-20]. Most of the past researches [21-22-23] has established that earth construction is sustainable with less drain on infrastructure. The earth technology has advanced with a modern face of CSEB and rammed earth walls [24]. Guillaud al. [25] reported that CSEB wall costs 32 % less than sand–cement blocks. The analysis of Taylor and Luther [26] showed that the large thermal capacity of earth walls improves their thermal properties above that expected by consideration of R-values alone. Morton [27] showed a sound reduction index of 46 db to 57 db, and that a 16 inch compressed earth block wall has a coefficient of acoustic attenuation (tested at 500 Hz) of 40 to 50 db. Earth improves indoor air quality and lowers embodied energy [21]. Earth bricks have the ability to absorb atmospheric moisture which creates a healthy environment inside a building for its occupants. These characteristics of CSEB are highly desirable in the ailing economy of hot tropical environment. In North Cameroon, the population uses part of those lateritic soils for the artisanal production of adobe and bricks. Indeed, these last three years, Cameroon has been involved in building infrastructures for the next African cup of nations in 2021. These infrastructures include roads, stadiums, hostels, hospitals which increase lateritic materials demand. However, the CSEB wall is rarely adopted for housing development in urban areas of Cameroon. Their utilization is still largely limited to schools, hospitals, few public places and some private houses. According to the bioclimatic aspects of local materials, lateritic soils of Garoua can be a solution for housing shortage and thermal comfort in the Sudano-Sahelian area if they are well exploited and transformed.

In this study, we investigate the physicochemical and mechanical properties of four lateritic soil samples derived from geological formation in Garoua III subdivision, in the Northern part of Cameroon. This research has been carried out on the improvement of lateritic soils for construction with the aim of promoting this technology. Emphasis has been laid on the products quality and environmentally friendly processes in order to promote the development of sustainable and environmentally favorable building policies.

2. Geographical and geological setting

The study area is located in the northern Cameroon, between latitudes 9°12'20"- 9°20'00"N and longitudes 13°24'- 13°32'E (Fig.1). The climate is Sudanian with two contrasted seasons: a humid one from May to October and a dry one from November to April. Total yearly precipitations vary between 900 and 1500 mm and mean annual temperature is 28°C [28]. The natural vegetation consists of tall grasses, deciduous trees and savannas [29]. The topography is slightly undulated with rounded low hills, occasional often elongated ridges, indicating the characteristics residue setting of a typical basement terrain, with an average altitude ranging between 300-500m a.s.l. [30]. Geological formations include granite, migmatite, pegmatite gneiss and sandstone [31-32]. The superficial formations are constituted of ferruginous soils and vertisols, the latter being the most abundant soils [33-34-35-36].

3. Material and Methods

3.1. Material

Field work consisted of direct observations, environmental settings and soil survey in order to locate lateritic soils deposit and the position of pits to be opened. Two sites were retained for sampling. Fourth main pits were dug in the two sites: one in Sanguéré-Ngal (SN2) and three in Sanguéré-Paul (SP2, SP3 and SP4), and described in detail. The main search characters were color, thickness of horizons, texture, structure, porosity, consistency and boundaries between horizons.

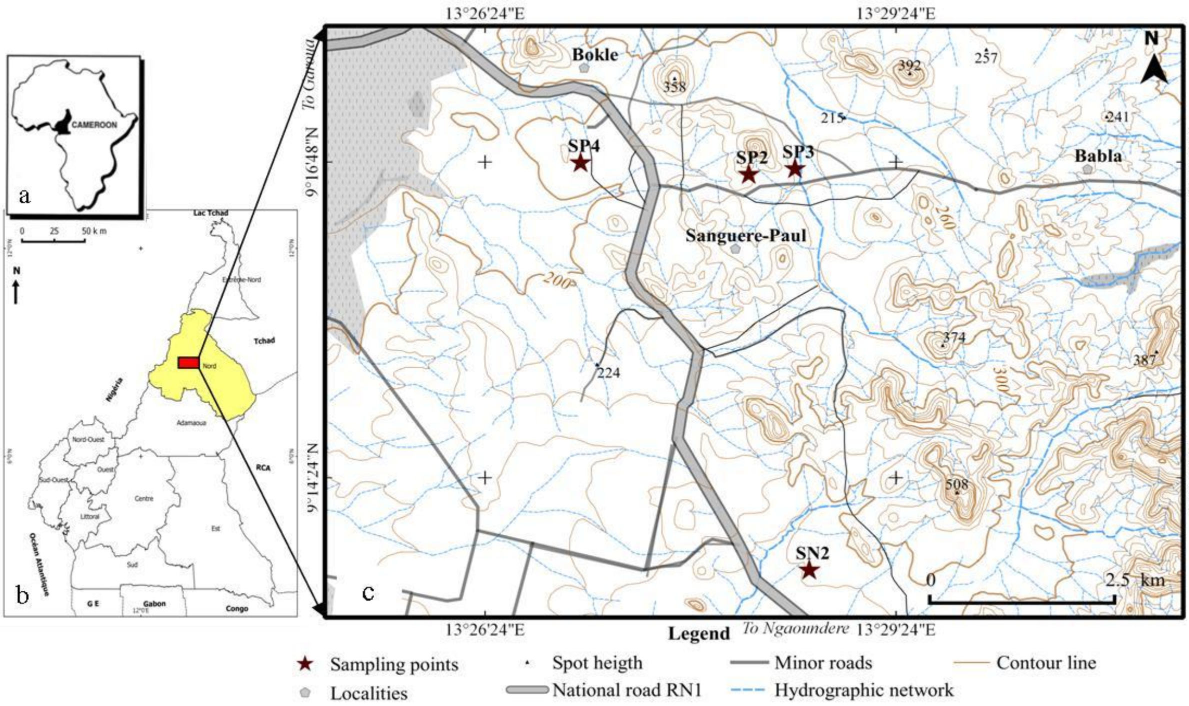

Figure 1: (a) Location of Cameroon in Africa, (b) Location of North Region in Cameroon, (c) Location of the study area

The SN2 profile, located at the Sanguéré-Ngal (9°13'32.7''N; 13°28'36.8''E and 270 m a.s.l.) is about 190 cm thick. It has three horizons which are as follow, from top to bottom (Figure 2 and Figure 3):

0-30 cm: layer 1, reddish brown (2.5YR5/4), granular structure, porous, slightly plastic, medium fraction contains most grain of quartz; diffuse lower boundary;

30-160 cm: layer 2, reddish brown (2.5YR5/4), compact, plastic; it is the principal exploitable horizon (lateritic soils); diffuse lower boundary;

160-190 cm: layer 3, brown reddish, gravelly lateritic soils, enriched with indurated elements of variable sizes along their horizons, porous, presence of numerous fragments of sandstone.

In the SP2 profile, located at Sanguéré-Paul (9°16'40.2''N, 13°28'25.18''E, and 270 m a.s.l.), three horizons were distinguished; they are, from top to bottom (Figure 2 and Figure 3):

0-20 cm: layer 1, lateritic horizon, dark reddish brown, porous, slightly plastic, presence of fines nodules, presence of medium fraction mainly constituted of quartz grains; diffuse lower boundary;

20-90 cm: layer 2, lateritic soils, the color of that principal exploitable horizon is reddish brown (2.5YR5/4), sub angular blocky, compact, presence of hard nodules which are known to contain crystalline to earthy hematite and limonite with considerable amount of quartz granules; diffuse lower boundary;

90-130 cm: layer 3, reddish brown (2.5YR5/4), gravelly lateritic soils enriched in indurated variable size particles along the horizon, presence of numerous voids, poorly crystallized nodules and angular fragments of sub rounded boulders of quartzite. The horizon is limited at the base by highly decomposed sandstone.

The SP3 profile is located in the same site as SP2, at 700m at the East (9°16'39.4''N and 13°28'28.20''E, and 240 m a.s.l.). It is also constituted of three horizons which are, from top to bottom (Figure 2 and Figure 3):

0-25 cm: layer 1, dark reddish brown, lateritic porous soils, slightly plastic, poorly crystallized nodules, presence of medium fraction mainly constituted of quartz grains; diffuse and irregular boundary;

25-90 cm: layer 2, the color is reddish brown (2.5YR5/4), lateritic soils, presence of fines nodules; diffuse boundary;

90-120 cm: layer 3, reddish brown, gravelly lateritic soils enriched in indurated variable sizes particles along the horizon, porous, presence angular fragments of surrounded boulders of quartz.

In SP4 profile, located at the Sanguéré-Paul (9°17'02.7''N and 13°27'16.3''E, and 219 m a.s.l.), only two horizons were distinguished. They are presented as follow, from top to bottom (Figure 2 and Figure 3):

0-30 cm: layer 1, dark reddish brown, lateritic soils, porous, slightly plastic, poorly crystallized nodules, presence of medium fraction mainly constituted of quartz grains; diffuse and irregular boundary.

30-195 cm: layer 2, the color is reddish brown, lateritic soils, sub angular blocky.

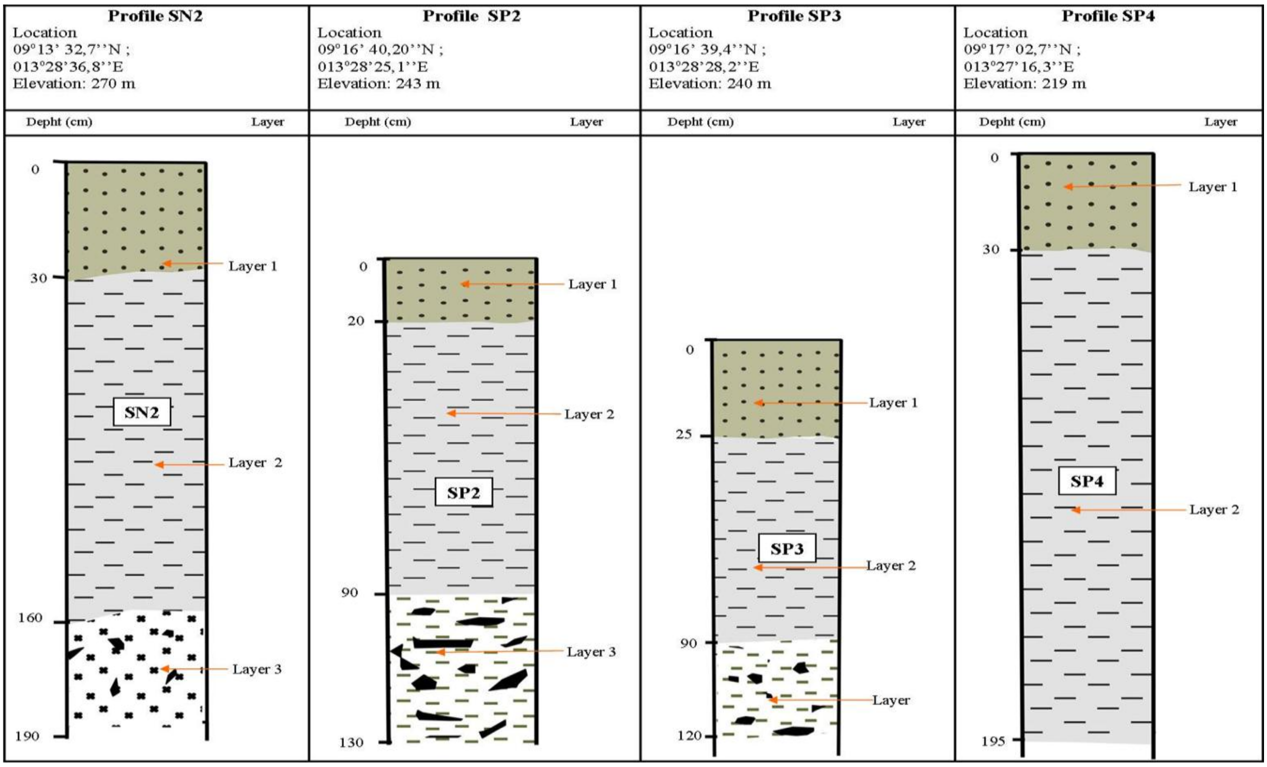

Figure 2: Schematic representations of the studied lateritic soils profile

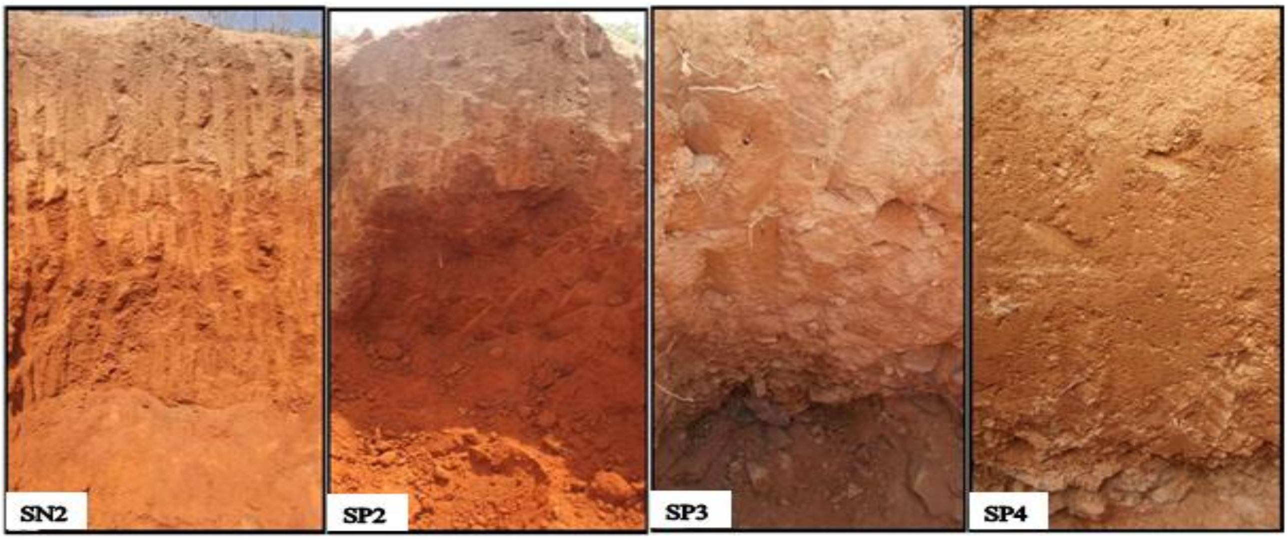

Figure 3: Photographic illustration of the studied lateritic soil profile.

3.2. Methods

Soils samples were collected only in the lateritic horizon (layer 2) from each pit and packaged in polyethylene bags, labeled and sent to the laboratory for soil analyses. Physico-chemical properties were determined at the laboratory of Locals Material Promotion Authority (MIPROMALO), Yaoundé Cameroon. The color of the dry samples was determined using the Munsell Soil Color chart. The grain size distribution was determined following the NF P18-560 standard [37] by dry sieving and the NF

P94-057 standard [38] by sedimentation. The liquid limit (LL) was measured and the plastic limit (PL) were determined using the Casagrande apparatus after wet-sieving the samples using a 400 µm sieve following the NF P94-051 standards [39]. Plasticity Index (PI) was determined by arithmetic difference between Wl and Wp. The optimum moisture content (OMC) and the maximum dry density (MDD) were determined according to NF P 94-93 standards [40]. The percentage of oxides (wt.%) in the soils was determined by X-ray spectrometric powder technique. The test was performed using an X-Ray Spectrometer model EDX-700HS with Energy Dispersive. Only samples from intermediate nodular layer (INC) were subjected to the XRF analyses. The cement DANGOTE 42.5 (manufactured by DANGOTE company in Cameroon) used for stabilization was bought in the local market. Laboratory specimens of the usual CSEB were produced. A block size of 80mm×40mm×20mm was adopted for this pilot study for ease of handling and adequate compressibility with an 8 ton hydraulic jack. A simple mechanical kit was fabricated to produce laboratory specimen of CSEB. The ratios of stabilizers (cement) were added in different percentages ranging from 4%, 6% and 8% respectively. The mixture blended with 15% water. Specimens were cured for the first 7 days in sealed polythene bags and then air-dried at ambient room temperature the 28th day to achieve maximum performance. The compressive strength after 28 days was taken as control and basis for comparison. Tests conducted include Compressive strength test and Water absorption. Compressive strength test was conducted in accordance with [42]. The water absorption (WA), expressed as a percentage of the weight relationship of water absorbed after soaking in water for 24h to the initial weight of the specimen. The water absorption is determined using ASTM [43]. WA was calculated as follow: $WA\ (\%) = [(W_2 - W_1)/W_1] \times 100$ (2) Where: W_2 = weight of soaked specimen and W_1= weight of specimen.

4. Results

4.1. Raw material characterization

4.1.1. Particle size distribution

Grain size analysis enabled the establishment of grain curves (Figure 4) which reveal similitudes between SP2 and SP4 on one hand and between SN2 and SP3 on the other hand. The proportions of particles more than 2 mm in size, vary from 5.7 to 14.7% (Table1). Sand is the most important fraction. Its quantities are 75.2%, 46.2%, 73.5% and 46.8% for the samples SN2, SP2, SP3 and SP4 respectively. Silt fraction has the lowest quantities which range between 1.5 and 10% with high value noted in SP4. Clay fraction has the medium quantities. They are 13.6, 34.3, 10.2 and 32.2% for SN2, SP2, SP3 and SP4 respectively (Table1).

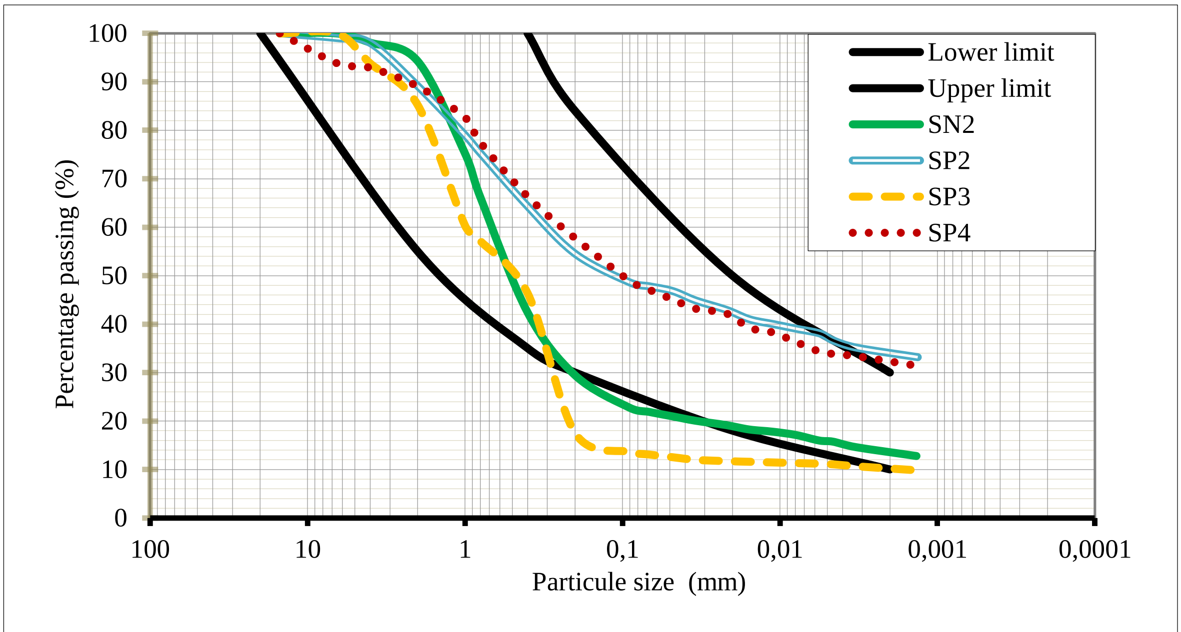

Figure 4: Grain size distribution curves, the lower limit and upper limit was established in according with Cameroonian Standards [44].

4.1.2. Physical property and Atterberg Limits

Table 1 also shows the summary of the geotechnical properties while Figure 5 is the Casagrande Classification Chart of the studied soils. The liquid limit (LL) values range between 40.8 and 62.8% with an average of 52.1% while those of plastic limits (PL) and plasticity index (PI) range respectively between 33.4 and 44.5% and between 7.4 and 18.3% (Table 1). The Cameroonian standards for CSEB recommends liquid limit from 25 to 50%, plastic limits from 20 to 35 % and plasticity index from 2 to 30% [44]. The results of Atterberg limits were projected in Casagrande's plasticity limit diagram. This diagram shows that SP3 and SN2 samples belong to the sector of medium plasticity silts while SP4 and SP2 to that of high plasticity silts (Fig. 5). The organic matter content of the samples ranged from 0.36 % for SP3 to 1.25% for SN2 and the higher values were recorded in sample SN2. Morel et al. [45] showed that the presence of organic matter in soil generally has a major effect on strength properties of cement-soil block.

Table 1: Summary of some geotechnical properties of lateritic soil deposits in parts of Garoua.

Physical parameters	Sample designation			
	SN2	SP2	SP3	SP4
Colour	Reddish brown			
Gravel (%) Φ>2 mm	5.7	10.9	14.7	11.0
Sand (%) 2>Φ> 0.02 mm	75.2	46.2	73.5	46.8
Silts (%) 0.02 >Φ> 0.002 mm	5.5	8.6	1.5	10.0
Clay (%) Φ <0.002 mm	13.6	34.3	10.2	32.2
Saturation water content (%)	0.53	0.57	0.14	0.93
Organic matter content (%)	1.25	1.24	0.36	0.93
Liquid limit LL (%)	44.1	62.8	40.8	60.9
Plastic limit PL (%)	35.9	44.5	33.4	43.3
Plasticity index PI (%)	8.2	18.3	7.4	17.6

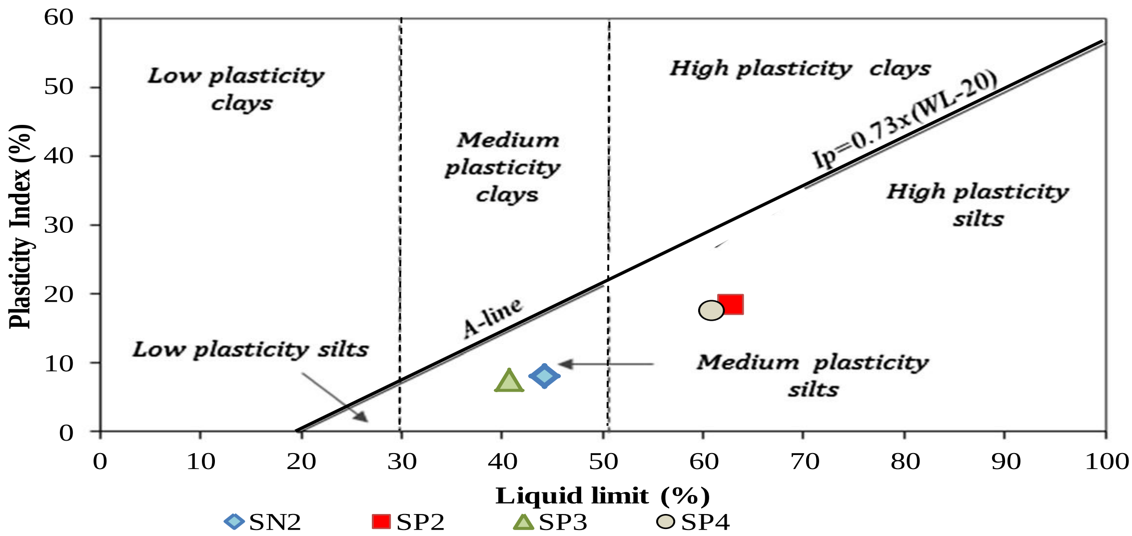

Figure 5: Casagrande chart classification of lateritic soils in the study area.

4.1.3. Geochemical analyses

It is observed in Table 2 that concentrations of major elements of all the four studied profiles display higher contents in silica (SiO_2, 56.61wt% for SP3 to 66.18 wt% SN2). SiO_2 is followed by alumina (Al_2O_3 14.87 % for SN2 and 20.48 wt% for SP2) and iron oxide (Fe_2O_3 4.47 SN2 to 6.96 wt% for SP3). The contents of other oxides, K_2O, MgO, TiO_2 and Na_2O are in lower proportion (respectively 0.55-1.58

wt%, 0.21-0.7 wt%, 0.21-0.62 wt%, 0.17-0.26 wt.%) excepted for CaO, which contents range between 1.01 and 3.1 wt% (Table 2). MnO and P_2O_5 oxides are present in trace. The value of loss on ignition is10.58%, and can be associated to the presence of clay minerals and hydroxides.

Table 2: Geochemical composition of the lateritic soil

	Sample designation			
Chemical composition (%)	SN2	SP2	SP3	SP4
SiO_2	66.18	57.7	56.61	58.19
Al_2O_3	14.87	20.48	19.09	18.77
Fe_2O_3	4.47	5.47	6.96	6.91
K_2O	1.58	0.83	0.77	0.55
CaO	1.18	3.1	2.77	1.01
MgO	0.7	0.47	0.24	0.21
TiO_2	0.62	0.21	0.22	0.96
Na_2O	0.26	0.2	0.17	0.18
MnO	0.12	0.13	0.12	0.17
P_2O_5	0.05	0.04	0.09	0.09
SO_3	0.04	0.29	0.65	0.61
Loss of ignition	9.02	10.53	11.48	11.31
Total	99.05	99.16	98.52	98.35

4.2.4. Stabilized specimens of Compressed Earth Blocks

4.2.4.1 Compressive strength and water absorption

The summary of the water absorption and compressive strength of studied stabilized specimens were determined in accordance to Cameroonian norm [44]. The results are showed in Table 3, Figures 6 and 7. The compressive strength increases with increasing cement content. Its values were 3.1-5.6 MPa at 4% cement stabilization, around 4.1-6.9 MPa at 6% of cement and 5-8.1 MPa at 8% of cement. The mixture cement laterite portrayed a positive effect by reducing the percentage of water absorption with increase cement content. The percentage of water absorption ranged from 18.5 to 19.5% for 4 % of cement stabilization, 17.3 to 18.3% for 6 % of cement and 16.4 to 17.1% for 8 % of cement.

Table 3: Tests and permissible limits compressive strength and water absorption

	Water absorption			Compressive strength		
Cement content	4%	6%	8%	4%	6%	8%
SN2	18.8	17.9	17	3.8	4.4	5.6
SP2	19.5	18.3	17.1	5	5.9	6.3
SP3	18.5	17.3	16.8	3.1	4.1	5
SP4	18.6	17.3	16.4	5.6	6.9	8.1
NC 102-104, 2002-2004	<15%			≥2MPa		

4.3. Discussion

The morphological features of lateritic soil showed that the weathering profile was made up of three visible layers with sandy texture globally and reddish brown color. These pigmentations are consistent with the observation of De Graff-Johnson [46] and Tardy [47] on the lateritic soils formed under oxidized conditions and good drainage. The studied lateritic soils derived from sandstones which constitute the basement rocks of the region. Its particle size distribution consisted globally of coarse size and sand constitutes the more represented fraction. It also reflects the composition of arkosic sandstone parent rock on which these soils were developed [35]. These characteristics were considered as good for various engineering application [48-49-50]. Moreover, their durability equally depends on parent rock material as well as the curing method and time.

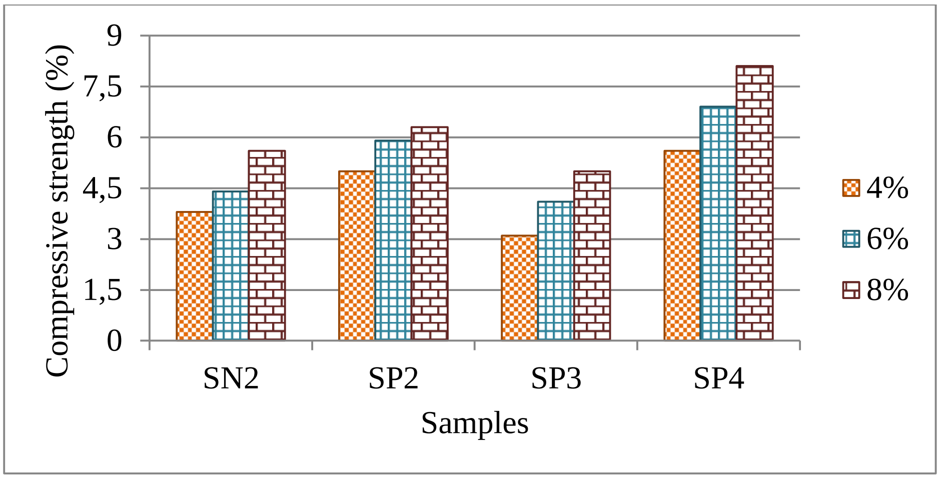

Figure 6: Comparative result of compressive strength of common laterite-cement block and in Garoua with earth of varied cement content

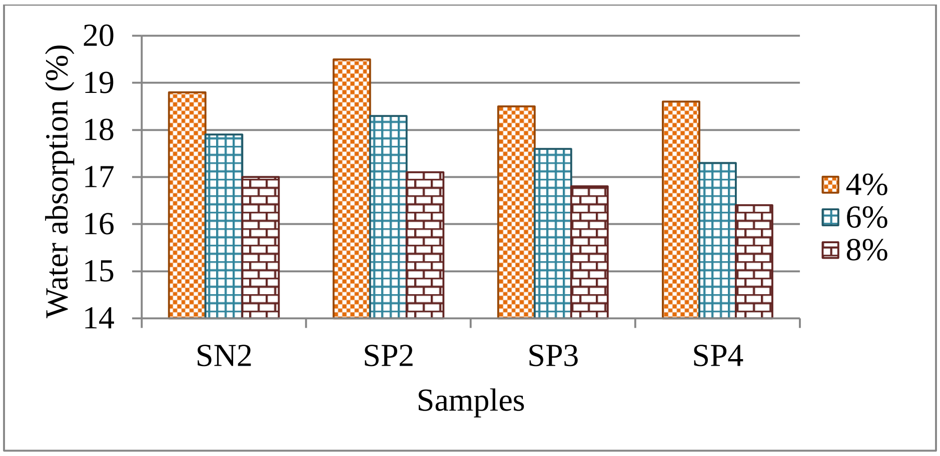

Figure 7: Initial rate of water absorption for different percentages of cement

The presence of fine and coarse particles increases the efficiency of soil compacted when clay particle tends to fill the void spaces between coarse portion of the soil [50]. The size compositions as well as the lateritic character of the studied soil indicate that it can be easily stabilized by conventional materials such as Portland cement. Many studies have shown that the presence of lots of medium to coarse particles within the material increases the compaction strength and the wearing capacity of the pavement [51-52]. According to Casagrande chart classification, the samples fall between medium plasticity silts and medium plasticity silts. This may be attributed to the presence of high amount of kaolinite in the studied soil. The organic matter contents of the tested materials were globally low ($\leq$1.25%). Indeed, the organic matter content is widely dependent on soil mineralogy and they are lower in sandy than in clayey soils [53]. The values obtained in the studied soils are in accordance with other studies [45]. Graft-Johnson [45] also showed that high organic matter content has a significant influence on resultant compressive strength of blocks at testing and strength reduces as moisture content increases due to the softening of binders by water and development of pore water pressures.

Liquid limit is an important index property since it is correlated with various engineering properties [54]. Plasticity charts illustrated in Fig. 5 show that soils from the study area have medium plasticity for SN2 and SP3 and high plasticity for SP4 and SP2. Base on the liquid limit and plasticity index recommendations for CSEB of the Cameroonian Standards Specification [44], the studied lateritic soils can be useful material for CSEB.

Analysis of the geochemical compositions shows that the raw material is mainly composed of silica, alumina and iron oxides. However, it also contains some minor elements such as potassium, sodium and titanium oxides. The predominance of SiO_2 (>56.61%) is an accordance with an importance amount of quartz observed in particle sizes distribution. The high ratio values of (SiO_2/Al_2O_3 > 1 wt%), suggests the presence of free-form of silica and clays minerals type 2:1 [55] and indicate high chemical maturity of the investigated samples [56]. Maignian [57] showed that the laterites density depends on its chemical composition. This density increases with iron oxide content and decreases with alumina content.

The compressive strength of CSEB depends on the soil type, amount of stabilizer and the compaction energy used to form the block [58]. The summary of the result from the test reveal a continuous increase of the compressive strength values with increase in cement rate. According to Meukam et al. [59] compressive strength of stabilized lateritic soil bricks ranged between 2 and 10 Mpa with 3 to 10% cement content and investigations revealed that the compressive strength increased with increase in cement content. The values of the studied specimens surpass the minimum strength requirement of 2MPa specified by the Cameroonian Standards [44] for CSEB. Water absorption is a key parameter to forecast on the durability of the soil cement blocks [60]. The results of water absorption for CSEB samples in this study show a general positive correlation between water absorption and cement content. The amount of the water absorption depends on the type of soil used and is related to the compressive strength and durability of the soil cement blocks. If the water absorption is high, it can be expected a rapid deterioration of the soil cement blocks. The values of water absorption for all samples exceed 15%, which do not satisfy the Cameroonian requirement Norms [44], but this norms did not defined the compressive strength which highly influence the porosity and the water absorption.

Conclusion

Some geotechnical and physico-chemical properties of four lateritic soils deposits from Garoua region were determined and their suitability for production of CSEB assessed. From the obtained field works and test results, the following conclusion can be drawn: The profile of studied lateritic soils is globally constituted of three layers and all the studied soil samples have well-graded particles-size distribution curves and reddish brown color, which are some of the aspects of good lateritic soils quality used in CSEB production. The studied lateritic soils had medium to high plasticity. Therefore, they can be used for the production of CSEB. The compressive strength values of all the lateritic soils are within the acceptable limits for good lateritic soils quality used for CSEB. Based on the values obtained from the various tests carried out, lateritic sols from Garoua (North Cameroon) are suitable soils for CSEB.

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