Relation of several pedological characteristics to engineering qualities in expansive clays of Northern Venezuela

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ABSTRACT

The Caribbean Coastal Region of Venezuela with a semi-arid climate presents adequate conditions for the development of soils with expansive clays, which are the main pathology registered by the roads and surrounding infrastructures in the region. Correlation studies in temperate soils have shown that there is a close association between Atterberg limits (AL) with the clay content, less information exists in the literature between the association of AL and other soil physical properties of soil (e.g. in situ water-content and soil particle density). The main objectives of this research were to: evaluate the presence of expansive clays in northern Venezuela through the limits and indices of Atterberg, and to relate the AL to soil physical properties determined during both soil surveys and geotechnical evaluation of risks. The plasticity index (PI) and the shrinkage limit (SL) of the clays are high, whereas the plasticity chart of the samples indicates two well-defined groups, a major one, in the area of low plasticity, the other group in the area of high plasticity. The information shown a close association between the original moisture content of the samples with the AL, highlighting, the strong association of LL and PI with moisture content in situ. However, the soil particle density and the bulk density were negatively related to moisture content. The information presented here for tropical samples confirms the information in the literature for temperate zones, where it is concluded that the liquid, plastic and plasticity index limits were highly significantly related to the clay content.

Keywords: *Casagrande chart, Liquid limit, Plastic limit, Soil humidity, Soil particle density.*

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Highlights of this paper

- The presence of expansive clays constitute the main pathology by the road of northern Venezuela.
- The plasticity index and the shrinkage limit of those clays are high.
- There was a close association between the original moisture content of soils with the Atterberg limits.

1. INTRODUCTION

According to the moisture content, the soil can present four states of consistency: thus, when dry, its state is solid, but by adding small portions of water it passes successively to the following states: semisolid, plastic and finally liquid; with that premise, and based on the gravimetric water content of the soil, Atterberg in 1911, defined for fine-grained soils three limits of consistency [1]. The upper limit or liquid limit (LL), when the soil passes from a plastic state to a liquid state, the lower plastic limit or plastic limit (PL), when it passes from a semisolid state to a plastic state, and the shrinkage limit (SL), when it passes from a semisolid state to a solid state, and contracts when it loses moisture. Consequently, the moisture contents at soil transition points from one state to another are the well-known Atterberg limits [2].

These consistency indices represent the ranges of water content in which specific mechanical behaviours occur. In the plastic range, the mechanical behaviour of the soil is plastic/irreversible so it does not crack when subjected to loads, while in the semi-solid state (between SL and PL), the soil is friable and behaves in a fragile manner [2-5].

Atterberg's original work was largely complemented by Casagrande in 1932 who developed methods for determining liquid and plastic limits, tests that are now internationally accepted [6].

Although the Atterberg limits (AL) were originally used for agronomic purposes (e.g. to define water levels in soils suitable for mechanical tillage), it is noteworthy that they have subsequently been widely used in the classification of soils for engineering purposes [6-8]. These limits also provide information for interpreting a set of mechanical and physical properties of soils, such as shear strength, load capacity, compressibility, and shrinkage potential [5, 6]. From the above it follows that AL have a dual practical use, since in soil science they generate valuable information for the genesis, classification and use of land, and in engineering sciences they are very useful in the design of infrastructures (construction of buildings and roads) [9]. Moreover, ALs have recently seen to play an important role as indicators of soil vulnerability to degradation processes due to natural and anthropic causes [10, 11].

Although, the analysis of the traditional physical and chemical properties of soils (e.g. granulometry, cation exchange capacity) are useful in the study of their morphology, genesis and mapping; similarly, relatively easy-to-obtain measures, such as Atterberg limits, help to complement that information. Therefore, these limits are widely used by geotectonic engineers in the evaluation of the properties and risks involved in the expansion-contraction of the sediments of their infrastructures, in particular those built on expansive clays (EC) [9].

In general, ECs are located in temperate, subtropical and tropical zones [9, 12-14] these clays are characterised because in their mineralogical composition present a significant proportion of 2:1 type phyllosilicates, which gives them a high capacity for expansion as a result of the location of water molecules between the silicate sheets [15]. ECs, due to their particular expansion-contraction characteristic with wetting, are susceptible to anomalous deformation due to the volumetric change induced by expansion, which, in turn, generates damage to infrastructure works as a result of harmful differential movements [16, 17]. Despite the fact that EC can be found in any climate, its presence is favoured, in regions of arid and semi-arid climate, where evaporation exceeds precipitation [17, 18].

In Venezuela, in the Caribbean Region, northern part of the country, with a semi-arid climate with low rainfall, there are adequate conditions for the development of soils with the presence of expansive clays. Thus, the presence of expansive clays is the main pathology registered by the road infrastructure in some sectors, which its concomitant problems of deterioration and deformation of road arteries, and in surrounding infrastructures [9].

Studies with single and multiple correlations of a large volume of samples in temperate soils have shown that there is a close association between the Atterberg limits (LL, PL) and the clay content of soils, while the association of these parameters with organic matter (OM), although significant, is of less relevance [1, 2]; less information exists in the literature between the association of AL and other physical properties of soil such as *in situ* water content of soil and soil particle density (ρ_s). When analysing the interrelationship between Atterberg limits and commonly measured soil physical properties, we hypothesize that in soils not subject to management such as those sampled here, there should be a good correlation between Atterberg limits and in situ water content, clay content, and bulk density, whereas that correlation should be lower for soil particle density. The main objectives of this research were to: 1) evaluate the presence of expansive clays as the main pathology of the road infrastructure in three regions of northern Venezuela through the limits and indices of Atterberg; 2) this paper relates clay content, soil particle density, bulk density and water retention of soils with Atterberg limits of a range of northern Venezuela expansive clays. Correlation regression analyses were employed to investigate these relationships.

2. MATERIALS AND METHODS

2.1. Geology of the Study Areas

In the areas studied the following geological formations were found: In Anzoátegui State: Quiamare Formation (Early-Late Miocene), and Las Piedras Formation (Late Miocene-Pliocene). In Falcón State: Guacharaca Formation (Oligocene), Casupial Formation (Middle Oligocene-Miocene) and San Lorenzo Formation (Early to Middle Miocene), whereas in Miranda State: Tuy Formation (Pliocene-Pleistocene) and Tucutunemo Formation (Late Cretaceous). The region presents a monsoon climate zone, transitional between tropical savannah and forest, typical of foothill regions or intramontane valleys. Temperatures vary between 22 and 29°C with a predominance of savannah-type vegetation.

2.2. Location and Extension of the Study Area

The study area comprises three locations located on stretches of roads in northern Venezuela as shown in Figure 1.

State Anzoátegui section: It includes a stretch of road from Barcelona (Universal Transversal Mercator (UTM) coordinates 314.616E-1.120.600N) to Cantaura (UTM coordinates 350.135E1.028.658N), the route is approximately 120 km long.

State Falcón section: It includes the road from Morón (coordinates UTM 587.090E-1.159.054N) to Mirimire (UTM coordinates 491.530E-1.255.216N), the route is approximately 150 km long.

State Miranda section: It includes two sections of road, the first goes from Charallave (UTM coordinates 734.166E-1.133.063N) to Ocumare (UTM coordinates 634.953E-1.156.505N), this route is approximately 20 km long; the second goes from Santa Teresa (coordinates 755.774E- 1.131.590N) to Charallave, the route is approximately 25 km long. All this information was taken from the topographic maps of the Geographic Institute "Simón Bolívar" of Venezuela.

2.3. Soil Sampling

In total, 81 subsoil samples were taken distributed as follows: in the Barcelona-Cantaura road were collected 41 samples, in the Morón-Mirimire 23, in the Charallave-Ocumare 10, and finally 7 samples in the Charallave-Santa

Teresa. Once collected, the samples were brought to the laboratory for determinations of the corresponding physical parameters.

2.4. Physical Determinations

The determinations of moisture content, soil particle density and bulk density were performed according to the methodology outlined by Anderson and Ingram [19] while the sieve particle size test was performed by sieving according to standard method American Standard for Testing and Materials (ASTM) ASTM D-422-63.

2.4.1. Atterberg Consistency Limits

The Liquid Limit (LL) and the Plastic Limit (PL) were determined according to the standard methods ASTM D4318-1. The Shrinkage Limit (SL) was determined according to ASTM D427-04.

2.4.2. Consistency Indices

The plasticity index (PI) is a range of consistency in which soil exhibits properties or behaves like a plastic material, it is a measure of its ability to develop cohesion. The IP corresponds to the numerical value of the difference between the liquid limit and the plastic limit.

Figure 1. Location of the areas studied. The eastern zone corresponds to the Anzoátegui State, the central one to Miranda and the more western to the Falcón State.

2.4.3. Percentage of Humidity

The water contents in the Atterberg boundaries were measured according to the standard method ASTM D2 216-19. After weighing the sample, it is placed in an oven and heated to 105°C for approximately 16-24 hours. Once dried the soil is weighed again. The difference between these two values is the soil water content.

2.5. Statistical Analysis

Descriptive statistical values, including minimum, maximum, and standard deviations (SD) values were calculated using SPSS. The coefficient of variation (CV) was used to explore the variability of the parameters and properties selected in the study areas. The statistical relationships between the values of the Atterberg limits, and between these and the physical properties of the soil were established by Pearson's correlation coefficient.

3. RESULTS

3.1. Physical Characterisation of Soils

3.1.1. Moisture Content of Soils in Situ

Table 1 presents a maximum humidity value for the total samples analysed of 43.91% and a minimum of 2.91%, respectively, with an average value of 14.56%.

Table 1. Descriptive statistics of the soil physical properties.

Parameters	**Minimum**	**Maximum**	**Mean**	**Sd.**	**CV**
% Humidity	2.91	43.91	14.56	9.84	0.676
% Sand	0.60	53.20	13.82	13.14	0.951
% Fine materials	38.1	99.40	84.31	15.0	0.178
Bulk density (g/cm^3)	1.50	2.98	2.04	0.302	0.148
Particle density(g/cm^3)	2.55	2.72	2.63	0.040	0.015

3.1.2. Density of Soil Particles and Bulk Density

For the soil particle density (ρ_s) test were used pycnometers, of the total universe of samples only 36 were analysed, which range from 2.55 to 2.72 g/cm^3 with an average of 2.63 g/cm^3 (Table 1). ρ_s often is assumed to range between 2.60 and 2.70 g/cm^3 or equal a constant value of 2.65 g/cm^3 for most quartz-dominated soils [8]. Due to the small range of variation of the $\rho_{s,}$ the standard deviation and the coefficient of variation of the samples analysed were very low (0.04 and 0.015 g/cm^3, respectively*)*. On the other hand, the bulk density (ρ_b) included only 34 samples, they fluctuate between 1.50 and 2.98 g/cm^3 and an average value of 2.04 g/cm^3, the lower ranges indicate that the soil is subject to a state of little compaction, while the highest results are soils correspond to very compacted soils (Table 1). As expected, the standard deviation and the coefficient of variation were higher respect the values for the soil particle density.

3.1.3. Granulometry

This test performed for the 81 samples collected indicates that the soils are mainly poorly graded, represented particularly by clay sediments. Table 1 indicates that fine particles are dominant for the whole universe of sample analysed with an average of 84.31%, whereas sand and gravel averaged 13.82% and 1.67%, respectively. For the fine component, the maximum value found was 99.4%, while the minimum was 38.1% (Table 1). When comparing the granulometry for the three areas studied, it was found that all sites have soils composed mainly of fine textures (Figure 2), those of the Anzoátegui and Falcón states have average contents of fine particles very similar (86% and

82% respectively, and as well in sand and gravel contents; while the soils of the Miranda state are more heterogeneous respect the other two zones, with much higher gravel and sand contents and a lower fine particle content (67%).

3.2. Atterberg Limits

3.2.1. Liquid Limit

The maximum value of the liquid limit (LL) was 78.88%, while the minimum value was 20.93%, so with an overall average of 43.61% the LL in the soils analysed is quite high. The coefficient of variation for all LL sites studied was moderate (0.34, Table 2).

3.2.2. Plastic Limit

The plastic limit (PL) presents ranges between 5.47 and 35.11%, respectively for their minimum and maximum values, while the average value (20.76%) corresponds to a fairly high value of the PL (Table 2). The values of the coefficient of variation were lower than those obtained for the LL (0.26).

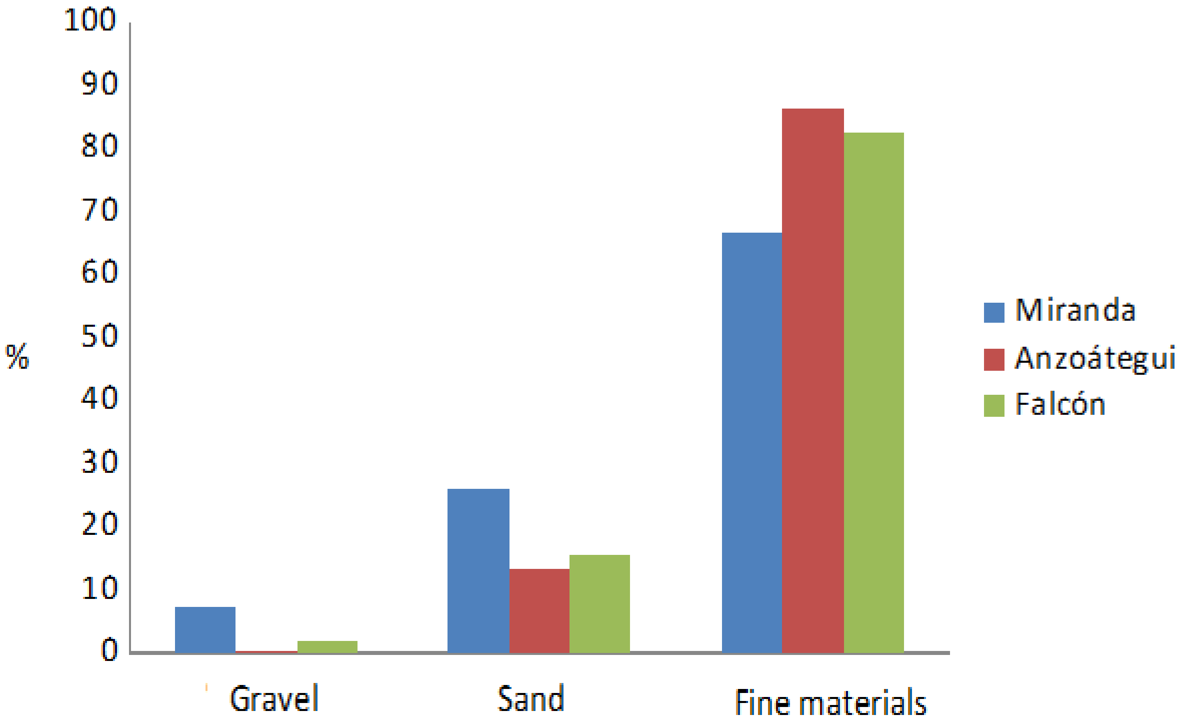

Figure 2. Average particle size (%) in the different zones studied.

Table 2. Values of the Atterberg limits (LL, PL and SL) and plasticity index (PI) of the analysed soils.

Parameters	Minimum	Maximum	Mean	Sd	CV
LL	20.93	78.88	43.61	14.69	0.34
PL (%)	5.47	35.11	20.76	5.47	0.26
SL (%)	16.39	75.43	24.51	7.62	0.31
PI	2.46	50.66	22.85	11.93	0.52

3.2.3. Shrinkage Limit

The shrinkage limit reached a very high maximum value (75.43%) although most of the values were below 30.0%, the minimum value was 16.39 and the global average was 24.51%. The coefficient of variation increased (0.31%) due to the presence of the sample with a very high value reported for Anzoátegui state.

3.3. Consistency Indices

3.3.1. Plasticity Index

The values of the plasticity index (PI) range between a very low IP value (2.46%, Table 2) and a very high (50.66%), whereas the weighted average value of IP 22.85% is considered high [4].

4. DISCUSSION

The information indicates the presence of expansive clays throughout the different study areas located in northern Venezuela. The granulometry of all the soils analysed is mainly composed of fine (silts and clays). The average size of fine grains is 86% in the state of Anzoátegui, while in Falcón and Miranda they are lower, 82% and 67% respectively (Figure 2).

The values of the Atterberg limits were, in general, comparable with the information from the literature for expansive soils [6, 9, 11, 20]. However, the scarce data presented in specialised journals on these parameters in tropical soils is striking. As a reference to this point, the extensive information presented by Keller and Dexter [2] where LL and PL data are included for 78 surface soils from different continents, only contemplates information for the temperate zone of North America, Europe and Australia.

In general, the plasticity index of the expansive clays of northern Venezuela is high, with an overall average of 22.85, with the region of Falcón state in the western part of the country presenting a moderate average (17.49). The average shrinkage limit of the clays of northern Venezuela is also high (24.51), higher than that presented by Zolfaghari, et al. [11] for loamy soils (12.0) of Iran, by García [21] for a well-graded sandy soil (5.24) of the savannas of Monagas, Venezuela, and by Codevilla [20] for expansive soils (12-18) of the Province of Buenos Aires, Argentina.

4.1. Relationships between Atterberg Limits

When the values of the different Atterberg limits are related to each other, very high correlations were found between LL with PL, SL and PI (Table 3). It highlights, as expected, the strong association between the liquid limit and the plasticity index (0.936^{****}; Figure 3), this relationship, as it is known, constitutes the scaffolding for the construction of the Casagrande plasticity chart. The plastic limit is also related, although with a lower probability, to the shrinkage limit and the plasticity limit (Table 3), finally, a strong association was also found between SL and PI. Similar information was made for surface soils and horizons B and C of Canada by Jong, et al. [1] who reported more robust statistical associations for deep horizons with respect to surface horizons. However, the correlation values between LL and PI reported by Jong, et al. [1] were lower than the value presented here.

Table 3. Relationships among the Atterberg´s parameters.

Atterberg parameters	**LL (%)**	**PL (%)**	**SL(%)**	**PI (%)**
LL (%)	-	0.643^{***}	0.497^{***}	0.936^{***}
PL (%)		-	0.381^{***}	0.334^{***}
SL			-	0.437^{***}
PI				-

Note: ***Significant at $P < 0.005$.

4.2. Plasticity Chart

As the liquid limit and the plastic index proposed by Atterberg are laboratory physical parameters very easy to obtain, Casagrande in 1932 studied the relationship between both indices for a wide universe of soil samples, achieving an adequate separation of clays and silts; the graph resulting from that relationship is known as the Plasticity Chart for the Unified Soil Classification System.

Figure 3 represents the relationship between the Plastic Index and the Liquid Limit of the total samples studied. In the plasticity chart, of the samples from northern Venezuela, two well-defined groups were observed, a major group (47 samples) located in the area of low plasticity clays (CL) mainly in the states of Anzoátegui and Miranda, the other group (21 samples), is characterised by high plasticity clays (CH) located mainly in the state of Falcón, in turn, there are 6 samples that are low plasticity silts (ML) mainly in the state of Miranda, and one sample of silty clay (CL-ML) and one of high plasticity silt (MH). It can be said that the samples taken in northern Venezuela are clays of low plasticity (CL).

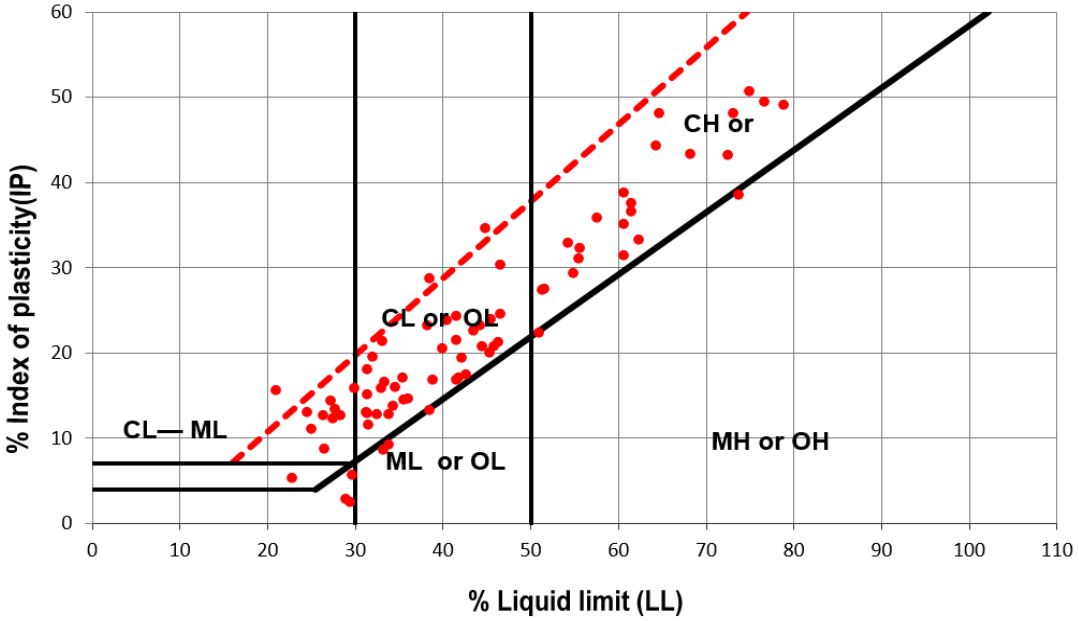

Figure 3. Plasticity chart of all the chosen samples.

4.3. Relationships between Soil Physical Properties and Atterberg Limits

Much of the information used by soil scientists for the mapping of soil units is generated based on the use of easy-to-measure physical properties, such as those provided by the limits generated by Atterberg (liquid limit, plastic limit and the plasticity index). Previous results have reported significant correlations of Atterberg limits and parameters that are routinely determined in the characterisation of soils such as: clay content, base exchange capacity and organic matter content [1, 22-24]. Atterberg limits have also been related to properties linked to surface phenomena (e.g. specific surface areas).

Less studied has been the relationships of the AL and some soil physical parameters such as the initial water content of the soil and soil densities (bulk and particle density). Table 4 shown that the original moisture content of the samples showed a close association with the different Atterberg limits, a result that is not surprising, since these parameters are generated based on differential moisture contents of the samples. Noteworthy is the very high association of LL and PI with soil moisture content (Table 4). Jong, et al. [1] presented very similar results for soils from Saskatchewan, Canada, particularly from the association of the PI and LL with water retained at different matrix states.

Likewise, moisture content showed a good correlation with clay and silt content and inversely with sand content (Table 4), information that is not surprising given the ability of fine grains to retain water as opposed to sand particles.

On the other hand, soil particle density and bulk density were negatively related to moisture content; particularly highlighting, as expected, is the high negative association between soil moisture and bulk density (Table 4).

Deng, et al. [6] in a trial conducted in gullies in southern China found a very weak negative correlation between bulk density and Atterberg limits (LL and PL), however in the case of Venezuelan soils the association was strongly negative, while the correlations between LL and PL with the particle density did not achieve significance (Table 4). It is striking that the contraction limit (SL) and the soil particle density have a significant positive correlation.

Table 4. Relationships between Atterberg´s limit and soil physical properties.

Parameters	% Humidity	% Sand	% Fine materials	Bulk density	Particle density
LL (%)	0.864^{***}	-0.463^{***}	0.403^{***}	-0.503^{***}	-0.202^{ns}
PL (%)	0.643^{***}	-0.292^{***}	0.229^{**}	-0.605^{***}	-0.124^{ns}
SL	0.497^{***}	-0.132^{ns}	0.083^{ns}	-0.064^{ns}	0.327^{**}
PI	0.760^{***}	-0.436^{***}	0.391^{***}	-0.380^{**}	-0.195^{ns}
% Humidity	-	-0.364^{***}	0.306^{***}	-0.563^{***}	-0.210^{**}
% Sand		-	-0.967^{***}	0.060^{ns}	0.060^{ns}
% Fine materials			-	-0.060^{ns}	-0.106^{ns}
Bulk density				-	-0.111^{ns}
Particle density					-

Note: ** and ***Significant at $P < 0.025$, and $P < 0.005$, respectively; ns= Non significant

Table 4 also relates the content of fine particles (silt plus clays) to the different Atterberg limits (LL, PL and PI). There is a high correlation ($P<0.005$) between fine particles with LL and PL, on the contrary, no significant association was found between clay and silt contents with the shrinkage limit (Table 3). The information presented here for 81 tropical samples confirms the work done by Jong, et al. [1] in a census of 500 samples over several years in Saskatchewan, Canada, where textures of the Ap, B and C horizons were examined in relation to the Atterberg limits by single and multiple correlation analysis. They concluded that the liquid and plastic limits and the plasticity index were highly significantly related to the clay content of soils. On the other hand, De la Rosa [23] reported similar information when related some pedological characteristics (organic matter content, cation exchange capacity and clay content) with two engineering parameters: plasticity index and optimal humidity. De la Rosa [23] point out that simple correlation coefficients demonstrated a significant relationship between clay content and cation exchange capacity with engineering determinations, while the relationships with organic matter were weak.

5. CONCLUSIONS

The Caribbean Region of Venezuela, characterised by a semi-arid climate with low rainfall, presents adequate conditions for the development of soils with the presence of expansive clays. The granulometry of these soils is mainly composed of fine particles with averages of 67-86% silt and clay.

The values of the Atterberg limits were, in general, comparable with the literature information for expansive soils from other regions of the world. However, the relatively scarce data presented in specialised journals on these parameters in tropical soils with respect to the abundant information for temperate zones is striking. Overall, the plasticity index of the expansive clays of northern Venezuela is high, with a global average of 22.85%. Likewise, the average contraction limit of these clays is also high, with values higher than those presented for other regions.

The plasticity chart of the samples indicates two well-defined groups, a majority group located in the area of low plasticity clays (LPC), the other group is characterised by high plasticity clays (HPC).

Although the Atterberg indices have been related to chemical parameters of routine use in the characterisation of soils (e.g. clay content, base exchange capacity and organic matter content), less studied has been the relationship of these limits with the initial water content of the soil and other physical properties. The information generated for the clays studied here shown a close association between the original moisture content of the samples with the different Atterberg limits, highlighting, in particular, the strong association of LL and PI with moisture content *in situ.* On the other hand, the soil particle density and the bulk density were negatively related to moisture content. Likewise, the content of fine particles (silt and clays) shows a high correlation between fine particles with LL and PL, on the contrary, no significant association was found between the contents of clay and silt with the shrinkage index. The information presented here for tropical samples confirms the extensive information in the literature for temperate zones that the liquid and plastic limits, and the plasticity index are highly related to the clay content of soils.

REFERENCES

[1] E. D. Jong, D. F. Acton, and H. B. Stonehouse, "Estimating the Atterberg limits of Southern Saskatchewan soils from texture and carbon contents," *Canadian Journal of Soil Science*, vol. 70, no. 4, pp. 543-554, 1990. https://doi.org/10.4141/cjss90-057

[2] T. Keller and A. R. Dexter, "Plastic limits of agricultural soils as functions of soil texture and organic matter content," *Soil Research*, vol. 50, no. 1, pp. 7-17, 2012. https://doi.org/10.1071/sr11174

[3] D. J. Campbell, *Liquid and plastic limits. In KA. Smith and C.E. Mullins (Eds.), Soil and environmental analysis: Physical methods*, 2nd ed. New York: Marcel Dekker, 2001.

[4] B. M. Das, *Principles of geotechnical engineering*. Stamford, CT: Thomson Learning College, 2006.

[5] R. A. McBride, "Soil consistency and lower plastic limits. In Carter MR, Gregorich EG (Eds.), Soil Sampling and Methods of Analysis," 2nd ed.: CRC Press, Canadian Society of Soil Science, 2008, p. 1262.

[6] Y. Deng, C. Cai, D. Xia, S. Ding, J. Chen, and T. Wang, "Soil Atterberg limits of different weathering profiles of the collapsing gullies in the hilly granitic region of southern china," *Solid Earth*, vol. 8, no. 2, pp. 499-513, 2017. https://doi.org/10.5194/se-8-499-2017

[7] L. Mueller, U. Schindler, N. R. Fausey, and R. Lal, "Comparison of methods for estimating maximum soil water content for optimum workability," *Soil and Tillage Research*, vol. 72, no. 1, pp. 9-20, 2003. https://doi.org/10.1016/s0167-1987(03)00046-1

[8] H. Blanco-Canqui, R. Lal, W. M. Post, R. C. Izaurralde, and M. J. Shipitalo, "Organic carbon influences on soil particle density and rheological properties," *Soil Science Society of America Journal*, vol. 70, no. 4, pp. 1407-1414, 2006. https://doi.org/10.2136/sssaj2005.0355

[9] D. Lopez-Hernandez, M. Mahia-Masip, W. Melendez, and A. Lopez-Contreras, "NH4+ fixation and ionic competition with K+ in a clayey soil from Ocumare Del Tuy, Venezuela," *Canadian Journal of Agriculture and Crops*, vol. 7, no. 2, pp. 38-45, 2022. https://doi.org/10.55284/cjac.v7i2.654

[10] S. Stanchi, M. Freppaz, and E. Zanini, "The influence of Alpine soil properties on shallow movement hazards, investigated through factor analysis," *Natural Hazards and Earth System Sciences*, vol. 12, no. 6, pp. 1845-1854, 2012. https://doi.org/10.5194/nhess-12-1845-2012

[11] Z. Zolfaghari, M. R. Mosaddeghi, S. Ayoubi, and H. Kelishadi, "Soil atterberg limits and consistency indices as influenced by land use and slope position in Western Iran," *Journal of Mountain Science*, vol. 12, pp. 1471-1483, 2015. https://doi.org/10.1007/s11629-014-3339-z

[12] B. Shi, H. Jiang, Z. Liu, and H. Y. Fang, "Engineering geological characteristics of expansive soils in China," *Engineering Geology*, vol. 67, no. 1-2, pp. 63-71, 2002. https://doi.org/10.1016/s0013-7952(02)00145-x

[13] S. Vorwerk, D. Cameron, and G. Keppel, *Clay soil in suburban environments: Movement and stabilization through vegetation. In Indraratna B, Chu J & Rujikiatkamjorn C (Eds.), Ground improvement case histories.* Butterworth-Heinemann. https://doi.org/10.1016/B978-0-08-100191-2.00022-8, 2015.

[14] D. López-Hernández, *Orinoco Savannahs: Primary production and biogeochemistry of the elements.* Caracas, Venezuela: Colección de Estudios Academia de Ciencias Físicas, Matemáticas y Naturales, 2019.

[15] A. Patel, *Geotechnical investigations and improvement of ground conditions.* Duxford: Woodhead Publishing, 2019.

[16] B. Kalantari, "Foundations on expansive soils: A review," *Research Journal of Applied Sciences, Engineering and Technology,* vol. 4, no. 18, pp. 3231-3237, 2012.

[17] C. López-Niño, E. Guevara, V. León, and D. López-Hernández, "Expansive clays from Northern Venezuela: Characterization using Atterberg limits, consistency indices and expansion tests," *Obras y Proyectos,* no. 34, pp. 111-122, 2023. https://doi.org/10.21703/0718-2813.2023.34.2451

[18] C. W. W. Ng and B. Menzies, *Advance unsaturated soil mechanics and engineering.* London and New York: Taylor & Francis Group, 2007.

[19] J. M. Anderson and J. S. I. Ingram, "Tropical soil biology and fertility: A handbook of methods," *Soil Science,* vol. 157, no. 4, p. 265, 1994. https://doi.org/10.1097/00010694-199404000-00012

[20] M. Codevilla, "Expansive clays of greater Buenos aires," presented at the XIX Argentine Congress of Soil Mechanics and Geotechnical Engineering. La Plata, Province of Buenos Aires, 2008.

[21] A. J. H. García, "Friability index of a sandy loam soil from the savannah of the Monagas state, Venezuela | Friability index of a savanna sandy loamy soil of Monagas state, Venezuela," *UDO Agrícola,* vol. 8, no. 1, pp. 107-117, 2018.

[22] R. T. Odell, T. H. Thornburn, and L. J. McKenzie, "Relationships of atterberg limits to some other properties of Illinois soils," *Soil Science Society of America Journal,* vol. 24, no. 4, pp. 297-300, 1960. https://doi.org/10.2136/sssaj1960.03615995002400040025x

[23] D. De la Rosa, "Relation of several pedological characteristics to engineering qualities of soil," *Journal of Soil Science,* vol. 30, no. 4, pp. 793-799, 1979. https://doi.org/10.1111/j.1365-2389.1979.tb01028.x

[24] J. M. D. L. D. Hernández-Sánchez, B. Figueroa-Sandoval, and M. R. Martínez Menes, "Physical properties of the soil and its relationship with plasticity in a traditional and no-till system," *Revista Mexicana de Ciencias Agrícolas,* vol. 10, no. SPE22, pp. 53-61, 2019.