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COMPRESSIBILITY OF OXISOL AGGREGATES UNDER NO-TILL IN RESPONSE TO SOIL WATER POTENTIAL[1]

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SUMMARY

The system of no-till sowing stands out as being a technology that suits the objectives of more rational use of the soil and greater protection against the erosion. However, through till, any of it, occurs modifications of the soil's structure. This current work aims to study the influence of the energy state of the water and of the organic matter on the mechanism of compaction of Red Oxisol under no-till management system. Humid and non-deformed sample were collected in horizon AP of two agricultural areas under no-till, with and without rotation of cultures. In the laboratory, these samples were broken into fragments and sifted to obtain aggregates of 4 to 5 mm sized, which were placed in equilibrium under four matrix potentials. Thereafter, they were exposed to uni-dimensional compression with pressures varying from 32 to 1,000 kPa. The results in such a way show that the highest compressibility of aggregates both for the tilling with rotation of cultures as for the tilling without rotation of cultures, occurred for matrix potential -32 kPa (humidity of 0.29–0.32 kg kg^{-1}, respectively), while the minor occurred for the potentials of -1 and -1,000 kPa (humidity of 0.35 and 0.27 kg kg^{-1}, respectively), indicating that this soil should not be worked with humidity ranging around 0.29 to 0.32 kg kg^{-1} and the highest reduction of volume of aggregates was obtained for the mechanical pressures lower than 600 inferior kPa, indicating that these soils showed to be very influenced by compression, when exposed to mechanical work. Also, the aggregates of soil under no-till and rotation of crops presented higher sensitivity to the compression than the aggregates of soil under no-till and without rotation of crops, possibly for having better structural conditions given to a higher content of organic matter.

Index terms: edometric assay, void index, total porosity, soil compression, soil compaction.

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RESUMO: *COMPRESSIBILIDADE DE AGREGADOS DE LATOSSOLO VERMELHO SOB PLANTIO DIRETO EM RESPOSTA AO POTENCIAL DA ÁGUA DO SOLO*

O sistema de semeadura direta destaca-se como uma tecnologia que atende aos objetivos de uso mais racional do solo e maior proteção contra a erosão. Entretanto, por meio do manejo, qualquer que seja ele, ocorrem modificações da estrutura do solo. O presente trabalho teve como objetivo estudar a influência do estado energético da água e do teor de matéria orgânica sobre o mecanismo de compactação de Latossolo Vermelho sob plantio direto. Utilizaram-se para este estudo amostras de solo úmidas e indeformadas, coletadas no horizonte Ap de duas áreas agrícolas sob plantio direto com e sem rotação de culturas. No laboratório, essas amostras foram fragmentadas e peneiradas para obtenção de agregados de 4 a 5 mm de diâmetro, os quais foram colocados em equilíbrio com umidade de quatro potenciais matriciais para, após essa etapa, sofrerem uma compressão uniaxial com pressões de 32 a 1.000 kPa. Os resultados mostram que a maior compressibilidade dos agregados tanto para o manejo com rotação de culturas como para o manejo sem rotação de culturas, ocorreu para o potencial matricial de -32 kPa (umidade entre 0,29 e 0,32 kg kg^{-1}), enquanto a menor ocorreu para os potenciais de -1 e -1.000 kPa (umidades de 0,35 e 0,27 kg kg^{-1}, respectivamente), indicando que esse solo não deve ser trabalhado com umidade em torno de 0,29–0,32 kg kg^{-1}. A maior redução de volume dos agregados foi obtida para pressões mecânicas inferiores a 600 kPa, indicando que esses solos mostraram-se bastante sensíveis à compactaçãoquando expostos ao trabalho mecânico. Além disso, os agregados do solo com plantio direto e rotação de culturas apresentaram sensibilidade maior à compressão que os agregados do solo com plantio direto e sem rotação de culturas, possivelmente por terem melhores condições estruturais, graças ao maior teor de matéria orgânica.

Temos de indexação: compressão edométrica, índice de vazios, porosidade total, compressão de solo, compactação de solo.

INTRODUCTION

The State of Paraná stands out on the national scene for the great agricultural development reached in less than 100 years, characterized by a diversified and productive agriculture for both the domestic and export markets (Muzilli, 2008; SRP, 2008), under very clayey Red Oxisols derived from basalts (group São Bento, Serra Geral Formation), which occupy 32 % of the State, and stands out as one of the richest and most productive soil of Brazil (Medeiros, 1989).

The process of occupation of agricultural lands in the Northern tropical zone of the State, from the 30's until the late 60's, was mainly made by coffee culture in an extensive mode, with low use of mechanization, and subsistence crops; and with the destruction of plantations by a severe frost in 1975 the process of modernization of agriculture occurred rapidly, especially in the lands of high fertility and where the topography was more favorable to mechanization, those soils became occupied by business orientated production systems, principally with the expansion of soybean and wheat cultures, with intensive management of soil, based on the use of disc ploughs and moldboards ploughs and burning of the wheat after the harvest. As a result, these soils suffered a process of depletion, with fast decomposition of organic matter, fertility reduction, occurrence of soil compaction, resulting in the worsening of erosion and reduction of crop yields, thus requiring, attitudes and strategies as to increase soil cover, the water infiltration and the surface overflow (Vieira, 1989; Casão Jr.et al., 2000; Muzilli, 2008).

Thus, from the 80's, no-till system was introduced as being the technology which best suits these objectives of more rational use of soil and more protection against erosion, being fastly adopted within the Paraná State, and in 1996 around 1.3 million of hectares in the summer and 700 thousand in the winter was under this production system (Casão Jr. et al., 2000).

Any soil management system, whatever it is, aims to create favorable physic conditions to the cultures to develop, but changes in the structures occur, which are more or less intense accordingly to the preparation mode applied (Assis & Lanças, 2005; Araujo et al., 2007). It is believed that the systems called conventional cause more structural modification in the soils, while the systems called conservationists, as the no-till, cause less impaction as they do not move the soil; although this lack of soil evolvement, associated to a intensive use of the soil exposes it, accordingly to Collares et al. (2006), to a heavy machine traffic in inadequate conditions of moisture and helps to change the structural quality of the same, which leads to an increase in compression with the disappearance of some of the soil pores, leading to a change in the infiltration properties and water availability, aeration and root penetration in the soil, thus affecting crop yields, and creating problems of erosion (Tavares Filho & Tessier, 1998; Silva et al., 2000; Tavares Filho et al., 2001; Goedert et al., 2002; Tavares Filho et al., 2005; Collares et al., 2006).

The no-till system seems to distinguish itself in reality, by the frequency and intensity of mechanical pressure exerted on the soil and by the effects of climate and biological activity. The heavy equipment used for no-till and the cultural practices which are distinct by the frequency and intensity of mechanical pressure exerted on the ground, seems to degrade these Oxisols at different intensities (Grimaldi et al., 1993). Accordingly to Kondo & Dias Júnior (1999a), one of the greatest barriers to the intensive mechanization is susceptibility of the soils to compaction that becomes critical in elevated humid conditions.

Tavares Filho (1995) and Tavares Filho & Tessier (1998) showed that the incorporation of Oxisols to the system has caused changes in their physical properties, seeming initially, that this soil has a special sensitivity to compaction accordingly to its mineral properties, organic matter content and soil preparation mode, and this sensitivity may be linked to cycles of wetting-drying in conjunction with the mechanical pressure exerted on the soil.

Amongst the works done about this theme, in laboratory controlled conditions, Faure (1978); Guerif (1982); Sala & Tessier (1993); Tavares Filho (1995); Tavares Filho et al. (2005) studied the density of soil-related materials submitted to dynamic and static compression and clarified the influence of a number of factors (extent of the mechanical pressure, moisture in the material, amount of clay and organic matter) on the state of the soil from the macroscopic viewpoint. Carpenedo (1994) studied the variation in water content under the tensions of 6, 100 and 300 kPa in three soils of Rio Grande do Sul and concluded that the soil compressibility have been influenced by soil management, by the water retention tensions and by the soil type. Kondo & Dias Júnior (1999b) studied the compressibility of three Oxisols in the city of Lavras (Minas Gerais State), and showed that the increase in water content caused the reduction of standing capacity of the soils, independently of the management system to which they have been submitted. The authors stated that the water content of soil was the main factor which affects the compression behavior of these soils. Silva et al., (2000) studied the susceptibility to compression of a red Oxisol and of a Clayey soil under conventional and no-till management and their humidity degrees of initial saturation and had concluded that the soil deformation was different for each soil type. Secco (2003), studying the state of compactness of a dystrophic Oxisol (Latossolo Vermelho distrófico - LV) and a dystroferric Oxisol (Latossolo Vermelho distroférrico - LVd), under no-till management system, concluded that the LV was more susceptible to compaction when moisture initial water saturation was 58 %, while for the LVd greater susceptibility occurred when this value was 65 %.

Figueiredo et al. (2000) studied the effect of different till systems on soil critical moisture for compaction and on maximum density of an Oxisol and concluded that the critical moisture corresponds to 90 % of plastic limit and to 90 % of water content at -10 kPa, that is practically equal to the water content at -33 kPa. Sala & Tessier (1993) and Tavares Filho (1995) show, working with clay aggregates, that is the matrix potential of soil water, rather than the water content of the material, which determines changes in behavior related to compaction when submitted to static mechanical pressures.

This work lies within the continuity of such work and, is lead by the hypothesis that a physical degradation of soil with structural changes and increased compression results from the pressure exerted on it by different levels of moisture and organic matter. The aim of the study was to verify the influence of energetic state of water and organic matter content on the compaction mechanism of Oxisol under no-till system, in order to better understand and be able to predict the behavior of these soils when subjected to agricultural mechanization.

METHODS

This work was based entirely on the method presented by Tavares Filho et al. (2005). It used aggregates of soil 4–5 mm, obtained from three soil blocks of 20 x 20 x 20 cm, collected in the Ap horizon of an Oxisol (Latossolo Vermelho eutroférrico) (Embrapa, 2006), whose coordinates are 23 ° 18 ' 36 " N, 51 ° 09 ' 46 " W; with an average altitude of 610 m Cfa and subtropical climate. Samples were collected under a deepness of 0.0 and 0.20 m, in a first cultivated area with crop rotation (RNT) (soybean, corn, wheat, sunflower) under no-till system for 22 years, and at the same depth in a second area cultivated in no-till without crop rotation (NT) (soybean, wheat) for 20 years. The physical, chemical and mineralogical characteristics of the two soil samples used are presented in table 1.

Accordingly to Sala (1991), Sala & Tessier (1993) and Tavares Filho et al. (2005) to correctly understand a soil compactness derived from mechanical pressure it is necessary a good characterization of its state water. Therefore, the method of preparation of the soil sample used is an important factor to be controlled. The experimental protocol consisted in part to prepare aggregates macroscopically homogeneous, obtained from non-deformed soil samples – soil blocks - under various matrix potentials of water, to submit

Table 1. Physical, chemical and mineralogical characteristics of soil samples collected under a no-till system with crop rotation (RNT) and without crop rotation (NT) between 0.0 and 0.20 m deepness in Oxisol (Latossolo Vermelho eutroférrico)

Characteristics	RNT	NT
Clay (g kg^{-1})	786	777
Silt (g kg^{-1})	190	191
Total sand (g kg^{-1})	24	32
Particles density (kg dm^{-3})	2.88	2.90
Organic Matter (g dm^{-3})	28.68	17.22
pH (in water)	6.0	5.8
CTC ($cmol_c$ dm^{-3})	10.5	6.6
Specific surface (m^2 g^{-1})	5.81	5.02

them, afterwards to the mechanical pressure of increasing intensity.

Thus, after collecting the blocks of humid soils (0.24 ± 0.03 kg kg^{-1} of water) in the two areas studied, they had been sent to the laboratory where they were manually fragmented with caution, and passed in sieves with diameter of 8 to 1 mm. The highest concentration of aggregates were obtained from the sieves from 4 to 5 mm, and this dimension was chosen and standardized, since, after the process of dry screening of fragmented soil samples, there was a concentration of such clusters in these sieves for the two soil samples worked. These aggregates were then separated in order to use the mechanism proposed by Sala & Tessier (1993) (Figure 1).

The aggregates were balanced with water, in the potentials of -1, -10, -32 and -100 kPa with the mechanism developed by Tessier & Barrier (1979) (Figure 1a), which works under the same principle of the mechanism developed by Richards (1947). After a week, until they had been balanced with the moisture in the matrix potential, the aggregates were weighed wet and after drying at 105 °C. The wet volume of aggregates, to determine their levels of voids, water and air, in natural state, without compression, was measured by the method proposed by Monnier et al. (1973)

After this first stage, a new set of clusters underwent the same procedures described in the preceding paragraph and, after reaching steadiness, were compressed with uniaxial pressure ranging from 32 to 1,000 kPa. To verify the condition of matrix potential and mechanical pressure, there was obtained the higher compression of aggregates.

In the second phase the mechanical pressure was applied to the aggregates using the device proposed by Sala & Tessier (1993) (Figure 1b), in order to assess the change in volume and at the same time, control the set of determinants properties of mechanical characteristics (initial structural state, values of water potential and mechanical pressure). It was then placed a piston inside the tube (Figure 1b), dividing the tube into two chambers, one high and one low, where the aggregates were placed in. The pressure in the upper chamber acted on the piston that transmitted it on the soil aggregates so that the device functioned as an edometric camera test. The uniaxial pressure used in this study ranged from 32 to 1,000 kPa, because it is believed that this range set is enough to cover the pressure made on soil by farm machinery, as Rusanov (1991) reported that till with track-type tractor exerted a pressure around 150 kPa, while a tractor with tires could ranged from 180 to 200 kPa. Carpenedo (1994) stated that, normally, the mean pressure applied on the soil surface by the tires of tractors and combine harvester were between 100 and 200 kPa, while the agricultural trucks exerted pressures that could reach values close to 600 kPa.

The pressures had been applied in sequence, and balance was reached almost instantly for each pressure. Even then, it was waited 3 min in each stage (each pressure applied) in order to know for sure that 90 % of maximum deformation was reached for each pressure value applied (Holtz & Kovacs, 1981).

Performed the test, the compression curves of the soil were obtained by checking the pressure applied on the x-axis in logarithmic scale, and void ratio index (e), in decimal scale, in the y-axis (Holtz & Kovacs, 1981).

It is noteworthy to highlight that for each matrix potential and pressure rated, sought to relate the different phases of the soil (solid, liquid and gas). Thus, the results, instead of being expressed as total porosity, were expressed in relation to the volume of solid phase, as according to Tessier (1984), this reference is more appropriate to the results obtained on materials which have a different volumetric mass in the solid phase. Thus, it is possible to compare results of materials which have different volumetric masses in the solid phase. So, to express the volume of voids, it was used the void index (e), which is provided by the ratio volume of voids/volume of solids, for the volume of water, it has been used the water index (θ) which is provided by the ratio of water content/solids contents, and for the volume of air, it has been used the index of air (a), which is obtained by the ratio air volume/volume of solids, or simply the difference between void index and water index. The higher the void index, the more porous the soil is and therefore, the lower its density. These rates were calculated from the following measures: the height of the sample into the tube (h) and its radius (r = 2 cm) allowed to calculate the volume of aggregates and their evolution under mechanical pressure; the masses (wet (Mu) and dry (Ms)) and the pull exerted by the sample in kerosene (Mq) were the mass displacement of kerosene, δ = 0.782 g cm^{-3} (method proposed by Monnier et al., 1973); and the densities of particles, determined by the pycnometer method, considered for the RNT and NT, were, respectively, 2.88 and 2.90 kg dm^{-3}.

The results calculated were presented as mean values of five replications, along with standard deviations obtained by matrix potential and pressure applied.

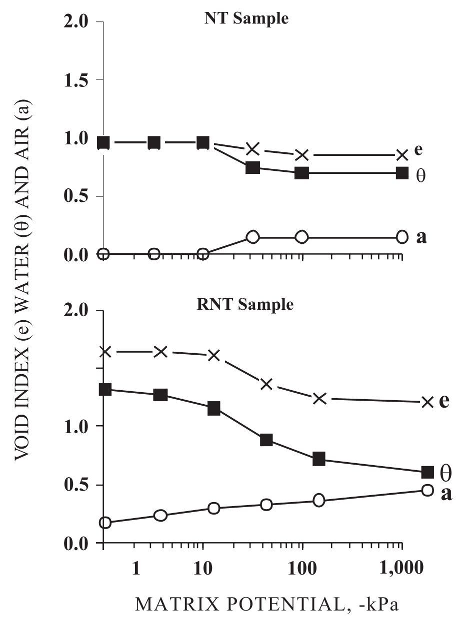

Figure 2. Index of voids (e), water (θ) and air (a), average of five repetitions of clusters aggregates of 4 to 5 mm in diameter, of Oxisol under NT (no-till without crop rotation) and RNT (no till with crop rotation).

RESULTS AND DISCUSSION

Aggregates behavior before edometric compression

The results of voids, water and air (Figure 2) are the average of five replications with a standard deviation lower than 0.0176 for the index, indicating good accuracy of laboratory tests, good homogeneity of the data and therefore, reliability to work with the average data presented.

Comparing the no-till system soil aggregates with the aggregates of the RNT soil (Figure 1), is perceived that the RNT aggregates have higher water retention capability and higher void volumes than the NT soil aggregates, as the void index (e), water (θ) and air (a) were systematically lower for the soil aggregates under the NT system. Another point to be observed is related to the air index (a), which presented a well differentiated behavior between the two types of aggregates studied, as for the soil sample under the NT system, the air index is low (ranges from 0.03 to 0.2) and this index curve has two distinct phases, or in other words, between the potentials of -1000 and -32 kPa there is no variation in the air index, between -32 and -3.2 kPa occurs a sharp reduction in this index, and between – 3.2 and 1 kPa the air index is null, indicating in this case that the aggregates are full of water. For the soil aggregates under the RNT system, the air index range from 0.30 to 0.55 and these index curves were characterized by a linear reduction of the air index(a), between -1,000 to 1 kPa and at no time the aggregates shown signs of water saturation.

Another point to be observed from the water index curve (θ) (Figure 2) is that moisture is systematically more elevated in the soil aggregates under RNT, mainly for the matrix potentials higher than -32 kPa, in which the humidity relies on pores distribution and as a consequence, suffer influence of the soil structure (Mathieu & Pieltain, 1998), indicating that the pores volume higher than 5 μm is more important in the RNT soil, where probably the soil is better structured due a higher organic mater content than in the NT soil. These results are very similar of those found in the works conducted in Oxisols in the State of Paraná by Tavares Filho (1995) and Yellow Oxisols of Amazon Rainforest by Chauvel et al. (1987); Chauvel et al. (1991) and Tavares Filho et al. (2005). In the case of lower potentials, the soil humidity suffers influence from the adsorption by soil particles, in other words, by soil texture, specific surface and also soil humus (Mathieu & Pieltain, 1998). Therefore, the higher soil humidity in the RNT system for these lower potentials reflects the results shown in table 1, where it is observed a higher content of clay organic mater and higher specific surface in this RNT soil, and in consequence higher capacity to adsorb water.

Aggregates behavior under edometric compression

The behavior of aggregates under edometric compression, whose results are average of five replications, is shown in figure 3a. The standard deviation for this laboratory analysis was 0.0477 for soil aggregates under NT and 0.0548 for the soil aggregates under RNT, indicating good accuracy and consistency of data results, and therefore reliability for work with the average data presented.

It was observed that the greatest reduction in volume in the soil aggregates in NT and RNT was obtained for mechanical pressure below 600 kPa (Figure 3a). These results are similar to those found in studies conducted in Red Oxisols of Paraná by Tavares Filho (1995) and Yellow Oxisol of the Amazon Rainforest by Chauvel et al. (1987), Chauvel et al. (1991) and Tavares Filho et al. (2005). Considering that the mean pressure applied on the soil surface by the tractors' tyres and combine harvester is between 100 and 200 kPa, while pressures of the trucks used in agricultural works could reach values close to 600 kPa (Carpenedo, 1994), the aggregates in question proved to be less sensitive to compaction, probably due to high content of Fe oxides, which give effect to the sticking microstructure of the soil, increasing its resistance to compression (Grimaldi et al., 1993).

In relation to the lower soil compression (lower reduction in the volume of aggregates - Figure 3a), this corresponds to the aggregates subject to higher water potential (-1 kPa) and to the lowest potential (-1,000 kPa). It was to the matrix potential of -32 kPa (Figure 3b) that the aggregate mass from the two soils under NT and RNT were more susceptible to compression within a narrow range of water content in the soil (Figure 3c) (0.29 kg kg^{-1} for soil aggregates under NT and 0.32 kg kg^{-1} for soil aggregates under RNT) which had the highest volume reduction (greater compression of the soil) to the end of mechanical pressure 1,000 kPa. These results are consistent with those presented by Sala & Tessier (1993), Tavares Filho (1995), Tavares Filho et al. (2005), that also found that working with different clay materials, verified that around the potential -32 kPa, occurred the greatest compression of these materials. Figueiredo et al. (2000) reported that the critical moisture (0.29 kg kg^{-1}) for compressing Purple Oxisol (Embrapa, 2006) accounted for 90 % of water content at -10 kPa, almost equal to the water content at -33 kPa.

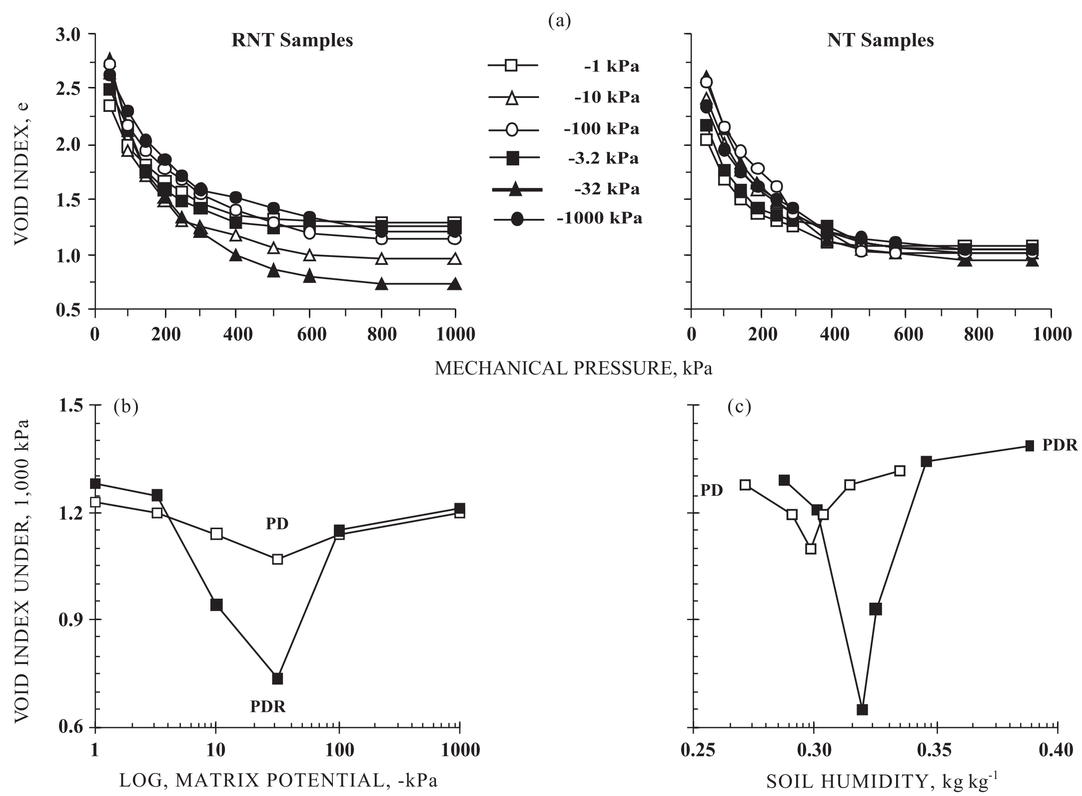

Figure 3. Evolution of void index (e) (average of five repetitions) of aggregates of a Red Oxisol under NT (no-till without crop rotation) and RNT (no-till with rotation), depending on the mechanical pressure involved (kPa) for moisture levels corresponding to matrix potentials of -1, -3.2, -10, -32, -100 and -1,000 kPa (a), and function of matrix potential (b) and final water content (c).

This higher sensitiveness of these aggregates within this range potential -32kPa can be explained by taking into account that the mass of aggregates used in these compaction test has basically two types of pores: the intra-aggregates pores, resulting from primary particles of the soil, mainly clay, and the pores between the aggregates, which resulted from the spaces between the aggregates themselves and, between -10 and -100 kPa, the maximum size of pores filled with water varies from 15 and 1,5 μm, sufficient size to make some of the pores between the aggregates fulfilled with water (Tavares Filho, 1995; Assouline et al., 1997; Tavares Filho et al., 2005). Thus, the aggregates are joined up by the traction exerted on its walls (Tessier et al., 1992; Sala & Tessier, 1993; Tavares Filho et al., 2005), and that aggregates meet humidity content in which capacity support decreases, as the water acts as a lubricant between the particles, reducing friction to the movement. The re-ordering of soil particles, makes the soil aggregates smoother, altering the consistency and making it more susceptible to compaction (Secco, 2003). Moreover, whe most of the pores are filled with water matric potential of -1 kPa, less susceptible to compression and become, in the case of a drier soil, and for the potential of -1,000 kPa water meet only the space between the poral clay crystals and capillary forces cannot contribute to the reorganization of aggregates, as shown by Faure (1978), Tavares Filho (1995) and Tavares Filho et al. (2005). In this situation, the appears to be greater seems to be the carrying capacity of aggregates for being the particles closer from each other (Secco, 2003), since the moisture is not enough to reduce friction to the movement and the rearrangement of soil particles, leaving the soil (aggregates) less susceptible to compaction.

These results also indicate that soil aggregates in NT are much denser than the soil in RNT, both before the application of mechanical pressure (Figure 1) (e_{NT} = 1.10 against e_{RNT} = 1.25), and after application mechanical pressure (Figure 2a), for the final pressure of 1,000 kPa, comes to e_{NT} = 1.07 against e_{RNT} = 0.73, indicating that the compression further accentuates the differences in the compactness of the Oxisol under no-till system with and without crop rotation.

Comparing these void values of the aggregates, after edometric compression, with the combined pre-edometric compression for the matrix potential of -32 kPa, it was found that the compression practically did not affect the volume of pores existing in the massive clusters of soil under NT (Δe_{final} = 0.03), as these aggregates were probably compacted when they had been collected in the field. In the case of the clusters collected in the soil under RNT system, there has been a clear decrease in the pores volume (Δe_{final} = 0.52), intra-aggregates and also between aggregate, as this sample presented a higher volume of pores bigger than 5μm as seem before and these pores between aggregates had almost disappeared because of aggregate coalescence (Tavares Filho et al., 2005).

Accordingly to Faure (1978); Sala & Tessier (1993); Tavares Filho (1995); Tavares Filho et al. (2005), considering the same matrix potential conditions and mechanical compression applied, the higher the humidity of a material, the lower is its compressibility, which seems not to have occurred in the results presented, as of the aggregates of the soil under RNT that presented higher compaction under edometric compression had also a better capability of water adsorption when compared with the NT soils. It might have occurred probably because of the two hypotheses: the mechanical pressure applied in these soil aggregates under RNT were enough to draw the water retained by households; and aggregates of soil under RNT, possibly by having a higher content of organic matter, provided the best framework conditions making the soil more susceptible to compression.

CONCLUSIONS

1. The higher compressibility of the aggregates of an Oxisol under no-till, both for the management with crop rotation and to management without crop rotation, occurred to the matrix potential -32 kPa (soil moisture between 0.29 to 0.32 kg kg^{-1}), and the lowest to potentials of -1 and -1,000 kPa (soil moisture of 0.35 and 0.27 kg kg^{-1}, respectively), indicating that the soil should not be worked with humidity around 0.29 to 0.32 kg kg^{-1}.

2. The largest reduction in volume of aggregates, both for the management of crop rotation and without crop rotation, was obtained for a mechanical pressure below 600 kPa, indicating that these soils are very sensitive to compaction when exposed to mechanical work.

3. The aggregates of soil under the no-till system and crop rotation had greater sensitivity to compression of soil than the aggregates managed without crop rotation, possibly because of better structural conditions due to a higher organic matter content.

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