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Short term changes on soil physical quality after different pasture renovation methods on a clayey oxidic Red Latosol

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ABSTRACT

Most of Brazilian agricultural land is occupied by pastures, which often show some degree of degradation. Grazing is usually associated to damages on soil structure because of soil compaction. The aim of this work was to evaluate short term changes on soil physical quality following different pasture renovation methods, including fertilization (FERT), conventional soil tillage (TILL) and two crop-livestock system (no-till and conventional tillage, respectively COTI and CONT), on a very clayey Red Latosol (Ustox), also comparing these to the original pasture and a nearby forest fragment. Bulk density and macroporosity were significantly different on the pasture sites (averaging 1.12 g cm^{-3} and 0.16 cm^3 cm^{-3} respectively) from that under the forest fragment (respectively 0.87 g cm^{-3} and 0.34 cm^3 cm^{-3}); however, significant differences between the renovation methods and the original pasture were not observed. The load bearing capacity model (LBCM), which relates decrease on soil precompression stress (σ_p) with increase on water content (U), obtained for the original pasture, ORIG ($\sigma_p = 10^{(2.82-1.21*U)}$), was considered different from that obtained for the soil under natural vegetation ($\sigma_p = 10^{(2.69-1.25*U)}$), with the former being more resistant to compaction. When the ordinate pairs (U, σ_p) obtained from soil cores collected on the different renovation methods experimental plots were plotted on the LBCM from ORIG, an increase on soil strength could be noticed, but with small differences between renovation methods. This was because of higher stocking rates on FERT and TILL and corn harvest for silage production on COTI and CONT. Tillage failed to improve soil physical quality even on the short turn (only one growing season) and should be disregarded as a renovation method for pastures on initial stages of degradation, while soil fertility is the main limitation.

Key words: load bearing capacity, precompression stress, soil compaction

Alterações na qualidade física do solo no curto prazo após diferentes métodos de renovação de pastagens em um Latossolo Vermelho argiloso oxídico

RESUMO

As pastagens ocupam a maior porção das terras agrícolas do Brasil e frequentemente apresentam algum grau de degradação. O pastejo animal geralmente está associado a danos à estrutura do solo, devido à compactação. O objetivo deste trabalho foi avaliar as mudanças no curto prazo na qualidade física de um Latossolo Vermelho muito argiloso, após diferentes métodos de renovação de pastagens, incluindo adubação (FERT), preparo convencional (TILL) e interação lavoura-pecuária (com preparo convencional do solo e em plantio direto, COTI e CONT respectivamente), comparando estes à pastagem original e a um fragmento de mata próximo. A densidade do solo e a macroporosidade nas áreas de pastagem (respectivamente 1,12 g cm^{-3} e 0,16 cm^3 cm^{-3}) foram significativamente diferentes em comparação ao solo sob mata (respectivamente 0,87 g.cm^{-3} e 0,34 cm^3 cm^{-3}); contudo, diferenças significativas entre os métodos de renovação e a pastagem original não foram observadas. O modelo de capacidade de suporte de carga (MCSC), que relaciona o decréscimo na pressão de pré-consolidação (σ_p) com o aumento da umidade (U), obtido para a pastagem original, ORIG ($\sigma_p = 10^{(2,82-1,21*U)}$), foi considerado diferente daquele obtido para o solo sob vegetação nativa ($\sigma_p = 10^{(2,69-1,25*U)}$), tendo o primeiro apresentado maior capacidade de suporte de carga. Quando os pares ordenados (U, σ_p) obtidos de amostras indeformadas coletadas nas parcelas experimentais com diferentes estratégias de renovação de pastagens foram plotados no MCSC de ORIG, foi possível observar um aumento na resistência do solo, mas com pequenas diferenças entre os métodos de renovação. Isto se deve às maiores taxas de lotação em FERT e TILL e à colheita do milho para silagem em CONT e COTI. O preparo do solo não foi eficiente em melhorar a qualidade física do solo mesmo no curto prazo (apenas uma estação de crescimento) e deveria ser desencorajado como um método de renovação de pastagens em estado inicial de degradação, enquanto a fertilidade do solo é o principal fator limitante.

Palavras-chave: capacidade de suporte de carga, pressão de pré-consolidação, compactação

Introduction

Most of Brazilian agricultural land is occupied by pastures and while export-oriented crops, such as soybean and sugarcane, take over grasslands, the agricultural frontier is expanded to support cattle production, based mainly on large areas with continuous grazing and low stocking rates (Martinelli et al., 2010). It is pointed out that pasture degradation compromises sustainable cattle production; and, while few ranchers are concerned with this issue, even fewer are recovering degraded pastures (Peron & Evangelista, 2004). Decrease on soil fertility is regarded as the main cause of pasture degradation, while environmental damage and natural resources deterioration takes place as soil compaction decreases infiltration, thus increasing run-off and erosion (Macedo, 2005).

Soil structure may deteriorate quite rapidly when it is subjected to destructive forces (Hillel, 1998). Soil compaction is a common cause of structural deterioration (Batey, 2009) and it will only cease when the soil becomes strong enough to withstand the applied stress (Dexter, 2004). Animal trampling may cause great damage to soil structure, due to both compaction and shearing (Trimble & Mendel, 1995). The pressure applied to the soil by cattle is usually underestimated, because it is commonly conceived as static and because the weight of the animal is usually thought to be divided by the basal area of the four hoofs (Martínez & Zinck, 2004).

Soil compaction due to animal trampling is a very common research subject. It is related to stocking rates and pasture management (Monaghan et al., 2005; Piggnataro Netto et al., 2009), pasture age (Martínez & Zinck, 2004), soil water content (Lima et al., 2004), and grass botanical aspects (Imhoff et al., 2000a). Nevertheless, degraded pasture renovation is rarely evaluated from the perspective of soil physical quality. Physical quality parameters are regarded as of great aid in stratifying environments (Araújo et al., 2007); as soil physics exerts great influence on chemical and biological processes within the soil, it plays a central role on soil quality evaluation studies (Dexter, 2004).

Soil physical quality under grasslands has been evaluated through different parameters, being the most common bulk density (Maciel et al., 2009), porosities (Sarmento et al., 2008), and soil resistance to penetration (Imhoff et al., 2000b, Piggnataro Netto et al., 2009). Other parameters applied to assess soil physical quality on pastures include water retention curve (Borges et al., 2009), least limiting water range (Leão et al., 2004), precompression stress (Kondo & Dias Junior, 1999, Lima et al., 2004), and load bearing capacity (Pires et al., 2012).

Each soil exhibits a specific relation between applied stress and deformation, known as stress/strain relationship (Horn & Lebert, 1994). This relationship may be assessed by means of uniaxial compression tests, which yields the soil compression curve (Keller et al., 2011). This is usually presented as the relationship between soil bulk density or void ratio and the log of the applied stress, generally showing a distinctive bend, which is recognized as precompression stress (Dias Junior & Pierce, 1995; Keller et al., 2011). The curve that relates precompression stress (σ_p), obtained from the soil compression curve, and gravimetric water content (U) is known as load bearing capacity model (LBCM), which is an regression adjustment of σ_p as a function of U in the form $\sigma_p = 10^{(a-b*U)}$ (Dias Junior et al., 2005).

The aim of this study was to evaluate the impact of different pasture renovation methods on some selected soil physical quality parameters of a very clayey Red Latosol (Acrudox), comparing them to the original pasture and to a nearby soil under natural vegetation (secondary forest fragment).

Material and Methods

The study was conducted on experimental plots (0.35 ha each) from the Animal Science Department at Lavras Federal University, on the city of Lavras-MG, southeastern Brazil. The local climate is defined as Cwa (Köppen climatic classification system), mesothermic with rainy summer and dry winter; with average annual precipitation of 1530 mm and mean annual temperature of 19.4 °C (Dantas et al., 2007). The soil on the experiment site was classified as dystroferric Red Latosol (Santos et al., 2006), Acrudox, and some of its characteristics can be seen on Table 1. The marandu-grass (*Urochloa brizantha* cv. Marandu) pasture was established on summer 2007, being intensively grazed since then with little nutrient reposition until the summer of 2011. At this occasion, initial signs of pasture degradation could be seen, as lower forage yield (forage mass averaging 2,200 kg ha^{-1} on all plots) and weed infestation. The slope on the experimental site is 15% on average (measured with clinometer).

Four different renovation methods were tested and compared to the original pasture and to a nearby (within 500 m radius) secondary forest fragment on the same soil unit (these are termed respectively ORIG and NATU). Renovation treatments were: fertilization (FERT), tillage renovation (TILL), indirect renovation with corn cultivation after soil tillage (COTI), and indirect renovation with corn cultivation on no-tillage system (CONT). Tillage, fertilization, and seeding were performed on December 2011. On TILL and COTI, soil was tilled twice with a heavy harrow (tillage depth of 20 cm); while on CONT glyphosate was applied 30 days prior to seeding. Fertilization on all renovation treatments consisted of 350 kg ha^{-1} of granular NPK fertilizer (08-28-16) on experiment implantation (broad application on FERT and TILL and row application on COTI and CONT) and 350 kg ha^{-1} of granular NPK fertilizer (20-0-20) on January 2012. The Marandu-grass seeds (8.75 kg ha^{-1}) were broadly applied on TILL and applied together with the fertilizer on COTI and CONT. On these two treatments, corn was harvested (whole plants) on May 2012 for silage production with a tractor coupled to a forage harvester.

All renovation treatments and the original pasture were submitted to the same grazing pressure, being the stocking rates defined based on forage yield (Table 1). Forage mass was determined prior to animal grazing, and daily forage allowance was set to 6% of live weight during the whole grazing period, that was 60 days (Table 1). Grazing began on June 2012. Animals were selected by their weight so that there would be at least two animals per plot. Pastures were grazed continuously for the whole grazing period. This sort of pasture management is known as stockpiling, and in this case it consisted of animal exclusion during the growing season (October to April), increasing available forage for consumption during the dry season (May to September). This procedure was adopted in order to allow pasture growth after corn harvest and to maintain the same grazing period (60 days) in all treatments. Animals were excluded from all the experimental plots until the beginning of the experiment, on June 2012.

Soil sampling was conducted after animal removal on August 2012. Each treatment was applied on two experimental plots, with half of the samples being randomly taken from each one of these (there were 10 experimental plots, two for each renovation method and two for the original pasture), while the samples from the forest fragment were taken from only one sampling point. Loose soil (one composite sample per treatment), clods (six samples per treatment) and cores (15 cores from each treatment) were collected at 0-5 cm, since this depth is usually the most affected by compaction due to animal trampling (Monaghan et al., 2005; Pietola et al., 2005; Sarmento et al., 2008; Piggnataro Netto et al., 2009; Torres et al., 2013) . Soil cores were collected on metal rings (6.4 cm diameter and 2.5 cm height) with an Uhland sampler, after careful removal of vegetation and litter from soil surface. After being removed from the sampler, soil cores were wrapped on plastic film and labeled. Clods and loose soil were collected with a hoe, being stored on identified plastic bags. Loose soil was air dried and sieved (2 mm) and then used on chemical, granulometric (pipeth method), and particle density analysis (ethanol and volumetric flask method) as described in Donagema et al. (2011).

Clod samples were air dried and sieved, being used the clods that passed through the 8.0 mm sieve and that were retained at the 4.75 mm sieve. Aggregate stability analysis was performed through wet sieving with pre-moistening of soil aggregates on sand bed (Kemper & Rosenau, 1986) and the geometric mean diameter (Mazurak, 1950) was adopted as aggregation index (sieve openings used were: 2, 1, 0.5, 0.25 and 0.105 mm). Six samples per treatment were used.

Microporosity was determined as the water retained at -6 kPa on water tension unit, while macroporosity was calculated as the difference between total porosity and microporosity (Danielson & Sutherland, 1986). Five samples per treatment were used.

Soil cores were saturated and/or air dried in the laboratory until the desired water content was reached (ranging from 0.05 to 0.5 g^3 g^{-1}) prior to uniaxial compression tests. These were performed on compressed air consolidometers (Terraload Consolidation Device S-450, Durham Geo Slope, USA), being applied stresses of 25, 50, 100, 200, 400, 800, and 1600 kPa (standard sequence according to Bowles, 1986) until 90% of maximum deformation was obtained (Taylor, 1948), what took from 4 to 15 minutes per load step. After load removal, soil cores were oven dried (105-110 °C for 48 hours) and water content and bulk density were determined (Blake & Hartge, 1986). Precompression stress was calculated according to Dias Junior & Pierce (1995). Precompression stress (σ_p) and gravimetric water content (U) values were used for generating the load bearing capacity models (for NATU and ORIG treatments), through fitting to the equation $\sigma_p = 10^{(a + bU)}$ (Dias Junior et al., 2005). These models were statistically compared with the test for generalized linear models from Snedecor & Cochran (1989). The impact of the renovation methods was evaluated through plotting the ordinated pairs (U, σ_p) on the load bearing capacity models, as described in Dias Junior et al. (2005). A total of 68 undisturbed samples were collected, being 14 for each load bearing capacity model (from NATU and ORIG) and 10 for each renovation method (FERT, TILL, COTI and CONT) for assessment of impacts. Analysis of variance and Tukey test were accomplished on the software Sisvar (Ferreira, 2011), while regressions and graphical procedures were performed on the software Sigma Plot (Jandel Scientific).

Results and Discussion

Aggregate stability was not affected neither by land use nor pasture renovation method (Table 2). Geometric mean diameter was only significantly different on CONT, averaging 4.39 mm, while the other treatments averaged from 4.64 to 4.85 mm, being this difference credited to some intrinsic variable that may have changed on this treatment, such as texture (higher

Table 1. Chemical and physical characteristics for the studied (0-5 cm depth) soils and stocking rates adopted

	Unit	NATU	ORIG	FERT	TILL	COTI	CONT
pH_{H2O}		4.6	5.9	5.4	5.3	5.5	5.6
SB	cmol$_c$ dm^{-3}	0.64	4.97	3.71	3.35	4.76	5.02
t	cmol$_c$ dm^{-3}	1.14	4.97	3.71	3.35	4.76	5.02
T	cmol$_c$ dm^{-3}	10.5	8.21	7.75	7.39	8.0	7.92
SOM	g kg^{-1}	37	46	40	41	44	44
Clay	g kg^{-1}	720	640	650	690	640	650
Sand	g kg^{-1}	160	180	160	120	130	210
Silt	g kg^{-1}	120	180	190	190	230	140
D_p	g cm^{-3}	2.61	2.61	2.61	2.61	2.61	2.61
Stocking rate (AU ha^{-1})*		7.6	11.0	12.6	4.0	4.8	
Forage mass before grazing (t ha^{-1})		8.0	10.9	10.0	2.1	3.1	
Forage mass after grazing (t ha^{-1})		1.7	4.7	2.1	0.6	1.3	

NATU: natural vegetation; ORIG: original pasture; FERT: renovation with fertilization; TILL: renovation with tillage; COTI: renovation with tillage and corn cultivation; CONT: renovation with no-tillage corn cultivation. SB: sum of bases; t: effective CEC; T: CEC at pH = 7,0; SOM: soil organic matter; D_p: particle density; AU: animal unit (450 kg of live weight).

*Stocking rates were calculated considering a daily forage allowance of 6% of live weight during the whole grazing period (60 days).

Table 2. Geometric mean diameter (GMD), total porosity (n), macroporosity (MACRO), microporosity (MICRO), and soil bulk density (D_b) determined on the different treatments (0-5 cm soil depth)

	GMD	n	MACRO	MICRO	D_b
	mm		cm^{-3} cm^{-3}		g cm^{-3}
NATU	4.72 a	0.67 a	0.34 a	0.32 b	0.87 b
ORIG	4.64 a	0.58 b	0.17 b	0.42 a	1.09 a
FERT	4.85 a	0.57 b	0.14 b	0.43 a	1.16 a
TILL	4.74 a	0.58 b	0.15 b	0.43 a	1.11 a
COTI	4.82 a	0.58 b	0.17 b	0.41 a	1.10 a
CONT	4.39 b	0.57 b	0.17 b	0.40 a	1.14 a
p	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
n	6	5	5	5	10

Means followed by the same letter, on columns, do not differ from each other (Tukey test at 5% significance).

NATU: natural vegetation; ORIG: original pasture; TILL: renovation with tillage; FERT: renovation with fertilization; COTI: renovation through tillage and corn cultivation; CONT: renovation with no-tillage corn cultivation; p: statistical significance; n: number of observations per treatment (repetitions) sand content). Tropical soils are well known for their incredibly high aggregate stability (Hillel, 1998), that is also enhanced by perennial grasses (Silva & Mielniczuk, 1998).

Bulk density on NATU was very low (0.87 g cm^{-3}), what is commonly observed on clayey and very clayey oxidic Latosols from the Cerrado region (Severiano et al., 2013). Bulk density values on pasture plots averaged from 1.09 to 1.16 g cm^{-3} (Table 2), what represents an increase of approximately 25 to 30% in comparison to the soil on NATU, but differences between pasture treatments were non-significant. Increase on bulk density is commonly observed in soils under pastures (Magalhães et al., 2001; Lima et al., 2004; Sarmento et al., 2008). Soil bulk density under pastures was observed by Monaghan et al. (2005) to show a cyclical behavior as animals are added or removed from the pasture, and this attribute may be significantly related to forage yield (Maciel et al., 2009).

Total porosity was higher on NATU (0.67 cm^3 cm^{-3}), which also yielded the lowest bulk density (0.87 g cm^{-3}). Macroporosity on soils under pasture (averaging from 0.14 to 0.17 cm^3 cm^{-3}) was almost half of that on the soil under NATU (0.34 cm^3 cm^{-3}), though microporosity had an increase of almost 30% on the former (Table 2). Decrease on macroporosity and increase on microporosity was also reported on pastures by Sarmento et al. (2008); while Borges et al. (2009) reported decrease on macroporosity, but not accompanied by increase on water retention when comparing soils under pastures and under Cerrado vegetation. Although compaction indeed occurred on pasture plots when compared to NATU, this may not be yet detrimental to forage production. The 30% increase on microporosity may aid water retention, while the macroporosity still stands above the benchmark limit frequently adopted of 0.10 cm^3 cm^{-3} (Tormena et al., 1998).

The load bearing capacity models (LBCM) generated for ORIG and NATU (Figure 1) were considered statistically different. Though the "b" parameter (angular coefficient) was considered non-significant, the intercept ("a" parameter) was significantly different (Table 3). This means that both curves have the same rate of decrease on precompression stress with increase on water content, but the position of the curve on the ordinate axis is different (Figure 2), i.e. the absolute value of precompression stress is different, with the soil under pasture showing higher load bearing capacity or higher resistance to compaction.

Precompression stress values and water contents obtained for the samples from the four renovation treatments were plotted as ordinate pairs (U, σ_p) on the LBCM obtained for ORIG (Figure 3), aiming to assess the impact of the different treatments on soil compressive behavior. The samples which fall above the upper 95% prediction band are characterized as compacted, while those located between the confidence interval limits are not considered yet compacted (Dias Junior et al., 2005). Although there were no significant differences between ORIG and the renovated plots regarding soil bulk density, total porosity and macroporosity, an increase on soil strength can be noticed on Figure 3. More than half of the samples (ranging from 60 to 70%) were considered compacted. On FERT and TILL, pasture renovation allowed an increase on stocking rates of 44 and 65% respectively, what

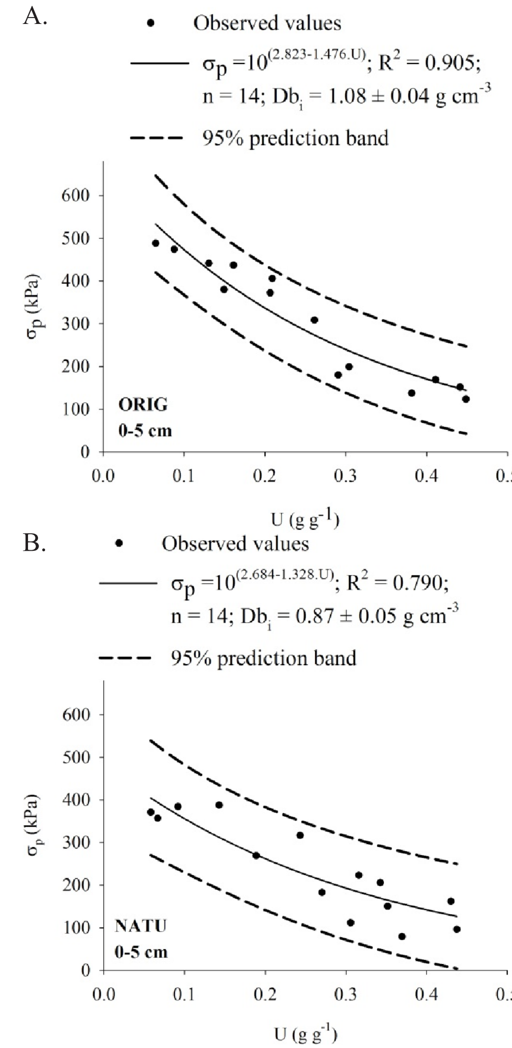


Figure 1. Load bearing capacity models generated for the soils under the original pasture (A) and natural vegetation (B) on the 0-5 cm superficial layer, which represents the change on soil precompression stress (σ_p) as a function of increase on gravimetric water content (U)

Table 3. Load bearing capacity model (LBCM) parameters and equations for the soil under the original pasture (ORIG) and natural vegetation (NATU) on the 0-5 cm superficial layer

	a**	b^{NS}	LBCM
ORIG	2,815	- 1,214	$\sigma_p = 10^{(2,815-1,214*\theta)}$
NATU	2,687	- 1,247	$\sigma_p = 10^{(2,687-1,247*\theta)}$

ORIG: original pasture; NATU: natural vegetation; a: linear coefficient; b: angular coefficient. ** = significant at 1%; NS = non-significant

may have contributed to this increase on soil strength, whereas on COTI and CONT stocking rates were 47 and 37% smaller. On these plots, the increase on soil strength is credited to corn harvest operations. During harvest operation for silage production soils may be trafficked while excessively moist, as the best stage for harvest is usually achieved close to the peak of the rainy season. In addition, as almost the whole plant is harvested, the biomass that needs to be transported is very high, what may cause the soil to suffer considerable pressures from farm machinery.

Renovation with FERT and TILL allowed an increase on forage production and stocking rates. The impact on soil physical quality could only be noticed on strength parameters

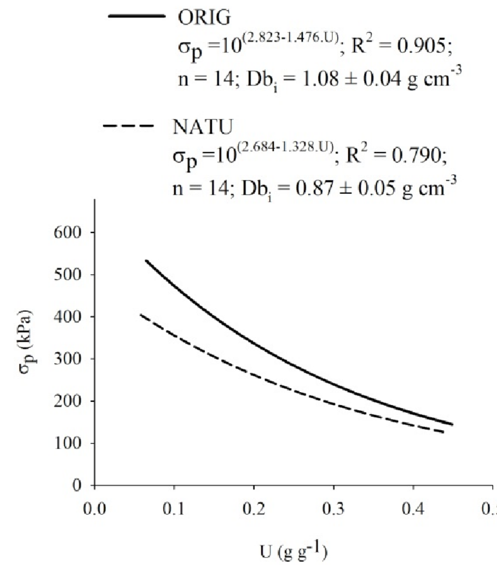
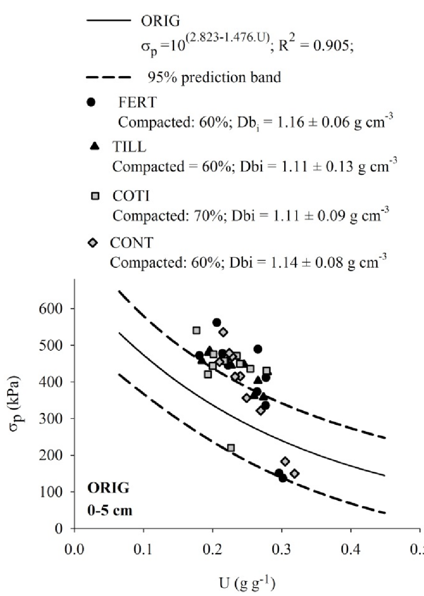


Figure 2. Load bearing capacity models for the soil under the original pasture (ORIG) and natural vegetation (NATU)



TILL: renovation with tillage; FERT: renovation with fertilization; COTI: renovation with tillage and corn cultivation; CONT: renovation with no-tillage corn cultivation. Black symbols: stocking hate above that of the original pasture; Gray symbols: stocking rate below that of the original pasture

Figure 3. Load bearing capacity model generated for the soil under the original pasture and the impact of the different renovation methods on precompression stress

and soil tillage had little impact on ameliorating general soil physical quality, although it most certainly increased soil loss during initial stages of pasture regrowth (Sparovek et al., 2007). As the pasture was yet on an initial stage of degradation, the main limitations were related to soil fertility (Macedo, 2005). In these circumstances, tillage practices would not be advisable, as they had no significant positive effect even after only a short duration grazing (60 days) during the dry season. On COTI and CONT, the same increase on soil strength was identified, as the soil was trafficked with heavy machinery during the rainy season. If corn were cropped for grain production, harvest could be performed on drier soil and compaction could be minimized, but the pasture would remain closed for a longer period.

The tillage voids created on TILL and COTI seems to have been largely, if not completely, obliterated, as the soil under these treatments yielded bulk densities and porosities not different from those under the original pasture. Tillage voids are not stable and the soil becomes denser soon after loads are applied (Kooistra & Tovey, 1994). Tillage should be disregarded as a renovation method for pastures on initial stages of degradation while soil fertility is the main limitation.

Conclusions

Soil compaction was higher under pasture than under natural vegetation, as assessed by soil bulk density, macroporosity and load bearing capacity, though it may not be detrimental to forage production yet.

Differences between the renovated plots and the original pasture were only noticed on soil strength parameters, with an increase on precompression stress values on renovated plots.

Tillage failed to improve soil physical quality and should be disregarded as a renovation method for pastures on initial stages of degradation, while soil fertility is the main limitation.

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Literature Cited

Araújo, R.; Goedert, W. J.; Lacerda, M. P. C. Qualidade de um solo sob diferentes usos e sob Cerrado nativo. Revista Brasileira de Ciência do Solo, Viçosa, v. 31, n. 5, p. 1099-1108, 2007. <http://dx.doi.org/10.1590/S0100-06832007000500025>.

Batey, T. Soil compaction and soil management - a review. Soil Use and Management, v. 25, n. 4, p. 335-345, 2009. <http://dx.doi.org/10.1111/j.1475-2743.2009.00236.x>.

Blake, G. R.; Hartge, K. H. Bulk density. In: Klute, A. (Ed.). Methods of soil analysis Part 1 - Physical and mineralogical methods. Madison: ASA/SSSA, 1986. p. 363-382.

Borges, T. A.; Oliveira, F. A.; Silva, E. M.; Goedert, W. J. Avaliação de parâmetros fisico-hídricos de Latossolo Vermelho sob pastejo e sob cerrado. Revista Brasileira de Engenharia Agrícola e Ambiental, v. 13, n. 1, p. 18-25, 2009. <http://dx.doi.org/10.1590/S1415-43662009000100003>. p.443-461.

Bowles, J. A. Engineering properties of soils and their measurements. New York: McGraw-Hill Book Company, 1986. 218 p.

Danielson, R. E.; Sutherland, P. L. Porosity. In: Klute, A. (Ed.). Methods of soil analysis. Part 1 - Physical and mineralogical methods. Madison: ASA/SSSA, 1986. 1358 p.

Dantas, A. A. A.; Carvalho, L. G. de; Ferreira, E. Classificação e tendências climáticas em Lavras, MG. Ciência e Agrotecnologia, v. 31, n. 6, p. 18621866, 2007. <http://dx.doi.org/10.1590/S1413-70542007000600039>.

Dexter, A. R. Soil physical quality Part I. Theory, effects of soil texture, density, and organic matter, and effects on root growth. Soil and Tillage Research, Amsterdam, v. 120, n. 3-4, p. 201-214, 2004. <http://dx.doi.org/10.1016/j.geoderma.2003.09.004>.

Dias Junior, M. S.; Leite, F. P.; Lasmar Júnior, E.; Araújo Júnior, C. F. Traffic effects on the soil preconsolidation pressure due to Eucalyptus harvest operations. Scientia Agricola, v. 62, n. 3, p. 248-255, 2005. <http://dx.doi.org/10.1590/S0103-90162005000300008>.

Dias Junior, M. S.; Pierce, F. J. A simple procedure for estimating preconsolidation pressure from soil compression curves. Soil Technology, v. 8, n. 2, p. 139-151, 1995. <http://dx.doi.org/10.1016/0933-3630(95)00015-8>.

Donagema, G. K.; Campos, D. V. B.; Calderano, S. B.; Teixeira, W. G.; Viana, J. H. M. Manual de métodos de análise de solos. Rio de Janeiro: Embrapa Solos, 2011. 230 p.

Ferreira, D. F. Sisvar: a computer statistical analysis system. Ciência e Agrotecnologia, v. 35, n. 6, p. 1039-1042, 2011. <http://dx.doi.org/10.1590/S1413-70542011000600001>.

Hillel, D. Environmental soil physics. San Diego: Academic Press, 1998. 771 p.

Horn, R.; Lebert, M. Soil compactability and compressibility. In: Soane, B.D.; van Ouwerkerk, C. (Ed.). Soil compaction in crop production. Amsterdam: Elsevier Science, 1994. 684 p.

Imhoff, S.; Silva, A. P.; Tormena, C. A. Aplicações da curva de resistância no controle da qualidade física de um solo sob pastagem. Pesquisa Agropecuária Brasileira, v. 35, n. 7, p. 1493-1500, 2000b. <http://dx.doi.org/10.1590/S0100-204X2000000700025>.

Imhoff, S.; Silva, A. P.; Tormena, C. A. Spatial heterogeneity of soil properties in areas under elephant-grass short-duration grazing system. Plant and Soil, v. 219, n. 1, p. 161-168, 2000a. <http://dx.doi.org/10.1023/A:1004770911906>.

Jandel Corporation. Sigma plot. Scientific Graphing Software. Versão 8.0. San Rafael: Jandel Corporation, 2002.

Keller, T.; Lamandé, M.; Schjønning, P.; Dexter, A. R. Analysis of soil compression curves from uniaxial confined compression tests. Geoderma, v. 163, n. 1-2, p. 13-23, 2011. <http://dx.doi.org/10.1016/j.geoderma.2011.02.006>.

Kemper, W. D.; Rosenau, R. C. Aggregate stability and size distribution. In: Klute, A. (Ed.). Methods of soil analysis. Part 1 - Physical and mineralogical methods. Madison: ASA/SSSA, 1986. p. 425-442.

Kondo, M. K.; Dias Junior, M. S. Efeito do manejo e da umidade no comportamento compressivo de três Latossolos. Revista Brasileira de Ciência do Solo, v. 23, n. 2, p. 497-506, 1999. <http://sbcs.solos.ufv.br/solos/revistas/v23n3a02.pdf>. 28 Jul. 2015.

Kooistra, M. J.; Tovey, N. K. Effects of compaction on soil microstructure. In: Soane, B.D.; van Ouwerkerk, C. (Ed). Soil compaction in crop production. Amsterdam: Elsevier Science, 1994. p. 91-111.

Leão, T. P.; Silva, A. P.; Macedo, M. C. M.; Imhoff, S.; Euclides, V. P .B. Intervalo Hídrico Ótimo na avaliação de sitemas de pastejo contínuo e rotacionado. Revista Brasileira de Ciência do Solo, v. 28, n. 3, p. 415-422, 2004. <http://dx.doi.org/10.1590/S0100-06832004000300002>

Lima, C. L. R.; Silva, A. P.; Imhoff, S.; Leão, T. P. Compressibilidade de um solo sob sistemas de pastejo rotacionado intensivo irrigado e não irrigado. Revista Brasileira de Ciência do Solo, v. 28, n. 6, p. 945-951, 2004. <http://dx.doi.org/10.1590/S0100-06832004000600002>.

Macedo, M. C. M. Degradação de pastagens: conceitos, alternativas e métodos de recuperação. Informe Agropecuário, v. 2, n. 226, p. 36-42, 2005. <http://www.epamig.br/index.php?option=com_docman&task=doc_download&gid=2245>. 28 Jul. 2015.

Maciel, G. A.; Ferreira, M. M.; Evangelista, A. R.; Oliveira, G. C. Relações de atributos físicos do solo e produtividade de pastagem em sub-bacias hidrográficas do município de Lavras-MG. Ciência e Agrotecnologia, v. 33, n. spe., p. 2025-2030, 2009. <http://dx.doi.org/10.1590/S1413-70542009000700055>.

Magalhães, R. T.; Kliemann, H. J.; Oliveira, I. P. Evolução das propriedades físicas de solos submetidos ao manejo do sistema Barreirão. Pesquisa Agropecuária Tropical, v. 31, n. 1, p. 7-13, 2001. <http://www.revistas.ufg.br/index.php/pat/article/view/2509>. 09 Abr. 2014.

Martinelli, L. A.; Joly, C. A.; Nobre, C. A.; Sparovek, G. A falsa dicotomia entre a preservação da vegetação natural e a produção agropecuária. Biota Neotropica, v. 10, n. 4, p. 323-330, 2010. <http://dx.doi.org/10.1590/S1676-06032010000400036>.

Martínez, L. J.; Zinck, J. A. Temporal variation of soil compaction and deterioration of soil quality in pasture areas of Colombian Amazonia. Soil and Tillage Research, v. 75, n. 1, p. 3-17, 2004. <http://dx.doi.org/10.1016/j.still.2002.12.001>.

Mazurak, A. P. Effect of gaseous phase on water-stable synthetic aggregates. Soil Science, v. 69, n. 2, p. 135-148, 1950. <http://dx.doi.org/10.1097/00010694-195002000-00005>.

Monaghan, R. M.; Paton, R. J.; Smith, L. C.; Drewry, J. J.; Littlejohn, R. P. The impacts of nitrogen fertilization and increased stocking rate on pasture yield, soil physical condition and nutrient losses in drainage from a cattle-grazed pasture. New Zeland Journal of Agricultural Research, v. 48, n. 2, p. 227-240, 2005. <http://dx.doi.org/10.1080/00288233.2005.9513652>.

Peron, A. J.; Evangelista, A. R. Degradação de pastagens em regiões de Cerrado. Ciência e Agrotecnologia, v. 28, n. 3, p. 655-661, 2004. <http://dx.doi.org/10.1590/S1413-70542004000300023>.

Pietola, L.; Horn, R.; Yli-Halla, M. Effects of trampling by cattle on the hydraulic and mechanical properties of soil. Soil and Tillage Research, v. 82, n. 1, p. 99-108, 2005. <http://dx.doi.org/10.1016/j.still.2004.08.004>.

Piggnataro Netto, I. T.; Kato, E.; Goedert, W. J. Atributos físicos e químicos de um Latossolo Vermelho-Amarelo sob pastagens com diferentes históricos de uso. Revista Brasileira de Ciência do Solo, v. 33, n. 5, p. 1441-1448, 2009. <http://dx.doi.org/10.1590/S0100-06832009000500034>.

Pires, B. S.; Dias Junior, M. S.; Araujo Junior, C. F.; Carvalho, R. C. R. Modelos de capacidade de suporte de carga de um Latossolo Vermelho-Amarelo sob diferentes usos e manejos. Revista Brasileira de Ciência do Solo, v. 36, n. 2, p. 635-642, 2012. <http://dx.doi.org/10.1590/S0100-06832012000200032>.

Santos, H. G.; Jacomine, P. K. T.; Anjos, L. H. C.; Oliveira, V. A.; Oliveira, J. B.; Coelho, M. R.; Lumberas, J. F.; Cunha, T. J F. Sistema brasileiro de classificação de solos. 2.ed. Rio de Janeiro: Embrapa Solos, 2006. 306p.

Sarmento, P.; Rodrigues, L. R. A.; Cruz, M. C. P.; Lugão, S. M. B.; Campos, F. P.; Centurion, J. F.; Ferreira, M. E. Atributos químicos e físicos de um Argissolo cultivado com Panicum maximum JACQ. cv IPR-86 Milênio, sob lotação rotacionada e adubado com nitrogênio. Revista Brasileira de Ciência do Solo, v. 32, n. 1, p.183-193, 2008. <http://dx.doi.org/10.1590/S0100-06832008000100018>.

Severiano, E. C.; Oliveira, G. C. de; Dias Júnior, M. de S.; Curi, N.; Costa, K. A. de P.; Carducci, C. E. Preconsolidation pressure, soil water retention characteristics, and texture of Latosols in the Brazilian Cerrado. Soil Research, v. 51, n. 3, p. 193-202, 2013. <http://dx.doi.org/10.1071/SR12366>.

Silva, I. F.; Mielniczuk, J. Sistema de cultivo e características do solo afetando a estabilidade de agregados. Revista Brasileira de Ciência do Solo, v. 22, n. 2, p. 311-317, 1998. <http://sbcs.solos.ufv.br/solos/revistas/v22n2a17.pdf>. 28 Jul. 2015.

Snedecor, G. W.; Cochran, W. G. Statistical methods. Ames: Iowa State University Press, 1989. 503p.

Sparovek, G.; Correchel, V.; Barretto, A. G. O. P. The risk of erosion in Brazilian cultivated pastures. Scientia Agricola, v. 64, n. 1, p. 77-82, 2007. <http://dx.doi.org/10.1590/S0103-90162007000100012>.

Taylor, D. W. Fundamentals of soil mechanics. New York: John Wiley & Sons, 1948. 700p.

Tormena, C. A.; Silva, A. P.; Libardi, P. L. Caracterização do intervalo hídrico ótimo de um Latossolo Roxo sob plantio direto. Revista Brasisleira de Ciência do Solo, v. 22, n. 4, p. 573-581, 1998. <http://www.scielo.br/pdf/rbcs/v22n4/02.pdf>. 28 Jul. 2015.

Torres, J. L. R; Rodrigues Junior, D. J.; Vieira, D. M. S. Alterações nos atributos físicos do solo em função da irrigação e do pastejo rotacionado. Irriga, v. 18, n. 3, p. 558-571, 2013. <http://dx.doi.org/10.15809/irriga.2013v18n3p558>.

Trimble, S. W.; Mendel, A. C. The cow as a geomorphic agent - A critical review. Geomorphology, v. 13, n. 1-4, p. 233-253, 1995. <http://dx.doi.org/10.1016/0169-555X(95)00028-4>.