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RELATIONSHIP OF WATER PARAMETERS WITH THE OPTIMUM MOISTURE CONTENT IN CLAY SOILS

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ABSTRACT

A compacted soil shows a deterioration in physical properties, affects the availability of water and the growth of plants. The amount of useful water in the soil is a characteristic of it that defines its agricultural aptitude and corresponds to the water that can be absorbed by the plants. This study aims to evaluate the relationship of water parameters, field capacity (FC) and permanent wilting point (PWP), with the optimum moisture content (OMC) in clay soils. The physical properties of the soil, such as texture, real and bulk density, maximum dry density (MDD) value and OMC are analyzed. The Proctor compaction test is used to determine the MDD and its OMC; a Richards Pressure Chamber is utilized to obtain the FC and PWP and a tension table to acquire other moisture retention parameters. The results indicated that in Latossolos (oxisols) of Brazil (LV, LVA) soils, the ratio for FC with water retention value of -100 hPa is 100% of OMC, and in Vertisol soil for -300 hPa is 100% of the OMC. For Latossolos (LV, LVA) soils, the PWP (-15000 hPa) is 80% of the OMC and for Vertisol soil 80% of the OMC. With statistical analyze a polynomial regression model is obtained to relate the water contents to OMC. This regression shows that exist a direct relationship between water retention and OMC values.

Keywords: proctor compaction test, compaction index, soil properties, soil water retention.

1. INTRODUCTION

The growth and development of plants are influenced by the environment, especially by the availability of water because it plays a vital role since it is practically involved in all physiological processes [1]. According to [2], the water deficit is due to the drought that triggers metabolic and physiological responses in plants affecting breathing, photosynthesis, both anatomical and metabolic reactions, nutrient absorption, development, growth, production, among others. The knowledge of the different ecophysiological strategies in the use of water by the species of the diverse communities is vital to be able to predict their response to fluctuations in the hydrological cycle susceptible to change by human activities, to establish programs of sustainable forest and livestock management [3].

Field capacity (FC) is the water content that is retained in the soil after being saturated with water [4]. In the case of non-saline soils, the water potential at field capacity varies between -0.1 to -0.3 bar. Water content is more significant than field capacity in fine textures with high clay and organic matter content [4]. In contrast to the field capacity, the permanent wilting point (PWP) is the most negative soil water potential at which the leaves of the plants do not recover their turgidity. The PWP is close to -15 bar (pF 4.2), although it depends on the type of plant [5].

Globally, the water potential of many plants has been investigated and related to the moisture present in the soil to properly plan irrigation, which allows the rational use of water. The amount of useful water in the soil is a characteristic of it that defines its agricultural aptitude and corresponds to the water that can be absorbed by the plants. Its limit is located between the field capacity (CC) and the wilting point (PM). The behavior of these clayey soils, with their mineralogy, determines the development and distribution of the root system of the crops that are established in them. Maintaining adequate levels of water in the soil is essential to ensure the success of crops in the field, together with factors of soil management, improved seeds and fertilizers. According to [6], the availability of water is the factor that governs the development of crops, because it strongly affects the rate of oxygen diffusion, temperature and mechanical resistance of the soil.

Soil compaction is one of the main problems for soil degradation in agriculture, and it is a severe problem due to the interaction between physical properties and plant growth and productivity, which leads to the need to have a parameter that integrates soil-plant interactions. When the compaction increases to excessive levels, the aeration can be affected if the humidity is high and on the other hand, in dry soil conditions, the soil resistance can restrict the growth of the plants [7]. Significant changes that occur in the soil structure in response to compaction, among others, will cause changes in the soil-water-air relationship and the mechanical resistance and, consequently, in the growth of plants in response to the physical characteristics of the soil [8].

The moisture content is important in compaction since it depends on the amount of water in the soil mass so that the particles and group of mineral particles can be rearranged under specific compaction energy, also determines the properties of the soil. Compaction humidity has a dominant effect on many properties of compacted soils [9] and dramatically affects soil infiltration. The compaction test, given its relative simplicity concerning equipment and procedures, represents a potential methodology to estimate the susceptibility or risks of soil compaction in the agricultural field [10]. Studies related to the compaction process have used tests frequently developed for use in soil mechanics [11]. An example of this is the application of the Proctor compaction test that is still rarely used in studies of tropical agricultural soils.

It is necessary to develop estimators to predict soil compaction processes to take the required preventive measures to reduce risks and avoid the adverse effects of this degradative process [12]. In this context, there is a need to develop indicators and methodologies that allow soil parameters to be related, so that knowing the optimum moisture content (OMC), the CC and PWP can be determined quickly and efficiently or vice versa, to maintain adequate levels of water in the soil for the good development and growth of crops. This study aims to evaluate the relationship of water retention, such as field capacity (CC) and permanent wilting point (PWP) in clay soils, with the optimum moisture content (OMC).

2. MATERIALS AND METHODS

A study area of 5000 m^2 was worked for each soil. Three types of soil were used. A Latossolo Vermelho (LV) from the municipality of Capinópolis, MG-Brazil, and a Latossolo Vermelho-Amarelo (LVA), from the municipality of Viçosa, MG-Brazil. The samples were collected at a depth of 0.4 to 0.6 m, and in the sequence, air-dried, passed through a 2 mm sieve (No. 10), physically characterized and organic matter (MO), moisture retention was also determined with equipment tension table and pressure chamber (Table-1). Mineralogical characterization of the clay fraction evidenced predominance of kaolinite and minor proportions of gibbsite, goethite and hematite.

The third soil type Vertisol (Vert) -Typic Haplustert, is located in the municipality of Sincelejo department of Sucre-Colombia, on the premises of the University of Sucre, at the headquarters "Red Door". The georeferencing is 9°19’6.84’’ N & Long: -75°23’35.52’’ E, and an elevation of 184 m.a.s.l. The climate of the area belongs to the classification of the tropical dry forest [13], has an annual rainfall of 1086.1 mm., and an average annual temperature of 27.5 °C. Geologically, in the study area, clay sedimentary materials have presented that alternate in some cases with sandstones and conglomerates. The physiography consists of landscapes located in colluvium-alluvial valleys surrounded by hills. Samples were collected from the first 0.2 m of the soil profile (Ap). The texture of the study site is clay type 2: 1, where Montmorillonite clay predominates; Physical characteristics such as moisture retention values are presented in Table-1.

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Table-1. Characterization of soil* samples sieved by 2 mm mesh.

Parameter	**LV**	**LVA**	**Vertisol**
Gross sand (kg kg^{-1})[1/]	0.13	0.14	0.03
Fine sand (kg kg^{-1})[1/]	0.12	0.06	0.02
Silt (kg kg^{-1})[2/]	0.16	0.06	0.38
Clay (kg kg^{-1})[2/]	0.59	0.74	0.57
Bulk density (kg dm^{-3})[3/]	1.16	0.97	1.22
Particle density (kg dm^{-3})[4/]	2.83	2.66	2.59
Porosity (m^3 m^{-3})[5/]	0.590	0.635	0.529
Macroporosity (m^3 m^{-3})[5/]	0.188	0.209	0.069
Microporosity (m^3 m^{-3})[6/]	0.402	0.426	0.460
Maximum Dry Density (kg dm^{-3})[7/]	1.64	1.37	1.42
Porosity in the Maximum Dry Density (m^3 m^{-3})[5/]	0.421	0.485	0.452
Optimum moisture content, gravimetric base (kg kg^{-1})[7/]	0.244	0.324	0.266
Optimum moisture content, volumetric base (m^3 m^{-3})[5]	0.400	0.444	0.377
Degree of saturation in the Optimum moisture content (m^3 m^{-3})[5]	0.950	0.915	0.834
Water retention (kg kg^{-1})[8/]			
-60 hPa	0.346	0.417	0.380
-100 hPa	0.276	0.359	0.341
-300 hPa	0.206	0.278	0.299
-1.000 hPa	0.186	0.256	0.246
-5.000 hPa	0.176	0.249	0.223
-15.000 hPa	0.170	0.235	0.214
Organic matter (dag/kg)[9/]	1.39	2.99	1.27

[*] LV - Latossolo Vermelho (Red Oxisol Soil; LVA - Latossolo Vermelho Amarelo (Red - Yellow Oxisol Soil); Vert - Vertisol Soil.
[1/] By sieve [18]. [2/] Pipette method [18]. [3/] Test tube method [18]. [4/] Volumetric Balloon Method [18]. [5/] [18]. [6/] Tension table [19]. [7/]Test NBR 7182 [20]. [8/] [21]. [9/] Modified Walkley-Black Method [22].

The Proctor test was used to determine the maximum dry density (MDD), concerning the amount of water. The samples were subjected to natural drying in the laboratory. Subsequently, the lumps crumbled and finally passed through sieve number four (# 4) of 4.75 mm. Samples of 3 kg of each soil material were taken and subsequently moistened with different moisture values; Then the soil was placed inside the Proctor cylinder so that it occupies a third of the volume of the test body (The three layers of the soil must have approximately the same height). The material received 25 blows from a 2.5 kg hammer at the height of 0.30 m, representing a compaction energy of 60.5 kg m m^{-3}. The excess soil was removed with a spatula, and finally, the whole was weighed, the density and humidity of a sample taken from the center of the mold were measured. The procedure was repeated five (5) times per test to obtain the 5 points of each graph (Density Vs. Humidity). The water content under which the maximum dry specific gravity is reached is called the optimum moisture content (OMC).

From the known OMC of the Proctor test for each soil, six (6) OMC Indexes (OMC-I) were worked: 1.0 (100% OMC value), 0.9 (90% OMC value), 0.8 (80% OMC value), 0.7 (70% OMC value), 0.6 (60% OMC value), 0.5 (50% OMC value); to compare them respectively with the different water retention values (matrix potentials): -60 hPa, -100 hPa, -300 hPa, -1000 hPa, -5000 hPa, -15000 hPa, obtained in tension table and pressure cookers (Table-2).

Table-2. Water retention and optimum moisture content index for the three (3) soils.

Soil type	Water Retention ($kg\ kg^{-1}$)	OMC-I ($kg\ kg^{-1}$)
1 LV	0.346	0.244
1 LV	0.276	0.219
1 LV	0.206	0.195
1 LV	0.186	0.171
1 LV	0.176	0.146
1 LV	0.17	0.122
2 LVA	0.417	0.324
2 LVA	0.359	0.291
2 LVA	0.278	0.259
2 LVA	0.256	0.226
2 LVA	0.249	0.194
2 LVA	0.235	0.162
3 Vert	0.38	0.266
3 Vert	0.341	0.239
3 Vert	0.299	0.212
3 Vert	0.246	0.186
3 Vert	0.223	0.159
3 Vert	0.214	0.133

Through the regression analysis, a polynomial equation of degree 2 was determined, together with the corresponding correlation coefficient, which quantified the degree of association between variables. The relationship between the variables was calculated using Statgraphics statistical software, variation (ANOVA) with a 5% level of significance and the comparison of means with the Tukey test was applied. A completely randomized block design was used, with a factorial arrangement and four repetitions.

3. RESULTS AND DISCUSSIONS

There is a direct proportionality between the soil water retention variables and the OMC-I. The best fit is the polynomial equation of degree 2, with a significant and positive value determination coefficient (0.84), and a correlation coefficient 0.92 denoting a high degree of association between the two variables as can be seen in Figure-1 (Water retention vs. OMC-I) for the three types of soils. The determined equation can be used to find the critical compaction humidity or moisture retention, in the kinds of soil studied.

According to Figure-1, in Latossolos (oxisols) of Brazil (LV, LVA) soils, the ratio for FC with water retention value of -100 hPa is 100% of OMC, and in Vertisol soil for -300 hPa is 100% of the OMC. For Latossolos (LV, LVA) soils, the PWP (-15000 hPa) is 80% of the OMC and for Vertisol soil 80% of the OMC.

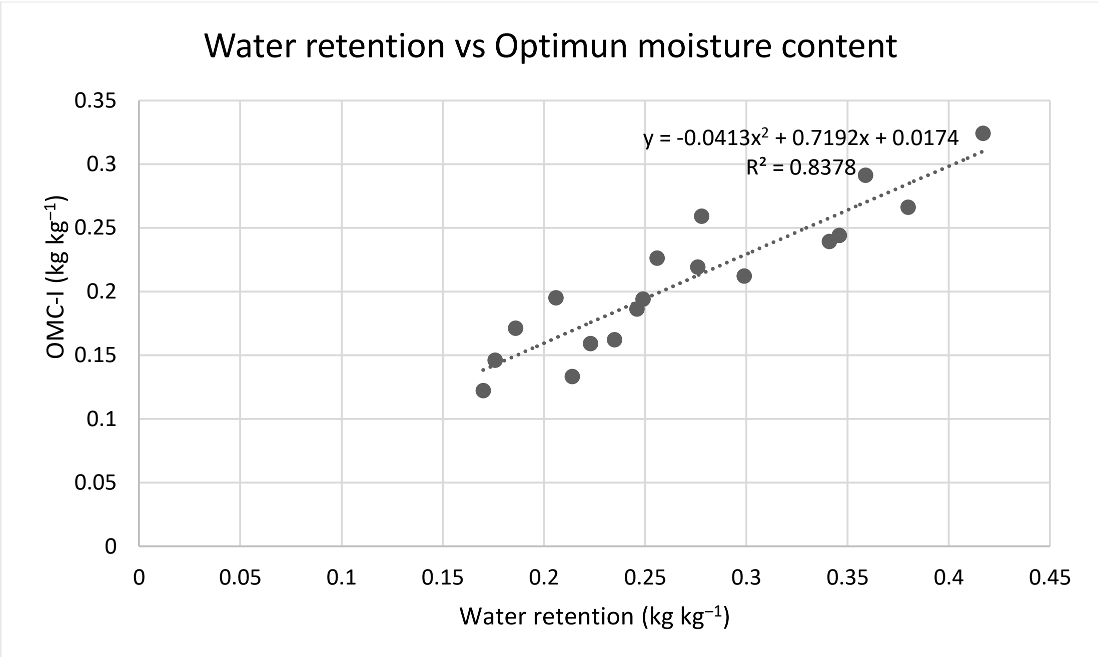

Figure-1. Characteristic curve of soil water retention and optimum moisture content.

The values of OMC obtained in this investigation can be considered as referents for the preparation of the soil with the purpose of not introducing agricultural machinery when the soil moisture is close to or higher than these values because they would increase the risks of compaction [13].

In Figure-2, it is observed that the water retention values are more distributed below the average than above it. For the OMC, the opposite occurs, which can be noted that a concentration of the OMC values generates concentration in water retention values.

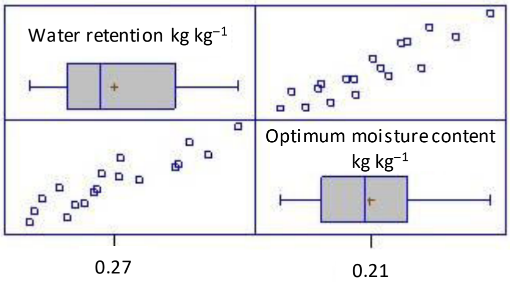

Figure-2. Water retention and optimum moisture content distribution.

The ratio of variables in Latossolos soils (LV, LVA) for field capacity (FC) with water retention value of -100 hPa is 100% of the HCC. FC has traditionally been used the equilibrium water content at -333 hPa [14]. This value, close to CC in temperate climate soils, with a predominance of silicated clays, is inadequate when they are native soils of tropical and humid regions, regardless of their particle size composition. According to [15], the FC in Brazilian soils was located in the range of approximately -60 to -100 hPa, with higher potential values in the sandiest materials and lower in the more clay. In [16] it was concluded that the use of -333 hPa to estimate the FC is incorrect after analyzing 88 Latossolos and Neossolos Quartzarênicos.

Concerning the organic matter of each soil (Table-1), the OMC is higher in soils with a higher percentage of clay and silt; this is because the soil acquires higher humidity and resistance to compaction as it incorporates more organic matter [13]. The strong correlation between humidity (OMC) for each of the moisture retention potentials of -100 hPa and -300 hPa for FC and -15000 hPa for PWP is relevant.

From the physical point of view, variations in the water content in the soil cause changes in consistency, due to the degree of cohesion of the soil mass and the adhesion of water to the constituents of the solid phase. Therefore, soils are more resistant to low soil moisture pressures and more susceptible to compaction with high soil moisture [17].

4. CONCLUSIONS

There is a direct relationship between soil water retention and optimum moisture content (OMC) in Latossolos clay and Vertisol soils, with a polynomial tendency. This mathematical model can be used starting from the OMC to determine the field capacity (FC) and the permanent wilting point (PWP) for the soils studied or vice versa.

In Latossolos (oxisols) of Brazil (LV, LVA) soils, the ratio for FC with water retention value of -100 hPa is 100% of OMC, and in Vertisol soil for -300 hPa is 100% of the OMC. For Latossolos (LV, LVA) soils, the PWP (-15000 hPa) is 80% of the OMC and for Vertisol soil 80% of the OMC.

It is recommended to extend the research to a more significant number of soils to increase the amount of compaction and moisture retention analyzes, and to determine the association between these soil characteristics, to make the obtaining of results more representative, and to have greater acceptance of the producers and professionals in the area.

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