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Tensile strength in horizons with and without cohesive character: Variability and relation with granulometry

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ABSTRACT

Soils of Coastal Tablelands are important for the economic and social development of the coastal region of Brazil. However, these soils appear to have a number of chemical and physical limitations. One of the most expressive physical limitations is the occurrence of cohesive character, whose genesis is still not fully understood. Thus, considering that the tensile strength is a direct measure of the cohesion of particles, this research was undertaken to discover how the size of soil particles influences the genesis of the cohesive character in Bt horizons of the Coastal Tablelands of Ceará, Brazil. The study was carried out in the municipality of Aquiraz-CE, where samples of two soils were collected (Argissolo Vermelho-Amarelo Distrófico típico – PVAd; Argissolo Amarelo Eutrocoeso abrúptico – PAex) in the horizons Bt1 (cohesive) and Bt2 (non-cohesive) in the top, middle and bottom portions. The results demonstrated that the size of the particles led to sandy clay loam texture in horizons of PVAd and sandy clay texture in the horizons of PAex. Regarding sand sorting, for all investigated horizons and in the three positions (top, middle and bottom), the medium sand fraction prevailed, followed successively by fine and very fine sands together, coarse and very coarse sands. Tensile strength values were higher in cohesive horizons, with reduction in the tensile strength of aggregates from top to bottom. It was concluded that tensile strength was a useful indicator for differentiating cohesive properties in the different soil horizons. There was significant variation of tensile strength in the soil horizon defined by the pedologist – which suggests that it is necessary to include as a valuable addition to the diagnostic tools available to the working pedologist, a tensile strength scale for the identification of cohesion to avoid subjectivity in the definition of the cohesive horizon. For the studied set of horizons, tensile strength decreased from top to bottom. Sand and clay fractions, despite not being the only determinant factor, influenced the genesis of the cohesive character in soils. For the sand fraction, poor degree of sand sorting led to a denser packing of particles, significantly contributing to the cohesion of aggregates. Our experiment strongly suggests that the packing of particles allows the increase of cohesion provided there is a cementing agent even in small quantity.

1. Introduction

Coastal Tablelands are geomorphological features that, in general, have flat or gently undulated topography and are related to the sediments of the Barreiras Formation, distributed over almost the entire coastline of Brazil. These soils are of great economic importance, because they are intensively used for the production of sugarcane, tropical fruit crops, cassava and also the rearing of livestock (Jacomine, 2001). However, some of these soils exhibit chemical and physical limitations.

Regarding physical limitations, one of the most expressive is the occurrence of horizons with cohesive character, which cause impediments to root penetration, alter water and air dynamics, affect root respiration, contribute to the appearance of saturated zone and interfere with agricultural yield (Souza et al., 2008; Vieira et al., 2012). The term “cohesive character” is widely used to define subsurface mineral horizons that are hard to extremely hard when dry, and friable to firm when wet (Embrapa, 2013).

It is important to add that there are reports of horizons with cohesive character in other parts of the world, for instance, hardsetting horizons in Australia, defined as compact, hard when dry, with

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aggregates that do not deform when pressed between thumb and index finger, but become soft after wetting (McDonald et al., 1990). The possibility of occurrence in Brazil of soils with behavior similar to hardsetting soils was mentioned by Mullins et al. (1990).

Horizons with cohesive and hardsetting character are limiting to root growth for most agricultural crops, because there is a resistance to penetration. One of the consequences is the water deficit due to the small volume explored. In irrigated crops, it is possible to overcome some limitations, but the collapse of soil structure when wet may lead to stress by lack of oxygen to the roots (Mullins, 1997; Rezende, 2000).

Continuous and excessive cultivation of the soils of Coastal Tablelands may cause degradation, by removing the superficial layer through erosive processes. It causes the cohesive horizon to become apparent or more superficial, compromising root development and substantially reducing crop yield. In this context, studies characterizing this type of soil, involving genetic aspects, are necessary to recommend the correct form of management to avoid degradation, especially when there is little research on the topic and the access to such information is very limited.

Studies have indicated that the horizon with cohesive character, of natural occurrence, results from the action of different pedogenetic processes that determined its formation: grain size (including degree of sand sorting), clay translocation, action of cementing agents poorly crystallized and densification resulting from the structure alteration by wetting-drying cycles (Ribeiro, 1986; Abrahão et al., 1998; Vieira et al., 2012). It is important to note that soils developed from the same parent material, with similar granulometry and mineralogical composition, can have profiles with and without cohesive horizons in the same area.

There are reports in the literature that parameters associated with the sand fraction, such as size distribution, degree of roundness, specificity and roughness have significant effect on pore-size distribution, compressibility and cohesion of soils with higher sand contents (Coulon and Bruand, 1989; Panayiotopoulos, 1989). Corrêa et al. (2008) and Lima Neto et al. (2009, 2010) suggest that the genesis of horizons with cohesive character may be related to the translocation of fine clay which, after dispersion, contributes to increasing the contact between larger soil particles (sands, for instance), consequently increasing tensile strength.

Tensile strength has been employed to measure the effect of the densification of horizons with cohesive character and can be understood as the force per area unit necessary to cause rupture of aggregates. It is a relevant parameter for determining the energy necessary to cultivate the soil and break it into smaller aggregates. It is important to note that soils with cohesive character exhibit high tensile strength, which results from the bonding of sand grains by clay and silt, maintaining a considerable stiffness (Giarola et al., 2003).

The present study considered the hypotheses that a) there is variation of tensile strength within the soil horizon and b) the genesis of cohesive character, whose magnitude of cohesion is directly and proportionally correlated with the tensile strength of the aggregates, is influenced by granulometry and poor degree of sand sorting. Therefore, the objective was to identify the tensile strength variability within the soil horizon and evaluate the contribution of granulometry and sorting of sands to the genesis of horizons with cohesive character on the Coastal Tablelands of Ceará, Brazil.

2. Material and methods

2.1. Soil collection and analyses

Both soils in which samples were collected, classified according to Embrapa (2013) as Argissolo Vermelho-Amarelo Distrófico típico (PVAd) and Argissolo Amarelo Eutrocoeso abrúptico (PAex), are located in the municipality of Aquiraz, Ceará state, Brazil (Fig. 1), in an area of Coastal Tableland. The criterion for selecting these soils was that, necessarily, at least one horizon showed cohesive character. The top of the cohesive Bt horizons starts at 81 cm and 107 cm below the soil surface for the PVAd and PAex, respectively. As to the non-cohesive Bt horizons, the horizon immediately below the cohesive Bt horizon was considered in each soil.

In each soil, Bt horizons with and without cohesive character were selected for the collection of three blocks with dimensions of $15 \times 20 \times 10$ cm (width × length × height), respectively. One block was collected in the top, one in the middle and one in the bottom of each horizon.

The blocks were wrapped in plastic film whilst still out in the field. In the laboratory, after being air-dried, each block was placed on a tray covered with a sponge (2-cm thick, approximately) and moistened with water, through capillarity, up to approximately field capacity. After reaching such condition, the samples were subdivided into aggregates through the application of a force that was minimal but sufficient to separate them by their points of weakness. Such manual break was performed until the aggregates passed through a 25-mm-mesh sieve, but were retained by a 19-mm-mesh sieve (Almeida, 2008), thus defining aggregates with diameter between 19 and 25 mm.

Aggregates were aired for 36 h for drying and water content homogenization and maintained in an oven at 60 °C for 24 h (Figueiredo et al., 2011). After this procedure and after the aggregates had been left at room temperature for 24 h, tensile strength tests were conducted using a linear electric actuator at constant speed of $0.03\ mm\ s^{-1}$ (Tormena et al., 2008). In each horizon, 90 aggregates were considered (30 from the top, 30 from the middle and 30 from the bottom), totaling 180 aggregates per soil profile. Six aggregates were considered to compose one replicate (due to the necessity of a sufficient amount of air-dried fine earth for physical analyses), based on the arithmetic mean of the data to define the value of the replicate. In this case, 30 aggregates were used to define five groups, each one composed of six aggregates, thus totaling five replicates.

Prior to the tensile strength test, each soil aggregate was weighed on analytical scales at room temperature (each aggregate weighed 14.5 g on average). The aggregate was individually placed at the most stable position between two metal plates: the lower one fixed to the base of the device and the upper one, mobile, connected to the extremity of the linear electric actuator's load cell, with capacity for 20 kgf. The value of the load used for tensile rupture was recorded by an electronic data acquisition system. After each rupture procedure, one portion of the six aggregates sample, 20 g (Uhland, 1951), was weighed on analytical scales and subjected to drying in an oven at 105 °C for 48 h, to calculate the water content of the soil aggregate. The remaining part of the aggregate samples was used for granulometry and sand sorting analyses.

Tensile strength was calculated according to Dexter and Kroesbergen (1985),

$$TS = (0.576\ P)/D^2\ 10^3)$$

where TS is the tensile strength of aggregates (kPa), 0.576 the proportionality constant of the relationship between the applied compressive stress and the tensile stress generated inside the aggregate, P is the applied force (N), and D is the effective diameter of the aggregate (m). The effective diameter of the aggregate was measured by the following equation (Watts and Dexter, 1998):

$$D = D_m\ (M/M_o)^{0.333}$$

where D_m is the mean diameter of the aggregates [(25 + 19)/2, in mm], determined by the average of the mesh sizes of the sieves, M is the mass (g) of the individual aggregate dried at 105 °C, and M_o is the average mass (g) of the 90 aggregates of each horizon dried at 105 °C.

For granulometry, the clay fraction was quantified through the pipette method, sand fraction through sieving, and silt by the difference between the total weight of the sample dried in the oven and the sum of sand and clay (Gee and Bauder, 1986). 1-N sodium hydroxide was used for chemical dispersion of the particles. Sand sorting was performed considering four classes of diameter: $1 < Ø \leq 2$ mm – very coarse