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Load-bearing capacity and its relationships with the physical and mechanical attributes of cohesive soil

Renato Paiva Lima [a,*], Mario Monteiro Rolim [b], Veronildo Souza Oliveira [b], Anderson Rodrigo Silva [d], Elvira Maria Regis Pedrosa [b], Rinaldo Luiz Caraciolo Ferreira [c]

[a] *Soil Science Department, Escola Superior de Agricultura Luiz de Queiroz, Universidade de São Paulo (USP), Pádua Dias, 11, Piracicaba, SP 13418-900, Brazil*

[b] *Programa de Pós-Graduacão em Engenharia Agrícola, Universidade Federal Rural de Pernambuco (UFRPE), Dom Manoel de Medeiros, s/n, Dois Irmãos, Recife, PE 52171-900, Brazil*

[c] *Programa de Pós Graduação em Ciências Florestais, Universidade Federal Rural de Pernambuco (UFRPE), Dom Manoel de Medeiros, s/n, Dois Irmãos, Recife, PE 52171-900, Brazil*

[d] *Goiano Federal Institute, Agronomy, Geraldo S. Nascimento Road, 75790-000, Urutaí, GO, Brazil*

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Abstract

In north-eastern Brazil, sugarcane is mostly explored in coastal tablelands, where the soil has a particular feature that is called the "cohesive character". This study aimed to analyse the relationship between physical properties of the soil and the preconsolidation pressure (σ_p) variation in cohesive soil. The work was performed in the Ultisol area, where sugarcane is cultivated. On a single plot, 42 points were delimited to obtain samples at depths of 0.10–0.13 and 0.30–0.33 m, which resulted in 84 samples in total. Deformed and undeformed samples were collected to measure the following variables: water content, bulk density, soil penetration resistance, organic carbon, clay content, liquid limit, plastic limit, and the σ_p. For each layer, a principal component analysis was performed. After the scores for those components were obtained, a linear multiple regression model was fitted for the σ_p data to establish the relationships between the variables. The water content and the organic carbon showed negative relations with σ_p. The bulk density, soil penetration resistance, clay content, liquid limit and plastic limit were positively related. Higher σ_p values are associated with higher values of bulk density, soil penetration resistance, clay content, liquid limit and plastic limit, and smaller values are linked to an increase in water content and organic carbon.

Keywords: Cohesive soil; Compressibility; Soil deformation; Multivariate analysis

1. Introduction

Brazil is the largest holder sugarcane production technology worldwide, and sugarcane is one of the most important crops in the Brazilian agricultural sector. In the Northeast, sugarcane is mostly explored in coastal tablelands, where the soil has a particular feature that is called the "cohesive character" (Farias et al., 2013).

According to Giarola et al. (2003), when cohesive soil is dry, the cohesiveness acts as a limiting factor for plant development and mechanised operations, which leads to productivity loss and energy demand for mechanisation. The most striking physical attributes of cohesive soil are its high bulk density, low permeability and high resistance to penetration when dry.

* Corresponding author.
E-mail address: renato_agro@usp.br (R.P. Lima).

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σ_p	preconsolidation pressure	α_j	the j-th regression coefficient associated with the j-th principal component
θ	soil moisture	ε_i	the random effect associated with the regression of y_i
BD	bulk density	R^2	multiple coefficient of determination
PR	resistance penetration	SE	standard error
OC	organic carbon	β_0	the intercept of the regression model based on the original variables
CC	clay content	β_j	the j-th regression coefficient associated with the j-th original variable
PL	plastic limit	$\bar{\mathbf{x}}$	the vector of the means of the explanatory variables
LL	liquid limit	D	diagonal matrix containing standard deviation
CV	coefficient of variation	V	the matrix of eigenvectors
PC	principal component		
PCA	principal components analysis		
a	eigenvector		
λ	eigenvalue		
y_i	response variable		
α_0	the intercept of the principal component regression		

Because of the traffic intensity in agricultural areas, the soil forms compacted layers (Hamza et al., 2011). The compaction process is influenced by soil moisture (Gao et al., 2012; Han et al., 2011), organic carbon (Pereira et al., 2007; Keller and Håkanssona, 2010), texture (Imhoff et al., 2004; Ampoorter et al., 2010) and consistency limits (Kondo and Dias Junior, 1999; Keller and Dexter, 2012), while the soil bulk density and the penetration resistance are diagnostic attributes of soil compaction process (Keller and Håkanssona, 2010; Gao et al., 2012).

In this sense, soil compaction becomes an important factor in soil management, particularly after the use of mechanised harvesting in some areas of the coastal tablelands. According to Hamza et al. (2011), the compression process can be understood by studying the compressibility.

The compressibility is characterised using a process that describes the decrease in soil volume when the soil is exposed to a mechanical load with or without water (Keller and Arvidsson, 2007). Therefore, this process is important for characterising the effects of pressures that are imposed on the soil by agricultural machinery.

The most important soil compressibility variable is the preconsolidation pressure. The preconsolidation pressure is a component of the compression curve, which reflects the history of the soil stress. Therefore, the preconsolidation pressure is the highest pressure that can be applied to the soil to prevent soil compaction (Dias Junior and Pierce, 1996; Keller and Arvidsson, 2007).

The compression process in the cohesive soils of the coastal tablelands was studied by Oliveira et al. (2011) for different management systems. The authors observed that for different water contents, the average preconsolidation pressure ranged from 57 to 140 kPa; under these conditions, the soil suffered compaction. According to the authors, the inflating pressure of a tire machine is approximately 180 kPa, which is far above the load-bearing soil capacity (Oliveira et al., 2011).

The conclusions of Oliveira et al. (2011) demonstrate the fragility of cohesive soils; therefore, advance research on the compressive behaviour is required for managing cohesive soils in coastal tablelands.

Although the preconsolidation pressure, which is widely used by Oliveira et al. (2011), Dias Junior and Pierce (1996) and Keller and Arvidsson (2007), is an important indicator for characterising the load-bearing capacity and the compressive behaviour of soil, it is a difficult variable to measure because of the demands of material collection (undisturbed sample), as well as laboratory conditions and modern equipment that are not common in research centres.

To solve this problem, researchers have proposed the use of relations or pedotransfer functions to understand the behaviour of a dependent variable as a function of one or more independent variables (Imhoff et al., 2004; Saffih-Hdadi et al., 2009; Severiano et al., 2010).

Some relationships between the soil physical properties and the preconsolidation pressure have been established to predict the soil load-bearing capacity and assist agricultural planning. However, we often propose models to predict the preconsolidation pressure in relation to a few variables (Imhoff et al., 2004; Dias Júnior et al., 2007; Pereira et al., 2007; Saffih-Hdadi et al., 2009; Severiano et al., 2010). However, in the soil system, there are other relationships that can be used to characterise the soil compression process (Imhoff et al., 2004).

In many studies (Imhoff et al., 2004; Dias Júnior et al., 2007; Pereira et al., 2007; Saffih-Hdadi et al., 2009; Severiano et al., 2010), the authors attempt to establish relationships between the preconsolidation pressure and the soil physical properties using univariate statistical tests; however, in nature, the phenomenon depends on many variables that have direct and indirect relationships (Manly, 1994). Thus, it is not sufficient to determine only the behaviour of a dependent variable; rather, its relationship with other variables must be analysed in a multivariate manner.