**Degree of compactness for no-tillage soils: reference bulk density and effects on soil physical properties and soybean yield**

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## 1. Introduction

Several parameters have been used to characterize the state of soil compactness, such as dry bulk density or total porosity, air-filled porosity or soil strenght. However, these parameters vary between soils and have limited value when different soils are compared. The relation between the current bulk density and some reference state or of maximum bulk density, named "degree of compactness" or "relative compaction", has been useful to characterize the soil compaction and crop growth in different soil types (Carter, 1990; Hakansson, 1990; Lipiec et al., 1991; Silva et al., 1997). The reference state or maximum dry bulk density is the densest state obtainable by a static pressure of 200 kPa in the uniaxial compression test (Hakansson, 1990) or by the Proctor test (Carter, 1990; Twerdoff et al., 1999), and in both tests are used disturbed samples. According to Hakansson (1990), the "degree of compactness" was defined only for soil layers annually disturbed by tillage, but Hakansson & Lipiec (2000) said that this concept might be extended for soils not disturbed annually by tillage, but this would require further methodological studies. Thus, this research aimed to evaluate the best load in the uniaxial compression test using undisturbed samples from no-tillage sites to obtain the reference bulk density, and verify its influence on soil physical properties and soybean (*Glycine max* L.) yield.

## 2. Material and methods

Soils used in this study included three Alfisols and three Oxisols from Rio Grande do Sul state, Brazil, which were under different tillages, predominantly no-tillage. The samples were taken during the first six months of 2004. The soils and their clay content in the depth of 0-0,30 m were: Rhodic Paleudalf (92 g $kg^{-1}$), Typic Paleudalf (278 g $kg^{-1}$), Typic

Haplohumult (400 g $kg^{-1}$), Rhodic Hapludox (463 g $kg^{-1}$), Rhodic Hapludox (545 g $kg^{-1}$) and Rhodic Hapludox (654 g $kg^{-1}$).

Soil penetration resistance was determined in the field with a digital penetrometer with a conical tip with 30º angle of penetration and readings every 1.5 cm depth. Average soil moisture in the penetration resistance was 11.82 $m^3$ $m^{-3}$ to the Rhodic Paleudalf (92 g $kg^{-1}$), 9.22 $m^3$ $m^{-3}$ to the Typic Paleudalf (278 g $kg^{-1}$), 8.22 $m^3$ $m^{-3}$ to the Typic Haplohumult (400 g $kg^{-1}$), 7.73 $m^3$ $m^{-3}$ to the Rhodic Hapludox (463 g $kg^{-1}$), 8.05 $m^3$ $m^{-3}$ to the Rhodic Hapludox (545 g $kg^{-1}$) and 16.73 $m^3$ $m^{-3}$ to the Rhodic Hapludox (654 g $kg^{-1}$). Samples were collected in cylinders with 3 cm height and 5.55 cm diameter in the depths 0-0.05, 0.05-0.10, 0.10-0.15, 0.15-0.20, 0.20-0.25 and 0.25-0.30 m, to determine the macroporosity (EMBRAPA, 1997).

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The "degree of compactness" or "relative compaction" of the soil, DC, was defined as:

DC = 100 BD/BDref where, BD is the current bulk density and BDref is the bulk density of the same soil in a reference state obtained at laboratory. The degree of compactness is expressed in percentage. To determine the current bulk density, soil cores were collected in the depths of 0-0.05, 0.05-0.10, 0.10-0.15, 0.15-0.20, 0.20-0.25 and 0.25-0.30 m, using cylinders with height of 3 cm and diameter of 5.55 cm. Soil cores were oven-dried at 105°C and weight to obtain dry bulk density. To obtain the reference bulk density, soil cores were collected in cylinders with height of 2.50 cm and diameter of 6.10 cm, in the depth of 0.08-0.13 m. Soil cores were equilibrated at a tension of 33 kPa and submitted to the uniaxial compression test, applying on separate samples the loads of 200, 400, 800, 1600 and 3200 kPa, while the compression curve (sequential loading on the same sample) was used for comparison. Six replicates for each test were used. The consolidometer Boart Longyear with application of pressure through compressed air for the uniaxial compression test was used. Soybean plants were sampled to evaluate their root length and soybean yield.

## 3. Results and discussion

To select the best load to estimate the reference bulk density, it was necessary to apply different loads to obtain a reference bulk density not too low, resulting in a high degree of

compactness, or a high reference bulk density resulting low degree of compactness. To obtain the reference bulk density, soil cores were collected in the layer of 0.08-0.13 m, considered
the most compacted due traffic of machines, since otherwise, for pressures such as the one of 200 kPa, the reference bulk density would be smaller than the current bulk density, generating values of degree of compactness higher than 100%. The bulk density values, obtained in the soil compression curve and from the application of only one load (200, 400, 800, 1600 or 3200 kPa) in separate soil core, were similar or a little greater when applying only one load, showing that to obtain the reference bulk density both the soil compression curve or just only one load application in the sample may be used (Figs. 1a and 1b). Considering the degree of compactness obtained for application of only one load and the results obtained in the literature using the Proctor test and load of 200 kPa in the uniaxial compression test and samples with not preserved soil structure, we propose the 1600 kPa as the best load to obtain the reference bulk density in the uniaxial compression test, using only one load or successive loads in the same sample with preserved structure. The degree of compactness with reference bulk density obtained with the load of 1600 kPa in the compression curve and with the application of only the load of 1600 kPa presented similar result (Fig. 1c). For a penetration resistance of 2 MPa as being impeditive to the root development of plants, for the Rhodic Paleudalf (92 g $kg^{-1}$ clay) this resistance corresponded to a degree of compactness of 93% , while for the Typic Paleudalf (278 g $kg^{-1}$ clay) and Typic Haplohumult (400 g $kg^{-1}$) it was around, respectively, 88 and 83% (Fig. 2a). For the Oxisols (Fig. 2b), it corresponded to a degree of compactness of approximately 71% for Rhodic Hapludox (545 g $kg^{-1}$ clay), 79% for Rhodic Hapludox (654 g $kg^{-1}$ clay), and 82% for Rhodic Hapludox (463 g $kg^{-1}$ clay). It should be pointed out that penetration resistance is function of moisture and particle size distribution of soil; thus, dry or clay soils present larger resistance if compared with wet or sandy soils.

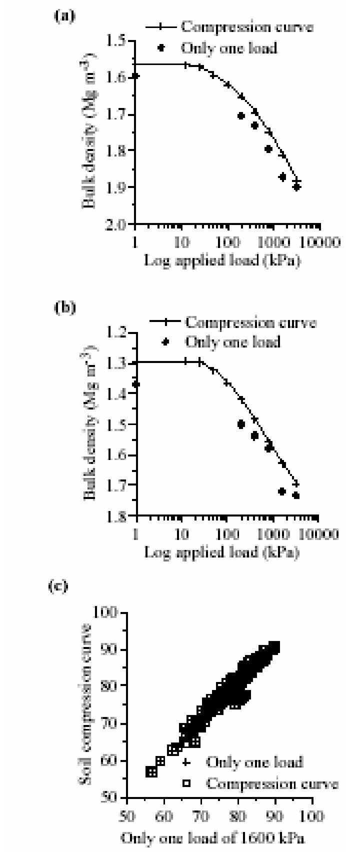


Fig. 1. Soil compression curve and bulk density after applied only one load (200, 400, 800, 1600 and 3200 kPa) in each sample for the Rhodic Paleudalf (92 g $kg^{-1}$ clay) (a) and Rhodic Hapludox (654 g $kg^{-1}$ clay) (b), and degree of compactness using reference bulk density obtained with the load of 1600 kPa from compression curve and only the load of 1600 kPa (c).

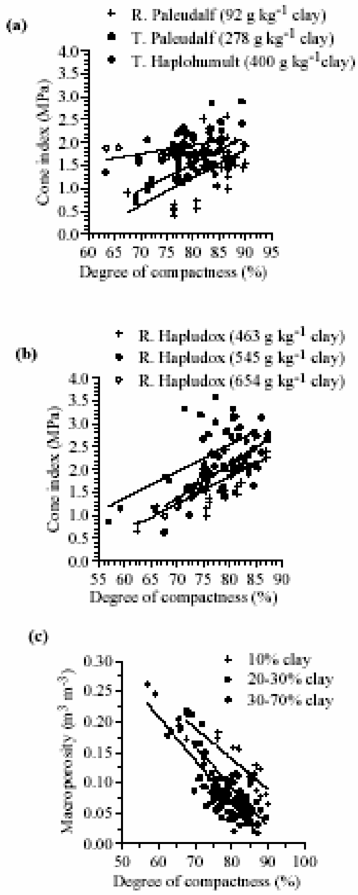


Fig. 2. Cone index for Alfisols (a) and Oxisols (b) and macroporosity (c) as a function of the degree of compactness with reference bulk density obtained by applying only the load of 1600 kPa. Considering a macroporosity of 0,10 $m^3$ $m^{-3}$ as minimum for the satisfactory growth and development of plants (Vomocil & Flocker, 1966), it corresponded to a degree of compactness of approximately 89% for soils with 10% of clay, 80% for soils with 20-30% of clay and 75% for soils with 30-70% of clay (Fig. 2c). Carter (1990) verified that a macroporosity of 0.10 $m^3$ $m^{-3}$ corresponded to a degree of compactness of 89% to the horizon Ap of two soils with respectively 12 and 7% of clay and 30 and 29% of silt (fine sandy loam). The larger soybean yield was obtained with a degree of compactness of approximately, 85% for Alfisols and 82% for Oxisols (Fig. 3a), and degree of compactness of approximately 90% restricted the soybean root growth at a depth of approximately 0.10 m (Fig. 3b). It should be noticed that a high degree of compactness may reduce the soil porosity and aeration, and increase bulk density and soil penetration resistance, difficulting

the root development. In contrast, a low degree of compactness may be indicative of a loose soil, limiting the water retention and the contact soil-seed in the sowing.

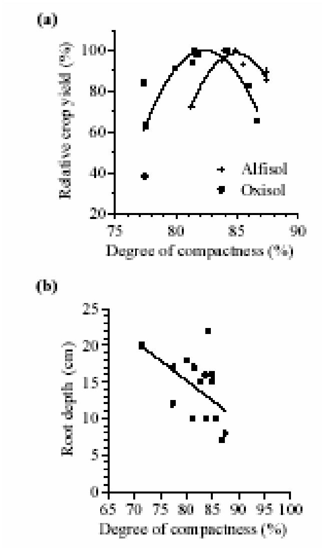


Fig. 3. Relative crop yield (a) and root depth (b) in function of degree of compactness with reference bulk density obtained by applying only the load of 1600 kPa. Other studies about degree of compactness and crop yield have demonstrated similar results. Beutler et al. (2004) verified an optimum degree of compactness of 80% to the soybean in an Oxisol of medium texture. Carter (1990) verified that a degree of compactness between 77,5-84% presented a relative crop yield of cereals larger or equal to 95%.

## 4. Conclusions

The load of 1600 kPa was the best one to obtain the reference bulk density in the uniaxial compression test using soil cores with preserved structure, independently if applying only one load or from the soil compression curve (sequential loading on the same sample), although this load does not represent that the soil will reach the maximum bulk density for these conditions, because increasing the load, the bulk density also increases. The highest soybean yield was obtained with the intermediate degree of compactness,

82% for Alfisols and 85% for Oxisols, showing that the maximum yield will not be obtained with an unstructured or a compacted soil. For other crops the optimum degree of compactness may be different. The degree of compactness was associated to changes in soil physical properties, such as soil penetration resistance and macroporosity. With increase of clay content the degree of compactness decreased.

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**References**

Beutler, A.N., Centurion, J.F., Roque, C.G, Ferraz, M.V., 2004. Densidade relativa de Latossolos e produtividade de soja. In: Manejo: Integrando a Ciência do Solo na Produção de Alimentos. In: Anais da Reunião Brasileira de Manejo e Conservação do Solo e da Água, 15, Santa Maria, Brasil, 25-30 julho. (CD-ROM)

Carter, M.R., 1990. Relative measures of soil bulk density to characterize compaction in tillage studies on fine sandy loams. Can. J. Soil Sci.70, 425-433.

EMBRAPA. Centro Nacional de Pesquisa de Solos (Rio de Janeiro, RJ), 1997. Manual de métodos de análise de solo. 2a ed. Rio de Janeiro, 212 pp.

Hakansson, I., 1990. A method for characterizing the state of compactness of the plough layer. Soil Tillage Res. 16, 105-120.

Hakansson, I., Lipiec, J., 2000. A review of the usefulness of relative bulk density values in studies of soil structure and compaction. Soil Tillage Res. 53, 71-85.

Lipiec, J., Hakansson, I., Tarkiewicz, S., Kossowski, J., 1991. Soil physical properties and growth of spring barley related to the degree of compactness of two soils. Soil Tillage Res. 19, 307-317.

Silva, A.P., Kay, B.D., Perfect, E., 1997. Managment versus inherent soil properties effects on bulk density and relative compaction. Soil Tillage Res. 44, 81-93.

Twedorff, D.A., Chanasyk, D.S., Mapfumo, E., Naeth, M.A., Baron, V.S., 1999. Impacts of forage grazing and cultivation on near-surface relative compaction. Can. J. Soil Sci.79, 465-471.

Vomocil, J.A., Flocker, W.J., 1966. Effect of soil compaction on storage and movement of soil, air and water. Trans. Am. Soc. Agric. Eng. 4, 242-246.