

Comissão 2.2 - Física do solo

COMPRESSIBILITY AND PENETRABILITY OF LATOSSOLO VERMELHO-AMARELO DISTRÓFICO (OXISOL) UNDER VARIED MANAGEMENT SYSTEMS AND LAND USES

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ABSTRACT

Soil compaction is one of the main degradation causes, provoked by inappropriate agricultural practices that override the limitations of the soil physical properties. Preconsolidation pressure and penetration resistance have proved effective as alternative to assess and identify soil compaction. Based on the interpretation of these physico-mechanical parameters, compaction can be prevented with a better adjusted soil management. This study was performed to generate preconsolidation pressure and penetration resistance models for Latosolo Vermelho-Amarelo distrófico (Oxisol) under various managements and uses; and evaluate which of these would lead to degradation or degradation susceptibility. The study was carried out in Curvelo, MG. Two managements and one land use were evaluated: no-tillage, sheep grazing and natural forest. Undisturbed soil samples collected from the 0-5 cm layer were subjected to uniaxial compression and penetration resistance tests. Preconsolidation pressure models for forest and no-tillage soils were not statistically different, demonstrating a low degradation potential in no-tillage systems. Preconsolidation pressure was higher in soil under sheep grazing at all water retention tensions and penetration resistance values were higher than under native forest indicating animal trampling as a potential degradation factor. Neither management presented penetration resistance values above 2 MPa at field

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capacity moisture. Only under sheep grazing the soil penetrability was near 2 MPa at field capacity and values greater than 2 MPa at 0.2 kg kg⁻¹.

Keywords: soil compaction, sheep grazing, no-tillage system, Atlantic rainforest.

RESUMO: COMPRESSIBILIDADE E RESISTÊNCIA À PENETRAÇÃO DE UM LATOSSOLO VERMELHO-AMARELO DISTRÓFICO SOB DIFERENTES MANEJOS E USO

Uma das principais causas da degradação do solo é a compactação, que é provocada por práticas agrícolas inadequadas, não respeitando os limites de seus atributos físicos. A pressão de pré-consolidação e a resistência à penetração têm-se evidenciado como alternativas eficazes para avaliar e identificar a compactação do solo. A partir da interpretação dos resultados das avaliações desses parâmetros físico-mecânicos, pode-se prevenir a compactação do solo pelo emprego do manejo mais adequado. Este estudo foi realizado com os seguintes objetivos: gerar modelos de pressão de pré-consolidação e de resistência à penetração de um Latossolo Vermelho-Amarelo distrófico, sob diferentes manejos e uso; e avaliar, por meio desses modelos, o uso ou manejo que apresenta a estrutura do solo degradada ou com susceptibilidade à degradação. O estudo foi realizado no município de Curvelo, MG. Foram avaliados dois manejos e um uso do solo, sendo esses: plantio direto de milho, pastagem de ovinos e mata natural. Amostras indeformadas de solo coletadas na camada de 0-5 cm foram submetidas a ensaios de compressão uniaxial e de resistência à penetração. Os modelos da pressão de pré-consolidação gerados para os solos sob mata e plantio direto não foram estatisticamente diferentes, demonstrando que o plantio direto não degradou o solo. O solo sob pastagem de ovinos apresentou maiores valores de pressão de pré-consolidação em todas as tensões de retenção de água e maiores valores de resistência à penetração do que a mata, demonstrando que o pisoteio animal apresentou potencial à degradação. Nenhum dos manejos evidenciou resistência à penetração superior aos 2 MPa na umidade de capacidade de campo. Apenas o solo sob pastagem de ovinos apresentou valor de resistência à penetração muito próximo a 2 MPa na capacidade de campo e valores maiores que 2MPa na umidade de 0,2 kg kg⁻¹.

Palavras-chave: compactação do solo, pastagem de ovinos, plantio direto, mata atlântica.

INTRODUCTION

If used correctly, soil is a renewable resource, given that the properties are respected to prevent degradation and minimize potential environmental impacts caused by the activities.

The lack of knowledge and technologies by farmers and ranchers have caused land degradation, and soil compaction caused by inappropriate agricultural practices, such as mechanization and animal trampling in inadequate moisture ranges, is the main cause.

Understanding and quantifying soil compaction have been the major concern of researchers, since in recent years mechanization in agricultural areas has been increasingly intensified due to the increased availability of technological resources (Raper, 2005; Hanza and Anderson, 2005).

Preconsolidation pressure has been shown to be an effective alternative to assess and identify soil compaction (Dias Junior and Pierce, 1996). According to Pires et al. (2012), understanding the soil compressive behavior is of great importance because, from the physical point of view, it is the basis to choose the management that less affects the soil structure.

Water content is a limiting factor for soil deformation, which indicates the importance of knowing the water-holding capacity within the soil. Gontijo et al. (2011) published results that show that preconsolidation pressure is inversely proportional to soil moisture.

Clayey and/or denser soils have a higher preconsolidation pressure due to higher friction and cohesive forces among particles (Imhoff, 2002).

Soil organic matter content affects preconsolidation pressure. According to Vasconcelos et al. (2012), organic matter plays an important role in the soil mechanical behavior, especially under external load.

Another quite efficient soil property to measure soil compaction is penetration resistance. It is directly related to plant growth due to its effect on plant metabolism and vital functions (Leão et al., 2006). Penetrability depends on soil texture, density, and especially moisture (Oliveira et al., 2005; Blainski et al., 2008), requiring careful use and interpretation (Silva et al., 2009).

The critical penetrability value for plant growth in different management systems is 2 MPa (Silva et al., 1994; Taylor et al., 1966; Tormena et al., 1998; Lapen et al., 2004).

Thus, the purpose of this study was to generate preconsolidation pressure and penetration resistance models for a Latossolo Vermelho-Amarelo distrófico (Oxisol) under different managements and uses and to identify, by these models, the uses or managements that degrade the structure or induce susceptibility to soil degradation.

MATERIAL AND METHODS

The study was carried out on the Experimental Farm of the Universidade Federal dos Vales do Jequitinhonha e Mucuri - UFVJM, located in Curvelo, State of Minas Gerais, Brazil. The soil type is Latossolo Vermelho-Amarelo distrófico (Oxisol) (Embrapa, 2006). Soil physical properties are presented in table 1.

The study areas consisted of: 4 ha Tifton 85 bermudagrass pasture with grazing sheep; 2 ha no-tillage corn; and 2 ha natural forest. The sheep grazing area was subjected to a grazing pressure of 7.5 animals ha⁻¹, for at least four years. From rearing to slaughter, the animals grazed in an extensive system. Nitrogenous fertilization was applied in three split applications of 250 kg ha⁻¹ N, during the rainy season. The soil cover in the no-tillage system consisted of *Brachiaria ruziziensis*. Fertilization at planting for an expected yield above 8 t ha⁻¹, consisted of 30 kg ha⁻¹ N, 100 kg ha⁻¹ P₂O₅, and 60 kg ha⁻¹ K₂O in an 8-28-16 NPK fertilizer; and top-dressing of 140 kg ha⁻¹ N in ammonium sulfate form. The area was managed in this way for four years. The native forest area was an Atlantic rainforest fragment in excellent condition. All planting and top-dressing fertilizations and liming were applied as recommended by Ribeiro et al. (1999).

For the preconsolidation pressure test and load-bearing capacity models, with an Uhland sampler, undisturbed soil samples were collected in volumetric rings (diameter 6.40 cm, height 2.54 cm). Thirty-two undisturbed soil samples were randomly collected from each management system (0-5 cm deep) (32 samples × three systems). Under animal grazing, the main soil deformations occur in the surface layer (Pires et al., 2012) and under machine traffic, they appear initially in the surface and then subsurface layers. Thus, samples were collected from

the 0-5-cm layer, due to animal grazing and for being a recently installed planting system.

The samples were taken to the Laboratory of Soil Physics of UFVJM, where they were adjusted to the ring volume. Subsequently, they were saturated with distilled water for 48 h. Water-saturated samples were weighed and then balanced at tensions of 2, 6 (field capacity), 10 and 33 kPa. A water-holding capacity of 6 kPa was considered field capacity, in line with Reichardt (1988) and Pires et al. (2012), who stated that soils in tropical regions, mainly in Oxisols with good permeability, the water-holding capacity should be 6 kPa. To balance the water-holding capacity, we used Richards' pressure plate apparatus described by (Embrapa, 1997). After sample balance at each applied tension, they were weighed again by the gravimetric method and the moisture content determined. Moisture and respective water-holding capacity are shown in table 1.

Samples balanced at 2, 6, 10, and 33 kPa were subjected to a uniaxial compression test, according to method proposed by Bowles (1986), adapted by Dias Junior (1994), using a consolidometer (Masquetto automação). The following pressures were applied to each sample: 25; 50; 100; 200; 400; 800; and 1,600 kPa, respectively. Each pressure was applied until the soil reached 90 % of maximum deformation (Taylor, 1948). Thereafter, the samples were dried at 105-110 °C for 24 h. Soil bulk density was determined by the volumetric ring method, as described by Blake and Hartge (1986).

The discarded sample fractions from the top and bottom parts of the rings were used for soil characterization, consisting of particle size analysis by the pipette method (Day, 1965; Embrapa, 1997) and organic matter content (Raij and Quaggio, 1983).

Preconsolidation pressures were calculated from the soil compression curve, as proposed by Dias Junior and Pierce (1995) (Figure 1).

The preconsolidation pressures of the uniaxial compression trial were plotted with the different water-holding capacity to obtain soil load-bearing capacity models through Sigma Plot 8.0 (2002). The mathematical equations were adjusted by the model proposed by Dias Junior (1994). Regressions were compared by procedures defined by Snedecor and Cochran (1989).

Table 1. Physical properties, moisture content at different tensions and organic matter of Latossolo Vermelho-Amarelo distrófico (Oxisol), under different management systems, in the 0-5 cm layer

Management	Sand	Silt	Clay	SBD	2 kPa	6 kPa	10 kPa	33 kPa	OM
No-tillage	470	170	360	1.13	0.85	0.31	0.28	0.19	22.40
Natural forest	460	170	370	1.02	0.89	0.33	0.26	0.21	32.00
Sheep grazing	480	160	360	1.23	0.65	0.28	0.22	0.18	17.40

SBD: soil bulk density; OM: organic matter.

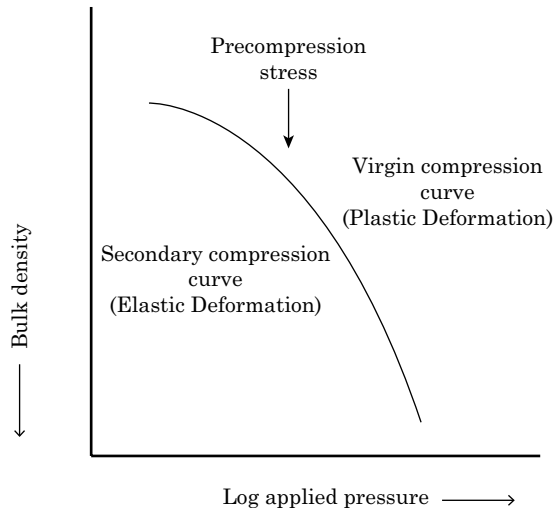


Figure 1. Soil compression curve. Adapted from Dias Junior (1994).

Moreover, soil resistance to penetration was tested in undisturbed samples from the 0-5 cm layer. This soil depth was chosen in agreement with Pires et al. (2012), due to animal trampling and recent traffic of agricultural machinery. The tests were performed as proposed by Dias Junior et al. (2004); thus, undisturbed soil was sampled with an Uhland cylinder with rings with known volume. In the laboratory, samples were adapted to the ring volume, facilitating the determination of soil bulk density (Embrapa, 1997) and sample handling. Five rings per study area were collected. For soil profile evaluation, we used a portable spring-type penetrometer (ELE International).

Once prepared, the samples were soaked in distilled water for 48 h. Penetration resistance tests started after soil saturation and consisted of measuring soil resistance in the ring with the above penetrometer and immediate weighing of the samples. This procedure was repeated until the soil had become air-dried and reached a moisture value that prevented penetration readings; then, samples were oven-dried at 105 °C for 24 h. Therefore, the different moisture contents of undisturbed samples, after saturation, were obtained after air-drying in the laboratory, on the evaluation days. With wet and dry soil mass values, the corresponding moisture contents could be calculated for respective penetration resistance. With the data of penetration resistance *versus* moisture, the maximum values of soil penetration resistance could be calculated. Then, equations were compared statistically by the Snedecor and Cochran (1989) test. The $y = a x^b$ model was fitted to the consolidation pressure curves of each treatment. To compare the curves, we proceeded to linearization [$\ln(y) = \ln(a) + b \ln(x)$], comparing

the linear and angular coefficient statistically among the treatments.

RESULTS AND DISCUSSION

The soils under natural forest and no-tillage retained more water, associated with the higher organic matter content and, possibly, soil microporosity and clay content (Table 1).

As mentioned by Vasconcelos et al. (2012), organic matter contributes to water retention, and the higher content comes from forest litter, mulch of brachiaria straw and crop residue incorporation during soil preparation for the no-tillage system. A comparison of irrigation in the no-tillage and sheep-grazed areas showed that the soil in the first system would retain more water for a longer time, favoring plant development and saving energy by sparing irrigation.

The behavior of preconsolidation pressure in soil under no-tillage, forest and sheep grazing systems is shown in figure 2. The table 2 shows the statistical analysis summary for preconsolidation pressure modeling of the different management systems.

By Snedecor and Cochran (1989) test, models generated for natural forest and no-tillage system soil did not differ statistically, thus, a new model was fitted to both management systems (Figure 2).

Models were adjusted as proposed by Dias Junior et al. (1999) that show the preconsolidation pressure behavior with water-holding capacity. The preconsolidation values were higher in drier soil and, consequently, the load-bearing capacity as well (Gontijo et al., 2011). Natural forest and no-tillage versus sheep grazing models are statistically different (Table 1), and the indices indicated superiority of the sheep grazing system. This behavior shows different deformations due to management; and conservation of the soil structure in the no-tillage system, since compared to natural forest, no significant changes were detected. Possibly, this behavior in this system was due to the initial preparation by moldboard plowing two years earlier, and to the organic matter content (Table 1), which according to Rocha et al. (2007), is one of the most important soil quality indices.

Natural forest and no-tillage had the lowest values of preconsolidation pressure (Table 3) on account of their better-preserved soil structure, both for the forest free of animal trampling and machinery traffic and the no-tillage system, in which, aside from soil preparation, straw mulch on the soil may have had a cushion effect, absorbing the applied pressures. Sheep grazing on the other hand had the greatest pressure values at all

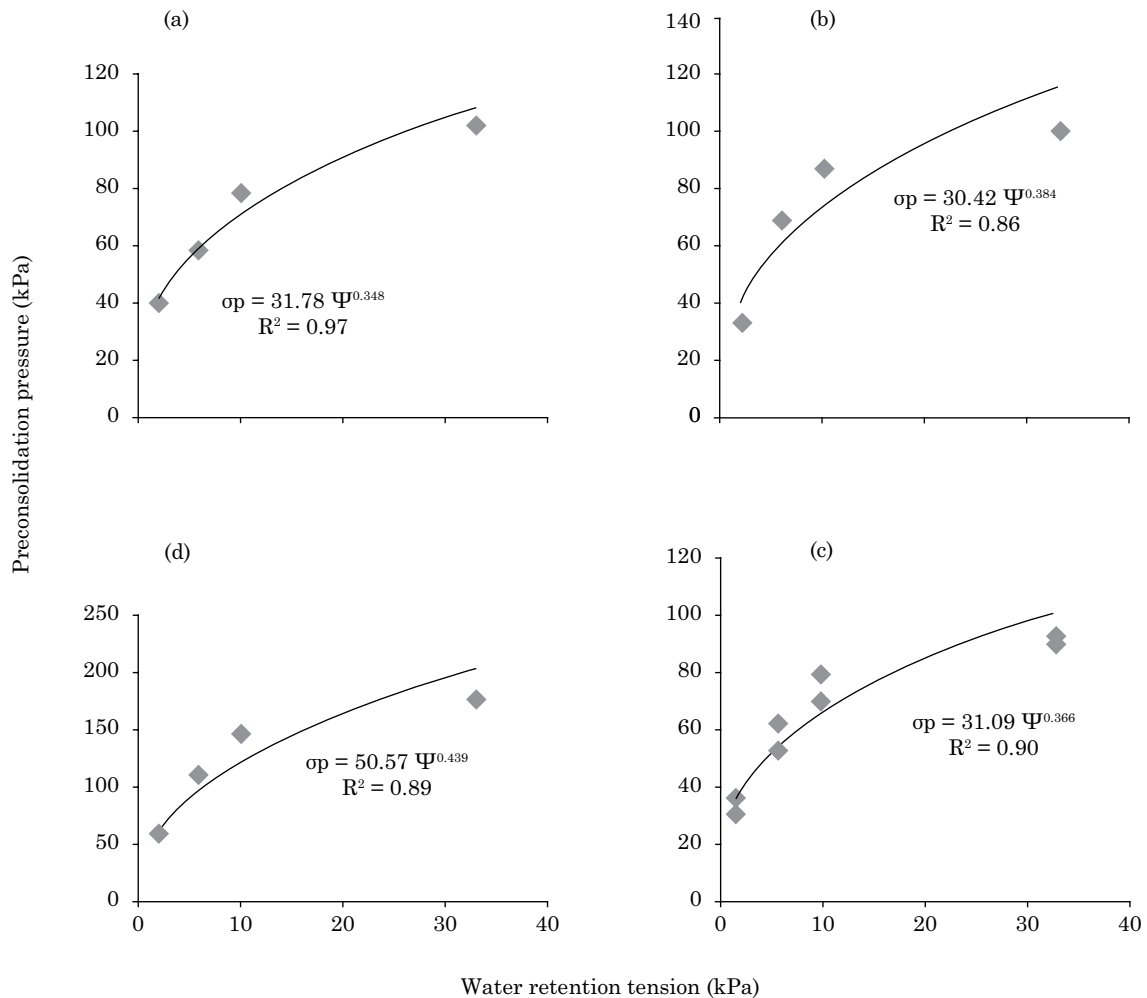


Figure 2. Preconsolidation pressure modeling (σ_p) in Latossolo Vermelho-Amarelo distrófico (Oxisol) under no-tillage system (a), natural forest (b), sheep grazing (c) and natural forest and no-tillage system (d) at varied water retention tensions.

Table 2. Snedecor and Cochran significance test among preconsolidation pressure modeling and coefficients of models fitted to soil resistance to penetration in Latossolo Vermelho-Amarelo distrófico (Oxisol) at different water retention tensions

Management	F	Angular coefficient (b)	Linear coefficient (a)
Preconsolidation pressure			
No-tillage vs natural forest	Homogeneous	ns	ns
No-tillage vs sheep grazing	Non-homogeneous	ns	**
Sheep grazing vs natural forest	Homogeneous	**	**
Soil resistance to penetration			
No-tillage vs natural forest	Homogeneous	ns	ns
No-tillage vs sheep grazing	Non-homogeneous	ns	**
Sheep grazing vs natural forest	Homogeneous	**	**

F: data homogeneity; b: angular coefficient of linear regression; a: linear regression intercept; ns: non-significant; * and **: significant at 1 and 5 % of significance, respectively.

water tensions due to animal trampling, which increased soil mechanical resistance, leading to a compaction process and reduced organic matter content, reflecting lower water-holding rates and consequently higher preconsolidation pressures.

Data of soil penetration resistance were analyzed in a complementary study, with modeling of soil penetration resistance to by moisture (Figure 3).

Table 2 presents a summary of the statistical analysis for soil resistance to penetration models.

Table 3. Preconsolidation pressure values (op) in soil under varied managements at different water retention tensions

Management	2 kPa	6 kPa	10 kPa	33 kPa
	op (kPa)			
No-tillage	68 a	111 a	139 a	235 a
Natural forest	40 b	59 b	71 b	107 b
Sheep grazing	40 b	60 b	74 b	116 b

Values followed by the same letter vertically do not differ from each other statistically by Snedecor and Cochran test.

By the Snedecor and Crochan (1989) test, the models generated for forest and no-tillage system did not differ significantly from each other, but were statistically different from the model for sheep grazing areas (Table 2).

For natural forest and no-tillage system, the data of penetration resistance were grouped and a new model was generated (Figure 3).

Based on the models, values of soil penetration resistance at field capacity were obtained (Table 4). Soil penetration resistance, as a direct measure of soil structure, indicates the presence or absence of compaction.

Soil penetration resistance was not higher than 2 MPa at field capacity in any of the management systems (Table 1). However, the sheep grazing areas must be treated with care, since the PR value was very close to the limit and according to preconsolidation pressure (Table 3). Pressures of above the limit of 111 kPa are a warning, calling for constant monitoring in this area, to avoid changes in the soil structure, resulting in a penetration resistance above 2 MPa, requiring soil decompaction. The results demonstrate that sheep

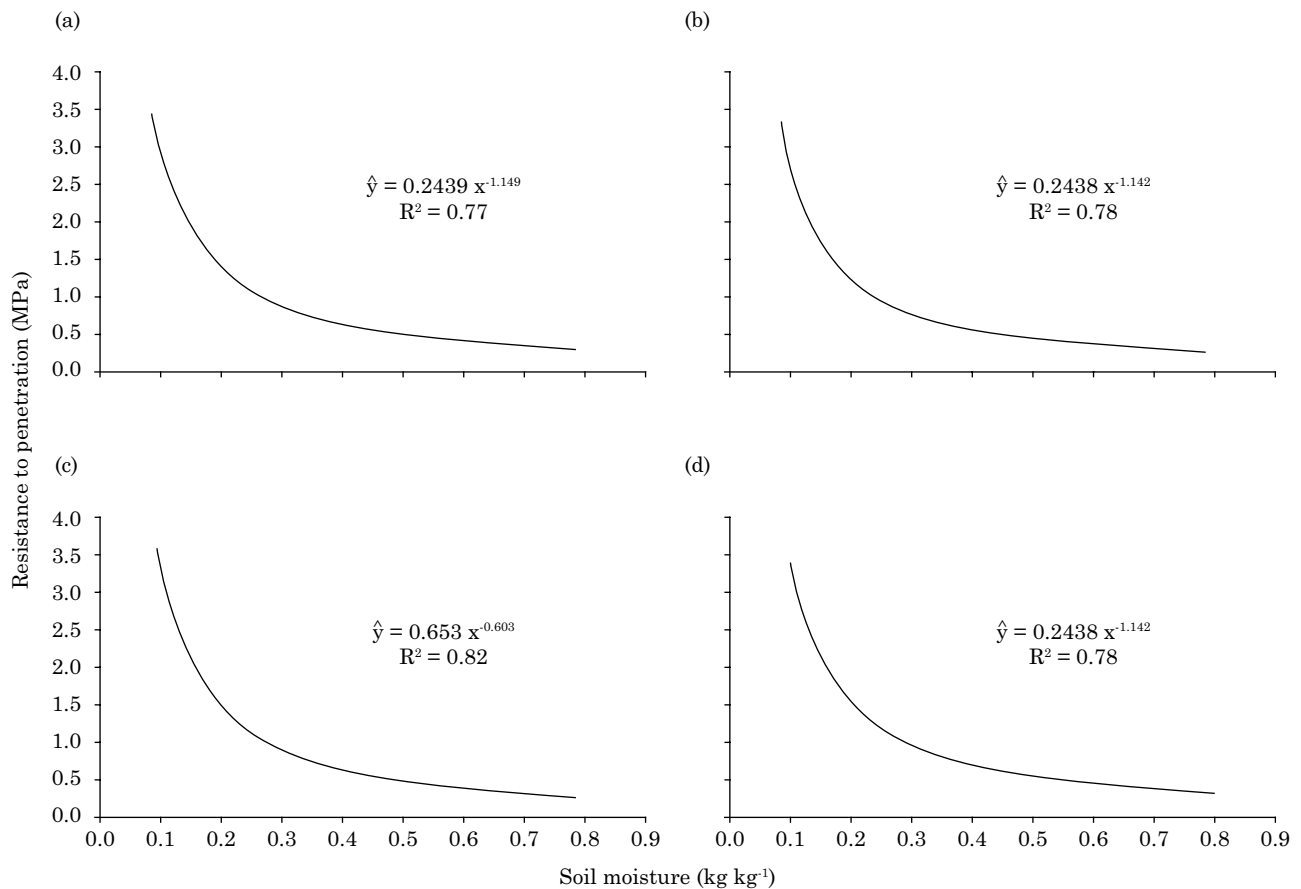


Figure 3. Modeling of soil resistance to penetration at varied moisture levels in Latossolo Vermelho-Amarelo distrófico (Oxisol) under no-tillage system (a), natural forest (b), sheep grazing (c) and natural forest and no-tillage system (d).

Table 4. Soil resistance to penetration (RP) for different management systems at moisture level of field capacity (6 kPa) and of 0.2 kg kg⁻¹

Management	6 kPa	0.2 kg kg ⁻¹
	MPa	
No-tillage	1.74 a	2.14 a
Natural forest	0.87 b	1.54 b
Sheep grazing	0.93 b	1.54 b

Values followed by the same letter vertically do not differ from each other statistically by Snedecor and Cochran test.

grazing degraded the soil structure in comparison with natural forest. These penetration resistance values, according to Merotto Jr. and Mundstock (1999), do not indicate soil compaction, however, as the areas are not irrigated and moisture is mostly low, a common field moisture level of 0.2 kg kg⁻¹ was simulated (Table 4).

In the soil under natural forest and no-tillage the values were still far from the critical limits, indicating that soil structure in no-tillage is still preserved, compared to the forest system (Table 4). In addition, under drier conditions, organic matter can reduce soil weight (Rocha et al., 2007), which would explain the lower PR values, compared to grazing areas. Nevertheless, RP in soil under sheep grazing exceeded 2 MPa. In this situation, the development of the root system would be hampered, which could adversely affect crop production.

CONCLUSIONS

Preconsolidation pressure models generated for soils under natural forest and no-tillage systems were not statistically different, demonstrating that tillage did not degrade the soil.

Soil under sheep grazing had higher preconsolidation pressure values for water retention tensions and higher penetration resistance than under natural forest, demonstrating the degradation potential of animal trampling.

Soil penetration resistance did not exceed 2 MPa at field capacity in any of the management systems.

Only under sheep grazing soil penetration resistance approached 2 MPa closely at field capacity and the values exceeded 2 MPa at a moisture of 0.2 kg kg⁻¹.

REFERENCES

Blainski E, Tormena CA, Fidalski J, Guimarães RML. Quantificação da degradação física do solo por meio da curva de resistência à penetração. *R Bras Ci Solo*. 2008;32:975-83.

Blake GR, Hartge KH. Bulk density. In: Klute A, editor. *Methods of soil analysis*. 2nd ed. Madison: American Society of Agronomy, 1986. Part 1, p.363-375.

Bowles JE. *Engineering properties of soils and their measurements*. 3th ed. New York: McGraw-Hill; 1986.

Day PR. Particle fractionation and particle-size analysis. In: Black CA, editor. *Methods of soil analysis*. Madison: American Society of Agronomy, 1965. Part I, p.545-567.

Dias Junior MS. *Compression of three soils under longterm tillage and wheel traffic* [thesis]. East Lansing: Michigan State University; 1994.

Dias Junior MS, Ferreira MM, Fonseca S, Silva AR, Ferreira DF. Avaliação quantitativa da sustentabilidade estrutural dos solos em sistemas florestais na região de Aracruz-ES. *R Árvore*. 1999;23:371-80.

Dias Junior MS, Pierce FJ. A simple procedure for estimating preconsolidation pressure from soil compression curves. *Soil Technol*. 1995;8:139-51.

Dias Junior MS, Pierce FJ. O processo de compactação do solo e sua modelagem. *R Bras Ci Solo*. 1996;20:175-82.

Dias Junior MS, Silva AR, Fonseca S, Leite FP. Método alternativo de avaliação da pressão de preconsolidação por meio de um penetrômetro. *R Bras Ci Solo*. 2004;28:805-10

Empresa Brasileira de Pesquisa Agropecuária - Embrapa. *Manual de métodos de análise de solo*. 2a ed. Brasília, DF: Centro Nacional de Pesquisas do Solo; 1997.

Empresa Brasileira de Pesquisa Agropecuária - Embrapa. *Sistema brasileiro de classificação de solos*. 2ª ed. Rio de Janeiro; 2006.

Gontijo I, Dias Junior MS, Guimarães PTG, Oliveira MS, Ajayi AE. Spatial patterns of preconsolidation pressure and soil moisture along transects in two directions under coffee. *R Bras Ci Solo*. 35:1189-96, 2011.

Hanza MA, Anderson WK. Soil compaction in cropping systems a review of the nature, causes and possible solutions. *Soil Till Res*. 2005;82:121-45.

Imhoff, S. *Indicadores de qualidade estrutural e trafegabilidade de Latossolos e Argissolos Vermelhos* [tese]. Piracicaba: Escola Superior de Agricultura "Luiz de Queiroz"; 2002.

Lapen DR, Topp GC, Gregorich EG, Curnoe WE. Least limiting water range indicators of soil quality and corn production, Eastern Ontario, Canada. *Soil Till Res*. 2004;78:151-70.

Leão TP, Silva AP, Macedo MCM, Imhoff S, Euclides APB. Least limiting water range: A potential indicator of changes in near-surface soil physical quality after the conversion of Brazilian Savanna into pasture. *Soil Till Res*. 2006;88:297-85.

Merotto Jr A, Mundstock CM. Wheat root growth as affected by soil strength. *R Bras Ci Solo*. 1999;23:197-202.

Oliveira PPA, Trivelin PCO, Oliveira WS, Corsi M. Fertilização com N e S na recuperação de pastagem de *Brachiaria brizantha* cv. Marandu em Neossolo Quartzarênico. *R Bras Zootec*. 2005;34:1121-9.

Pires BS, Dias Junior MS, Rocha WW, Araujo Junior CF, Carvalho RCR. Modelos de capacidade de suporte de carga de um Latossolo Vermelho-Amarelo sob diferentes usos e manejos. *R Bras Ci Solo*. 2012;36:635-42.

- Raij BV, Quaggio JA. Métodos de análise de solo para fins de fertilidade. Campinas: Instituto Agrônomo de Campinas; 1983. (Boletim técnico, 81).
- Raper DL. Agricultural traffic impacts on soil. *J Terramech.* 2005;42:259-80.
- Reichardt K. Capacidade de campo. *R Bras Ci Solo.* 1988;12:211-6.
- Rocha WW, Borges SR, Victória EP, Nunes AB. Resistência ao cisalhamento do solo do ponto de vista ambiental. In: Abreu MHN, organizador. *Ciências Ambientais: Abordagem multidisciplinar.* Belo Horizonte: Universidade do Estado de Minas Gerais; 2007. p.87-124.
- Ribeiro AC, Guimaraes PTG, Alvarez V VH, editores. *Recomendação para o uso de corretivos e fertilizantes em Minas Gerais: 5ª Aproximação.* 1ª ed. Viçosa, MG: Comissão de Fertilidade do Solo do Estado de Minas Gerais; 1999.
- Silva AP, Kay BD, Perfect E. Characterization of the least limiting water range. *Soil Sci Soc Am J.* 1994;58:1775-81.
- Silva AP, Tormena CA, Imhoff S, Fidalski J, Neves Junior AF. Intervalo hídrico ótimo e sua importância para as plantas. In: Ribeiro MR, Nascimento CWA, Ribeiro Filho MR, Cantalice JRB, ed. *Tópicos em ciência do solo.* Viçosa, MG: Sociedade Brasileira de Ciência do Solo; 2009. v.6, p.1-30.
- Snedecor GW, Cochran WG. *Statistical methods.* 8th ed. Ames: Iowa State University Press; 1989.
- SigmaPlot. *Scientific Graphing Software.* Versão 8.0. San Rafael: Jandel Corporation; 2002.
- Taylor DW. *Fundamentals of soil mechanics.* New York: John Wiley; 1948.
- Taylor HM, Robertson GM, Parker JJ. Soil strength root penetration for medium to coarse textured soil materials. *Soil Sci Soc Am J.* 1966;102:18-22.
- Tormena CA, Silva AP, Libardi P. Caracterização do intervalo hídrico ótimo de um Latossolo Roxo sob plantio direto *R Bras Ci Solo.* 1998;22:573-81.
- Vasconcelos RFB, Cantalice JRB, Moura GBA, Rolim MM, Montenegro CEV. Compactabilidade de um Latossolo Amarelo distrocoeso dos tabuleiros costeiros de Alagoas sob diferentes sistemas de manejo da cana-de-açúcar. *R Bras Ci Solo.* 2012;36:537-45.