MECHANICAL PROPERTIES OF AN ALFISSOL SUBMITTED TO AGRICULTURAL MACHINERY TRAFFIC IN A SEMIARID REGION IN BRAZIL

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ABSTRACT

The load carrying capacity of the soil can be determined from preconsolidation curves, being sensitive to the variation of loads and extremely sensitive to changes in soil moisture. For this study, the water content in soil was 2.50% and 10.58% for the layer from 0 to 0.15 m. Soil samples were collected before and after traffic with one and two passes of a tractor weighing 7100 kg, equipped with 14.4-24 R1 bias tires on the front with inflation pressure of 82.74 kPa and 18.9-34 R1 rear tires with inflation pressure of 96.53 kPa, and a tire ground contact area of 0.11 m^2 and 0.13 respectively for the front and rear tires. The speed at the time of the pass for each treatment was 2.22 m s^{-1}. Regardless of the soil water content, the load carrying capacity increases with the traffic of machines due to reduction of voids. Preconsolidation curves should be used with caution due to the use of samples for determining the points in saturated conditions, and when recommended for load-bearing capacity, unsaturated samples should be used.

Keywords: Preconsolidation pressure. Void index. Compression index

RESUMO

PROPRIEDADES MECÂNICAS DE UM ARGISSOLO VERMELHO AMARELO SUBMETIDO AO TRÁFEGO DE MÁQUINAS AGRÍCOLAS DE UMA REGIÃO SEMI-ÁRIDA NO BRASIL

A capacidade de suporte de carga do solo pode ser determinada pelas curvas de preconsolidação, sendo sensível à variação das cargas e extremamente sensível às mudanças na umidade do solo. Para realização deste trabalho, o teor de água no solo foi de 2,50% e 10,58% para a camada de 0 a 0,15m. As coletas de solo foram realizadas antes e depois do tráfego com uma e duas passadas de um trator agrícola com peso de 7.100 kg, equipado com pneus diagonais dianteiros 14.4-24 R1, pressão de inflação de 82,74 kPa e pneus traseiros 18,9-34 R1 com pressão de inflação de 96,53 kPa, e área de contato pneu solo de 0,11 e 0,13 m^2 para o pneu dianteiro e traseiro, respectivamente. A velocidade de deslocamento no momento da passada para cada tratamento foi de 8 km h^{-1}. Independente do teor de água do solo, a capacidade de suporte de carga aumenta com o tráfego de máquinas devido à redução do índice de vazios. As curvas de preconsolidação devem ser utilizadas com ressalvas, devido ao uso das amostras para determinação dos pontos em condições saturadas, e quando recomendadas para capacidade de suporte de carga devem ser utilizadas amostras não saturadas.

Palavras-chave: Pressão de preconsolidação. Índice de vazios. Índice de compressão

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INTRODUCTION

A major cause of compaction of agricultural soils is the heavy traffic of machines and carrying out agricultural activities when the water content is greater than that recommended for operations. Dexter *et al*. (2007) reported that there is a reduction of the pore space, especially macropores.

Impacts on the macropores are of particular concern, since these structures play a crucial role in soil processes, such as drainage and aeration, as reported by Blackwell *et al*, (1990) and Allaire-Leung *et al*., (2000). According to Schäfer-Landefeld *et al*., (2004), although the effect caused by one machine in a single pass over the ground is minimal, these small changes can have additive effects with frequent use.

The reduction in soil porosity due to external pressures exerted by agricultural machines has been simulated by an uniaxial compression test, obtaining the soil compression curve, which plots the relationship between the parameters of soil structure, void index and porosity or bulk density as a function of the vertical pressure applied (CAVALIERI *et al*., 2008; KRUMMELBEIN *et al*., 2008), which is generally regarded as a stress where soil deformation changes from elastic and reversible to plastic and therefore irreversible (LEBERT; HORN, 1991; KIRBY, 1991).

The concept was originally derived from measurements in saturated soils (Casagrande, 1936), but was also suitable for unsaturated conditions (LEBERT; HORN, 1991). Casagrande (1936) developed a graphical procedure to determine the strain of pre-compression and void index on the logarithm of the applied tension. This is still considered the standard process for determining the pre-compression stress (ARVIDSSON ; KELLER, 2004; BERLI *et al*. 2004; HORN, 2004; KELLER *et al*., 2004). These stresses, also referred to as normal stress and shear stress, are transmitted to the soil mass by the wheel set-soil contact area (BARBOSA *et al*., 2004).

Poodt *et al*. (2003) identified cohesion and tension of pre-consolidation as the most important parameters in predicting risk to subsurface compaction parameters and are widely used in the compaction model (DEFOSSEZ ; RICHARD, 2002; PEREIRA *et al.* 2007).

The objective of the present study was to assess the pre-consolidation stress and compression index of the soil due to the effect of a 4x2 MW tractor on Alfissol at different moisture levels.

MATERIALS AND METHODS

The experiment was conducted in Fortaleza (Ceará State, Brazil, 3° 44’’ 47 ‘S and 38° 34’’ 51’ W, and average elevation of 26 m). The climate is part of the second classification by Koppen as Aw’, wet tropical, with average annual temperature of 28 °C and precipitation of 900 mm. The soil under study was classified as an Alfissol (EMBRAPA, 2006), with spontaneous vegetation and has been fallow for six months.

To determine the physical properties of the soil, undisturbed soil samples were collected randomly at 0-0.20 m depth, using a Uhland-type sampler, and then taken to the Laboratory of Soil Analysis, Federal University of Ceará, for determination of particle density, bulk density, liquid limit, plastic limit, limit of consistency and particle size, according to the methodology of EMBRAPA (2006). Table 1 shows the results of the physical properties of the soil in the study area.

Table 1. Properties of the soil.

Texture classification	Sandy-loam	Liquid limit	13.47
Particle density (g cm^{-3})	2.72	Plasticity limit	NP
Soil density (g cm^{-3})	1.68	Shrinkage limit	NC
Porosity (%)	36.23	Clay (%)	10.62
Initial saturation	62.13	Sand (%)	82.91
Sample moisture	15.13	Silt (%)	6.46

For the uniaxial compression tests, undisturbed samples were randomly collected with a 4x2 MFWD tractor using metallic cylinders measuring 0.110 m in diameter and 0.95 m tall, under the following conditions: 1) where the soil collected showed 2.5% moisture, considered dry soil; and 2) after precipitation where soil moisture was at 10.58%, considered moist, thus indicating two treatments for the study area.

For each treatment, three samples were collected before submitted to traffic, and after one and two passes of the tractor. The total weight of the tractor is 5.700 kg, with diagonal type pneumatic tires having the following specifications: 14.4-24 R1 front tires with inflation pressure of 82.74 kPa and rear tires from 18.9 to 34 R1 with inflation pressure of 96.53 kPa, with tire ground contact area of 0.11 and 0.13 m^2, respectively, for the front and rear tires; the speed at the time of the pass for each treatment was 2.22 m s^{-1}.

Upon completion of the collection, the samples were properly sealed using cotton cloth and paraffin, with the goal of maintaining the moisture content and history of tension, as they were in the field. The determination of these attributes allowed a current assessment of the effect of management on soil structure at different moisture contents.

Soil samples were subjected to a uniaxial compression test in a Bishop of Solotest® press of 1:10 density ratio and static loads of 25, 50, 100, 200, 400, 800 and 1600 kPa were applied for 30 minutes according to the standard NBR-12007/90 (ABNT, 1990). From this test we obtained the uniaxial compression curves of the soil, which graphically represent the relationship between the logarithm of applied pressure and void index.

For this purpose, the soil compression curve enabled indentification of the point of maximum curvature, and thus drawing a parallel to the y-axis and a tangent to the curve. The angle formed between these two lines formed the bisectrix. The abscissa for the point of intersection with the extension of the bisectrix of the dashed line corresponds to the preconsolidation pressure.

The void ratio was determined according to Equation (1); the variable "e" was determined before the compression test (e_i) and after application of each pressure.

$$e = Vv/Vs \tag{1}$$

Where,

e = void index;
Vv = void volume; and
Vs = volume of solids.

In determining the coefficient of compressibility (Cc), we used the methodology developed by Casagrande (1936), according to Equation 2.

$$Cc = \frac{e1 - e2}{log\sigma 2 - log\sigma 1} \tag{2}$$

Where,

e = Void index; and
σ = standard pressure at points located on the characteristic curve of soil compressibility.

Statistical analysis for comparison of means between treatments was performed using the statistical program ASSISTAT 7.6 BETA.

RESULTS AND DISCUSSION

Graphical representation of the relationship between the decrease in void index and the addition of the logarithm of pressure applied to the soil can be observed by the soil compression curve in Figure 1, which represents the behavior before tractor traffic (A and B), with one tractor pass (C and D) and two passes of the tractor (E and F) in wet and dry soil, respectively.

For the soil compression curve, we estimated values of pre-consolidation pressure (σpc), which are considered the load-bearing capacity of the soil, as reported by Hartge and Horn (1984); Imhoff *et al*, (2004); Lebert and Horn (1991). Values were found of 60, 68 and 84 kPa for the wet soil condition, and 95, 98 and 181 kPa for the dry soil condition after 0, 1 and 2 passes, respectively.

Considering that the mechanical properties of the soil are strongly influenced by soil water content, which in general become more resistant to compaction when the water content is low (HORN

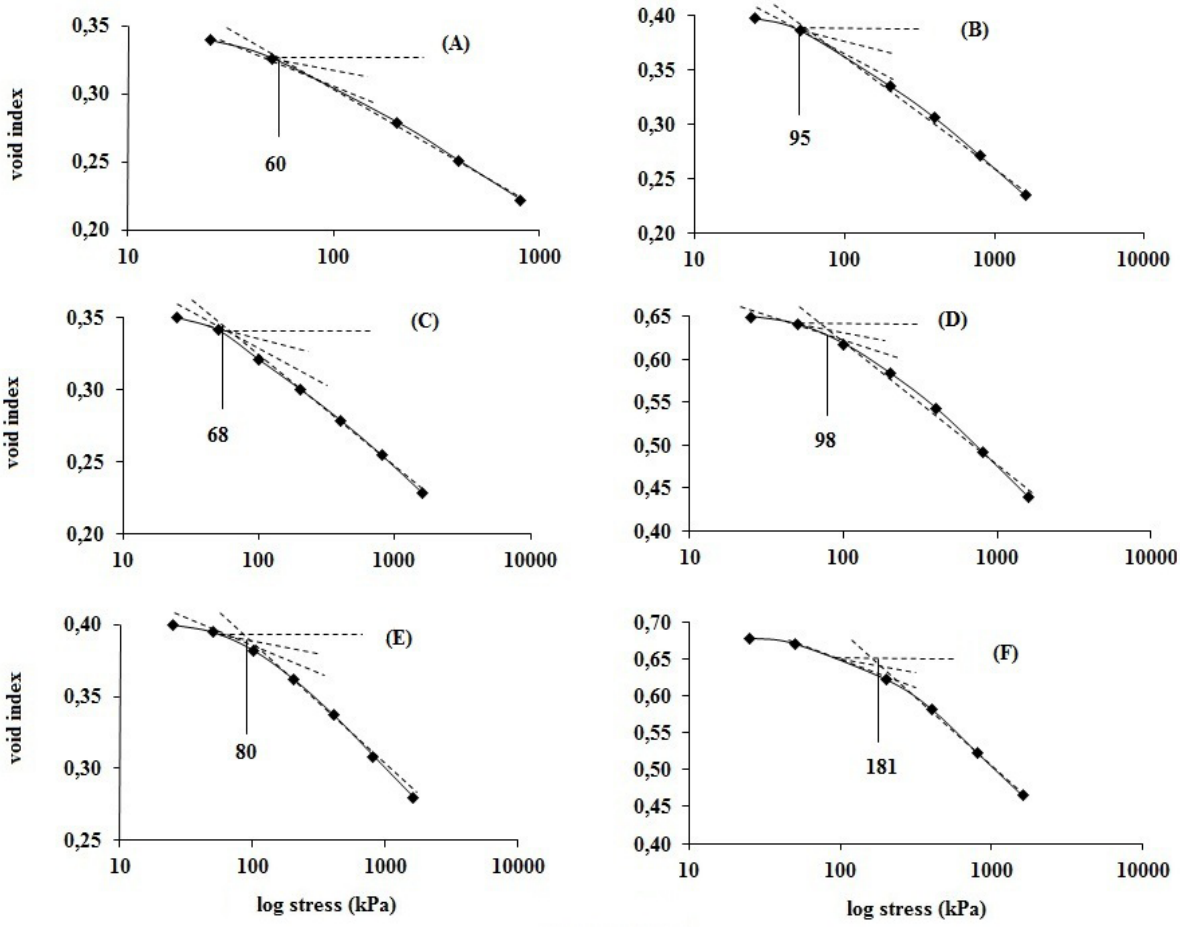

Figure 1. Compression curve of soil with no traffic when wet (A) and (B), with traffic (one pass) wet (C) and dry (D), and with traffic (two passes), wet (E) and dry (F).

et al., 1998), we observed the highest σpc values in the dry soil condition. This behavior of the dry soil is due to the following facts: there is increased resistance to shearing, changes in water pressure in the soil voids are practically zero when subjected to loads, cracks and expansion/collapse of the soil, or to increased water content. In contrast, soils with higher moisture content present less resistance when subjected to varying loads and occasional occurrence of high water pressure in the soil voids; and in soils with plastic behavior there is no expansion/collapse.

Dry soils are more resistant to changes in the distribution of pore size and their resistance is reduced with increasing water content (EAVIS, 1972). The lubrication of solid particles by water favors their rearrangement; however, when the soil is saturated, compression may not occur for an applied pressure in a short period of time. Thus, soils with high water content, close to saturation, are subject to excessive shear stresses and plastic flow, and therefore less susceptible to the reduction of pores than those with intermediate level. In any case, high compacting pressures can be effective when applied over a period of time (CHANCELLOR, 1977).

Another feature of the curve is the verification of transition between elastic (recoverable) and plastic deformation (not recoverable). Since the soil behaves elastically when applying pressures below the σpc pressure, it is possible to avoid compacting the soil by agricultural tractor traffic, limiting the strain exerted by these machines for pressure values that are below this limit (VAN

DEN AKKER, 2004; ALAKUKKU *et al*., 2003).

The greatest influence of tractor traffic on the compression curve, ie, on the σpc, occurred when there were two passes of the machine on dry soil, which recorded the highest value. According to Horn *et al*. (2003), the greater the machine traffic on the soil, the higher the rearrangement of soil particles; hence it becomes more compressed.

In evaluating the compaction of a loam clay soil after multiple tractor passes, Patel and Mani (2011) found that soil bulk density and penetration resistance increased continuously with this traffic, and this impact was greater in the depth of 0-15 cm due to increased tension at the tire-soil interface.

Figure 2 presents the behavior of the soil compression curves under different numbers of passes and water content according to the applied load, noting that there was an increase of voids in the dry soil condition at all traffic levels. This occurred because the void index is the ratio between the volume of voids and solids, and when the soil has high moisture content, the void volume is lower due to the presence of water in the pores. The void index does not provide information on the size of voids, and in sandy soils, there is a predominance of larger pores. In the soil compaction process by machinery traffic, there is a rearrangement of the porous system, with changes in continuity and distribution of pores and a reduction in the volume of macropores that are replaced by smaller pores, according to remarks reported by Dexter (2004).

Soil compaction often prevents the growth of plant roots, and therefore the absorption of water and nutrients (WAY *et al*., 2009), negatively affecting crop growth and resulting in low productivity (PATEL ; MANI, 2011). However, in very porous soils like those of sandy texture, compression may not affect root growth. Kooistra *et al*. (1992) showed that a small compression is beneficial to increase the contact area between the soil and the root, thus providing better water retention and better absorption of nutrients per root unit.

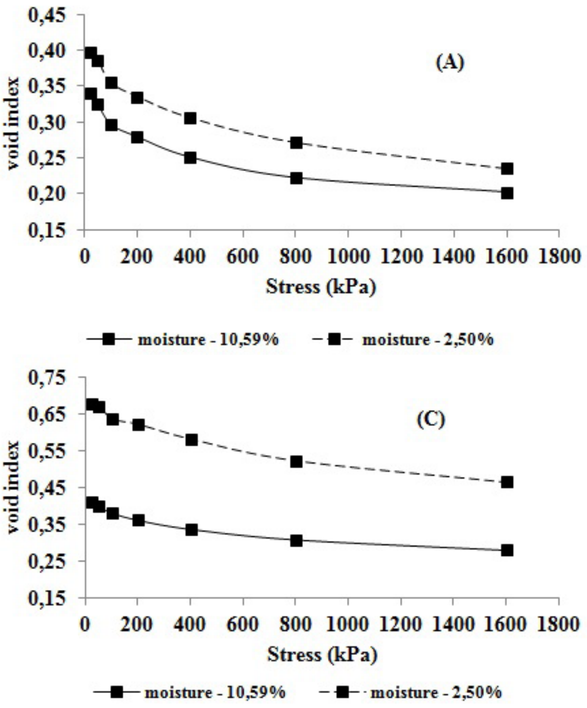

Figure 2. Soil compression curve with no tractor pass (A), with one tractor pass (B), and with two passes of the tractor (C), where - -■- - represents the curve of the dry soil and -■- represents the curve of the wet soil.

Table 2 shows that there was a difference, the interaction between the number of tractor passes and the variation of soil moisture, on the pre-consolidation pressure in the layer studied. Tractor traffic increased the σpc in both moisture levels, noting that the highest number of passes resulted in significantly higher values of pre-consolidation pressure.

The influence of moisture was significant in the three levels of passes, with σpc values increasing with reduced soil moisture, which shows the highest soil resistance to external pressure as the water content of soil decreases. This has also been discovered by other authors, including Schäffer *et al*. (2008) and Veiga *et al*. (2007).

This is due to the greater cohesion between the soil particles that occurs in the lowest water contents, which makes the soil matrix more resistant to deformation caused by external forces (OLIVEIRA *et al*., 2011). The lowest σpc values found in the soil with high water content are associated with better conditions for plant growth, as they indicate less resistance (SILVA; CABEDA, 2006).

There was no significant difference of interaction between the number of tractor passes and moisture content on the rate of compression (Table 3), a parameter which indicates soil susceptibility to compaction, *ie*, the higher the compression rate, the more compressible is the soil (IMHOFF *et al*, 2004; KUAN *et al*, 2007; SAFFIH-HDADI *et al*., 2009; MION *et al*. 2013). However, it appears that the higher values of the compression index occurred in wet soil conditions and at all levels of tractor passes, which shows lower resistance of the soil to compression when the water content is higher. According to Al-Shaya (2001), this phenomenon occurs because the water acts as a lubricant and facilitates the movement and rearrangement of particles, resulting in increased soil compressibility.

The adequate moisture content for performing agricultural activities and the maximum pressure that the soil can support are important to prevent degradation of the structure and compaction of cultivated soils (SILVA; CABEDA, 2006). In this sense, the higher water content and traffic on the soil influenced its deformation, highlighting the need for strict control of soil moisture in the decision to control machinery traffic in agricultural areas.

Table 2. Pre-consolidation pressure (kPa) of an Alfissol depending on traffic and soil moisture

Traffic	Moisture (10.58%)	Moisture (2.50%)
	σpc (kPa)	σpc (kPa)
0	60 bB	95 bA
1	68 abB	98 bA
2	84 aB	181 aA

Means followed by the same lower case letter in columns and upper case letters in rows for each attribute do not differ at 5% because of Tukey test.

Table 3. Compression index of an Alfissol submitted to machinery traffic at different soil moisture contents.

Traffic	Moisture	
	Moisture (10.58%)	Moisture (2.50%)
0	0.118 aA	0.082 aA
1	0.091 aA	0.093 aA
2	0.082 aA	0.066 aA

Means followed by the same lower case letter in columns and upper case letter in rows for each attribute, do not differ at 5% because of Tukey test.

CONCLUSIONS

- Regardless of soil water content, the load carrying capacity increases with machinery traffic due to the reduction of voids;
- Preconsolidation curves should be used with caution due to the use of samples to determine the points in saturated conditions, and when recommended for load-bearing capacity unsaturated samples should be used;
- The rate of compressible soil is affected by tractor traffic.

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