Revista Brasileira de Ciência do Solo
ISSN: 0100-0683
revista@sbcs.org.br
Sociedade Brasileira de Ciência do Solo
Brasil

Ribeiro Carvalho, Rita de Cássia; Rocha, Wellington Willian; Cardoso Pinto, José; Silva Pires, Bruno da; Souza Dias Junior, Moacir de; Braga Nunes, Ayeska Hubner
SOIL SHEAR STRENGTH UNDER NON-IRRIGATED AND IRRIGATED SHORT DURATION GRAZING SYSTEMS
Revista Brasileira de Ciência do Solo, vol. 34, núm. 3, mayo-junio, 2010, pp. 631-638
Sociedade Brasileira de Ciência do Solo
Viçosa, Brasil

SOIL SHEAR STRENGTH UNDER NON-IRRIGATED AND IRRIGATED SHORT DURATION GRAZING SYSTEMS[1]

Rita de Cássia Ribeiro Carvalho[2], Wellington Willian Rocha[3], José Cardoso Pinto[4], Bruno da Silva Pires[5], Moacir de Souza dias Junior[6] & Ayeska Hubner Braga Nunes[7]

SUMMARY

Pasture productivity can drop due to soil compaction caused by animal trampling. Physical and mechanical alterations are therefore extremely important indicators for pasture management. The objective of this research was to: draw and evaluate the Mohr failure line of a Red Yellow Latossol under different pasture cycles and natural forest; calculate apparent cohesion; observe possible physical alterations in this soil; and propose a correction factor for stocking rates based on shear strength properties. This study was conducted between March/2006 and March/2007 on the Experimental Farm of Fundação de Ensino Superior de Passos, in Passos, state of Minas Gerais. The total study area covered 6 ha, of which 2 ha were irrigated pasture, 2 ha non-irrigated pasture and 2 ha natural forest. *Brachiaria brizantha* cv. MG-5 Vitória was used as forage plant. The pasture area was divided into paddocks. The Mohr failure line of samples of a Red Yellow Latossol under irrigated pasture equilibrated at a tension of water content of 6 kPa indicated higher shear strength than under non-irrigated pasture. The shear strength under irrigated pasture and natural forest was higher than under non-irrigated pasture. At a tension of water content of 33 kPa no difference was found in shear strength between management and use. Possible changes in soil structure were caused by apparent cohesion. The values of the correction factor were close to 1, which may indicate a possible soil compaction in prolonged periods of management.

Index terms: Soil compaction, pasture, animal trampling.

---

[1] Part of PhD Thesis in Animal Science presented by the first author to Universidade Federal de Lavras – UFLA, received for publications in March of 2009 and approved in March of 2010.

[2] Professor at the Estate University of Minas Gerais, Passos. E-mail: ritarcarvalho@uol.com.br

[3] Professor Adjunct, Department of Agronomy (soil physics), Federal University of Vales do Jequitinhonha and Mucuri, Diamantina, MG. wwillian@ufvjm.edu.br

[4] Professor Associate, Department of Animal Science, Federal University of Lavras, MG. Fellow researcher by CNPq. josecard@dzo.ufla.br

[5] PhD student in Soil Science from Universidade Federal de Lavras, MG. piresbruno@yahoo.com.br

[6] Professor Associate, Department of Soil Science, Federal University of Lavras, MG. Fellow researcher by CNPq. msouzadj@dcs.ufla.br

[7] M.Sc. in Soil Science from Universidade Federal de Lavras, MG. ayeska@yahoo.com.br

RESUMO: *RESISTÊNCIA AO CISALHAMENTO DE UM SOLO SOB PASTEJO ROTACIONADO COM E SEM IRRIGAÇÃO*

A produtividade da pastagem pode sofrer redução devido à compactação do solo exercida pelo pisoteio animal. Assim, alterações físicas e mecânicas constituem importantes indicadores para seu manejo. Objetivou-se neste estudo: traçar e comparar as envoltórias de resistência ao cisalhamento de um Latossolo Vermelho-Amarelo distrófico submetido a diferentes manejos e uso; calcular a coesão aparente desse solo; detectar se o manejo provocou alteração física nesse solo; e propor, usando propriedades da física do solo, um índice de correção para cálculo da Taxa de lotação para pastagens. As atividades de campo ocorreram no período de março de 2006 a março de 2007 na Fazenda Experimental da Fundação de Ensino Superior de Passos, unidade associada à Universidade do Estado de Minas Gerais. Foram utilizados 6 hectares, sendo: 2 ha de mata, 2 ha de pastagem irrigada e 2 ha de pastagem não irrigada. A forrageira usada foi a Brachiaria brizanta *cv MG-5 Vitória. A área da pastagem foi dividida em piquetes. Dois lotes distintos de animais foram usados: um para a área irrigada e outro para a área não irrigada. Nas áreas, foram coletadas amostras indeformadas de solo, as quais foram submetidas ao ensaio de cisalhamento direto. As envoltórias de resistência ao cisalhamento em uma tensão de 6 kPa para pastagem irrigada apresentaram tensão cisalhante superior à da pastagem não irrigada. A pastagem irrigada e mata natural apresentaram tensão cisalhante superior à da pastagem não irrigada na tensão de 6 kPa. Na tensão de 33 kPa não foram encontradas diferenças na resistência ao cisalhamento entre os manejos e uso. A coesão aparente foi responsável pelas possíveis alterações da estrutura do solo. Os valores para fator de correção foram muito próximos a 1, o que pode indicar uma possível compactação em períodos de manejo prolongados.*

Termos de indexação: compactação do solo, pastagem, pisoteio animal.

INTRODUCTION

Grazing degradation has caused some concern in terms of the sustainability of the productive system of meat and milk in Brazil (Bertol, et al., 1998). Most studies in this area are related to factors inherent to the management, such as stocking rate, morphology and loss of energy of forage plants, non-replacement of soil nutrients and improper application of technologies, which all contribute to the process of pasture degradation. The reduction of pasture quality and productivity and consequently reduced animal weight may also be related to the soil physical degradation caused by animal trampling, principally when the pasture is irrigated, since soil moisture is one the controlling factors of compaction (Pires, 2007).

Compaction can be understood as reduction of the soil porous space due to the application of external strength, as for example, by animal trampling (Rocha et al., 2007). Improper soil management, caused mainly by mechanical preparation or trampling under improper moisture conditions, and the high number of animals in the grazing area have contributed to the increase of compacted areas in Brazil. The situation represents a challenge for science to discover more precise techniques to evaluate, quantify, control, and prevent this effect of compaction (Rocha, 2003).

In many irrigated crops, soil compaction is a actually a concern, because the soil remains humid and the capacity of cargo holding is consequently low (Kondo & Dias Junior, 1999). That compaction is caused by machine traffic and/or animal trampling is confirmed in several studies (Kondo & Dias Junior, 1999; Lima et al., 2004; Oliveira et al., 2007).

Among the several available techniques to evaluate the soil physical conditions, shear strength is one of the most important since, in this study, all forces involved in the dynamic process of compaction are related and correlated with bulk density, penetration resistance, porosity, and weathering degree (Rocha et al., 2002).

Soil shear strength is the maximum shear stress the soil can stand without rupturing, or the soil shear stress on the surface where the rupture occurs, expressed in the Coulomb equation - $\tau = c + \sigma n \text{ tg}\phi$ (Ramamurphy, 2001), where τ is the maximum shear stress supported by the soil; σn is the normal stress the failure surface is subjected to; c is the cohesion intercept or apparent cohesion of the soil; ϕ is the soil internal friction angle (angle formed by the normal strength with the strength the soil bulk is subjected to) This equation defines the rupture line as the limit line of soil strength, that is, any shear stress on this line will result in soil rupture (Rocha, 2003).

Pires (2007) found no differences in shear strength in irrigated and non-irrigated LVAd pastures at a tension of 6 kPa, after animal trampling. Differences between natural fields and pastures after animal trampling were not found either. The author concluded that there was no soil degradation after animal trampling. However, he highlighted that, because the results were obtained in only one year of exploration, they are not consistent, and trampling in the grazing area was insufficient to induce greater soil resistance.

The objectives of this study were to a) draw and evaluate the Mohr failure line of a Red-Yellow Latosol under different pasture cycles and natural forest; b) calculate the apparent cohesion; c) observe whether there were physical alterations in this soil and d) propose, based on soil physical parameters, the correction factor for grazing stocking rates.

MATERIAL AND METHODS

This study was carried out from March/2006 to May/2007, on the Experimental Farm of Fundação de Ensino Superior de Passos (FESP), a unit of the Universidade do Estado de Minas Gerais (UEMG), in a dystrophic Red-Yellow Latosol (LVAd). The experiment was carried out in an area of 6 ha and divided into two management systems and one use system with: 2 ha irrigated and 2 ha non-irrigated pasture, divided into 32 paddocks (16 irrigated and 16 non-irrigated) and natural forest. The animals were rotated every two days and the paddocks rested for 30 days, totalizing a grazing cycle of 32 days. Formation and cover fertilization consisted of 120 kg of P_2O_5 and 200 kg ha^{-1} of N, respectively. A resting area was established, where mineral salt and water were freely available.

The paddocks were separated by electric fences, with a battery fed by a solar panel. The lot has a mean slope of 5.6 % and the soil is classified as dystrophic Red-Yellow Latosol, mean A texture (Embrapa, 2006) and the pasture used was *Brachiaria brizantha* cv. MG-5 Vitória.

In each management system, 32 undisturbed samples were collected randomly from the surface layer (0–3 cm) (32 samples x 2 management systems). A natural forest area of 2 ha situated nearby with the same soil as the grazing area was used as reference. Samplers were used that are especially designed for shear assays direct in squares of 5.95 x 5.95 cm and 2.2 cm high (Rocha et al., 2002). These samples were taken to the Soil Physics Laboratory of Universidade Federal de Lavras, where they were saturated. Of the 32 saturated samples of each management, 16 were equilibrated at a tension of 6 kPa (field capacity) and the 16 remaining were equilibrated at a tension of 33 kPa (drier soil), procedure carried out in the porous plate apparatus of Richard. Once the water retention tensions had been determined, the samples were submitted to direct shear tests according to Rocha et al., 2007.

For the direct shear test a compactor of ELE International (Digital Shear Machine, 26-112-9901X0089) was used. The equipment was set to work at a speed of horizontal displacement of 2 mm min^{-1} and normal stress of 194, 304, 415, and 526 kPa (Pires, 2007). After the application of the normal stress (x) and determination of the maximum shear stress (y), the straight lines of strength were drawn, obtaining the intercept (soil cohesion) and angular coefficient (internal friction angle of the soil), in each management system. The statistical comparisons between the rupture lines, i.e., between the straight line equations, were carried out according to Snedecor & Cochran (1989).

The disposable parts of the undisturbed samples from upper and lower parts of the sample rings were used for a pre- characterization of the soil, consisting of a granulometric analysis by the pipette method (Day, 1965; Embrapa, 1997), with the use of the chemical dispersant (1 mol L^{-1} NaOH). The particle density was determined by the volumetric flask method (Blake & Hartge, 1986) and the values of soil organic matter were determined according to the procedure described by Raij & Quaggio, 1983. The porous total volume was calculated by the ratio between bulk density and particle density; microporosity was determined by the volumetric moisture of the undisturbed samples of the soil submitted to the tension of 6 kPa and macroporosity was determined by the difference between the porous total volume and microporosity.

In the direct shear test, combining normal stress and shear stress, it is possible to calculate the resulting tension, a variable of great importance in this study, because it combines the tensions imposed to the soil by the animal weight itself and its displacement (Figure 1).

An animal that is moving about causes shear stress and normal stress (Rocha, 2007), (Figure 1). On this basis, the resulting tension was calculated for each management and the ratio between the forest tension (σrM)/ tension of each management studied (σrm)]. This ratio was denoted correction factor (CF). Based on this correction factor it is possible to evaluate soil structure alterations in relation to preserved soil

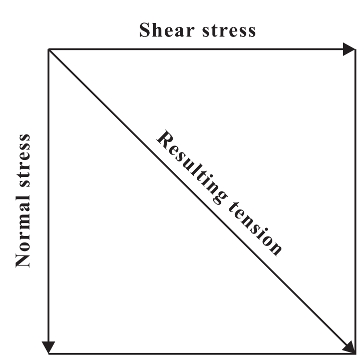

Figure 1. Scheme of tension distribution in the direct shear test.

(natural forest area). Values below 1 indicate a structural alteration that can mean soil compaction, since the natural forest can be considered the soil use where the original structure is preserved.

This correction factor can be used to correct the stocking rate (unit animal/ha) depending on a possible compaction: Corrected stocking rate = calculated stocking rate *versus* CF. It is worth mentioning that this correction is necessary with a view to the future reduction of forage offer due to the soil compaction induced and possibly to justify correction measures of compaction such as the use of sub soiling and scarification.

Of the rupture lines obtained by the direct shear test, the shear stress was calculated for a normal stress of 450 kPa, which, according to Betterige et al. (1999), is the common pressure applied by animals to soil. Once the normal and shear stress was known, the resulting tension was calculated according to Pythagoras's Theorem in which: σr = resulting tension (kPa), τ = shear stress (kPa) σn = normal stress (kPa).

RESULTS AND DISCUSSION

The Total Pore Volume did not alter with the different managements and uses studied (Tables 1 and 2). In a study of the porosity of a dystrophic Red-Yellow Latosol under *Brachiaria decumbens* pasture, Moraes et al. (2002) obtained macroporosity values below 0.15 $m^3\ m^{-3}$, characterizing compaction or soil in process of compaction. The results found in this paper for the different managements, compared to those of Moraes et al. (2002), did however not characterize compaction, although lower values of soil macroporosity were observed in irrigated and non-irrigated grazing areas compared to the natural forest, indicating an initial process of compaction.

The rupture lines of LVAd submitted to different managements and uses with samples equilibrated at tension of water retention of 6 kPa are represented in figure 2. The coefficient of determination of all of them was high, demonstrating a good fitting of the mathematical model.

The rupture lines of LVAd for irrigated and non-irrigated pastures differed statistically (Table 3), as also found for non-irrigated pasture versus natural forest.

Table 2. Total Pore Volume, macro and micro porosity of Dystrophic Red-Yellow Latosol (LVAd) under different uses and managements in the 0–3 cm layer

Management	TVP	Macro	Micro
	$m^3\ m^{-3}$		
IP	0.49 a	0.14 a	0.35 a
NIP	0.48 a	0.15 a	0.33 a
Forest	0.51 a	0.19 a	0.32 a

TPV: Total Pore Volume ($m^3\ m^{-3}$); Macro: macroporosity ($m^3\ m^{-3}$); Micro: microporosity ($m^3\ m^{-3}$); CF: correction factor of stocking rate; IP: Irrigated pasture e NIP: Non-irrigated pasture. Means followed by the same letter in the vertical position do not differ statistically by test t, at 5 %.

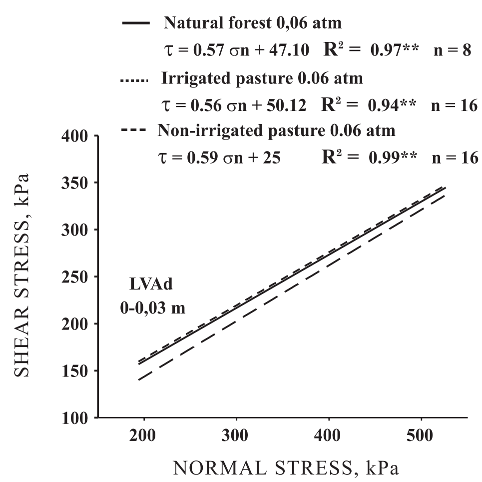

Figure 2. Shear rupture lines of an LVAd submitted to different managements, with samples at a water tension of 6 kPa.

Table 1. Water-physical characterization and organic matter of the Red-Yellow Latosol (LVAd) under different managements and uses in the 0–0.03 m layer

Management	Clay	Sand	Silt	OM	FC	PWP	Pd	Bd
	$g\ kg^{-1}$				$kg\ kg^{-1}$		$Mg\ m^{-3}$	
Ip	280 a	620 a	100 a	16 c	0.26 a	0.16 a	2.64 a	1.35
Nip	270 a	620 a	110 a	20 a	0.24 a	0.15 a	2.65 a	1.38
Forest	270 a	600 a	130 a	27 a	0.25 a	0.15 a	2.64 a	1.30

Ip: irrigated pasture; Nip: non-irrigated pasture; OM: Organic matter; FC: field capacity – samples submitted to a water tension of 6 kPa); PWP: permanent wilting point (samples submitted to a water tension of 1,500 kPa); PD: particle density; Bd: bulk density. Means followed by the same letter in the vertical position do not differ statistically by test t, at 5 %.

Table 3. Significance test according to Snedecor & Cochran (1989) between the shear rupture lines of a Red-Yellow Latosol with equilibrated samples at 6 kPa

Management	F	F	
		Angular coefficient	Linear coefficient
Irrigated pasture *vs* Non-irrigated pasture	NH	ns	**
Irrigated pasture *vs* Natural Forest	H	ns	ns
Non-irrigated pasture *vs* Natural Forest	NH	ns	**

F: test F; H: homogêneo (homogeneous); NH: não homogêneo (NO homogeneous); ns: non significant and **: significant ($p < 0.05$).

The statistical analysis showed that the internal friction angle was not influenced by soil shear strength, since the coefficient angles were not statistically different from each other, because the angle is obtained by the tangent arc of this coefficient. Apparent cohesion is therefore a part of the shear strength responsible for the quantification of possible soil structural modifications. Comparing the results obtained in soil under irrigated pasture to the use of natural forest (Table 3) showed that there is no statistical difference. A new equation was therefore adjusted to all shear and normal stress values. Figure 3 shows the new rupture lines of samples equilibrated at a water tension of 6 kPa.

Apparent cohesion (Table 4) was greater under irrigated management and natural forest and these were statistically different from non-irrigated pasture (Table 3). This fact that can be explained due to the more humid soil under irrigated management (Table 1), because the water acts as a lubricant of soil solid particles, when there is external stress by animal trampling and these particles approach each other more intensively (Rocha et al., 2007). In general, in more compacted soils, shear strength is greater (Azevedo, 1999), due to the shorter distance between the particles, with a consequently lower void index and greater bulk density and a greater effort required, for example, to prepare the soil. The greatest values of organic matter in the natural forest area of the soil favored its aggregation, establishing a block structure which is transformed into granules. This structure results in a greater contact area of the particles and consequently, higher apparent cohesion values, according to Rocha et al. (2002).

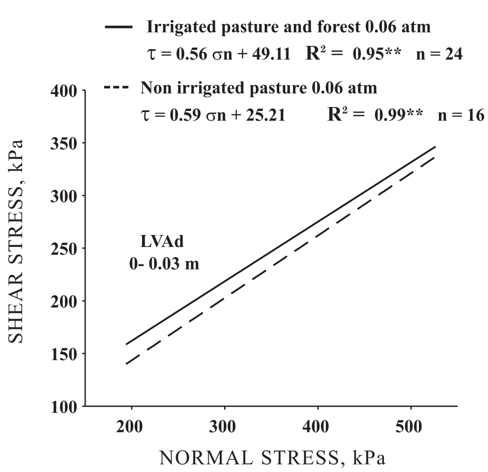

Figure 3. Rupture lines of an LVAd submitted to different managements, with samples equilibrated at a water tension at 6 kPa, result of the unification of curves obtained for the soil of irrigated pasture area and forest.

The fact that the non-irrigated pasture soil presents the smaller apparent cohesion value (Table 4), can be related to the preparation system, because at pasture implementation, this soil was plowed once and disked three times, promoting segregation of the soil particles, making it looser and reducing the apparent cohesion values. Although the experimental areas under irrigated management had received the same initial soil preparation, the mechanical resistance to compaction in those under non-irrigated management was higher, due to the drier soil conditions, thus avoiding that animal trampling would allow a greater approximation of the soil particles, with a significant increase in apparent cohesion.

In the study of Pires (2007), in the same study area and management, the apparent cohesion values in the irrigated area, at a water retention of 6 kPa, were 34.73 kPa. In the present study, highlighting that sampling was carried out one year after that of Pires (2007), the cohesion value found for the same management was 50.12 kPa (Figure 2). This evidences the occurrence of a progressive increase of the apparent cohesion values of the soil.

Table 4. Results of the direct shear test with samples equilibrated at a water tension of 6 kPa

Management	Internal friction angle	Apparent cohesion (*c*)
	ϕ	kPa
Irrigated pasture and natural forest	29.25	49.11
Non-irrigated pasture	30.54	25.21

If a tension of 6 kPa is adopted in the irrigation management of this soil (Pires, 2007), extreme care should be taken with the irrigated pasture, because moisture at field capacity in this Latosol associated to machine traffic and/or animal trampling can induce a progressive process of compaction.

The statistical analysis (Table 5) showed that there were no statistical differences between the straight lines using Snedecor and Crochan's method (1989). Therefore, a new and unique equation (Figure 5) was adjusted to all normal and shear stress values. The lack of statistical difference between the rupture lines is possibly due to soil moisture, because drier soil becomes more resistant and the differences in mechanical strength may not be detected.

The internal friction angle 29.68º and apparent cohesion 71.15 kPa were obtained from the new equation adjusted to both the managements and use studied (Figure 5, Table 6).

Although statistical differences between the rupture lines of irrigated and non-irrigated management were not detected, the results (Figure 4) clearly showed that the irrigated management induces greater apparent soil cohesion, followed by natural forest and then by non-irrigated management.

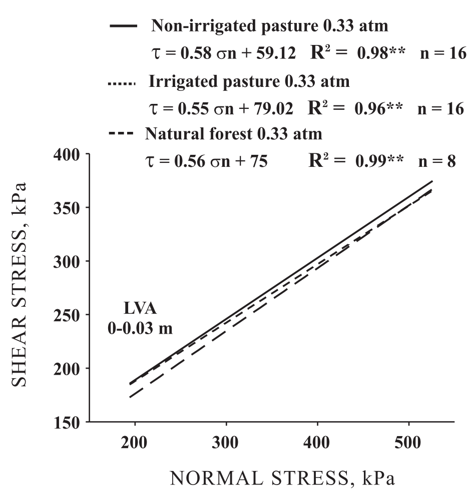

Figure 4. Rupture lines of an LVAd submitted to different managements, with samples equilibrated at a water tension of 33kPa.

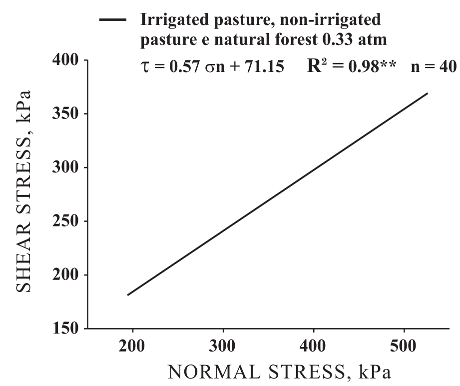

Figure 5. Rupture lines of an LVAd submitted to different management, with samples equilibrated at a water tension of 33 kPa. (Unification of curves of Figure 4).

Table 6. Results of the shear tests direct from soil samples exposed to a water tension of 33 kPa

Managements	Internal friction angle	Apparent Cohesion (*c*)
	ϕ	kPa
Irrigated, Non-irrigated pastures and Natural forest	29.68	71.15

Because the correction factor (CF) is a suggestion for stocking rate, the values are presented for different managements, at water tensions of 6 kPa and 33 kPa in table 7, due to soil compaction.

The correction factor values are obtained by the ratio of natural forest tension and tension resulting from management, and since values below 1 indicate structural alteration and, consequently, additional compaction. It was observed that the correction factor values of none of the management forms was below 1 (Table 7). However, the values were close to the unit, which may nevertheless indicate a tendency towards soil structure modifications over time. It is assumed that the constancy of this management may lead to soil compaction; the correction factor values are therefore of great use to detect the occurrence of

Table 5. Significance test according to Snedecor & Cochran (1989) between the rupture lines of a Red-Yellow Latosol with samples equilibrated at 33 kPa

Management	F	F	
		Angular coefficient	Linear coefficient
Irrigated pasture *versus natural forest*	H	ns	ns
Non-irrigated pasture *versus* natural forest	H	ns	ns
Irrigated pastured *versus* non-irrigated pasture	H	ns	ns

ns: non significant, F: test f, H: homogeneous.

Table 7. Correction factor in different managements and water tensions to calculate the stocking rate

Management	CF (6 kPa)	CF (33 kPa)
IP	1.0015	1.0005
NIP	1.0132	1.0073

CF: correction factor of stocking rate; IP: Irrigated pasture e NIP: Non-irrigated pasture.

compacted layers. But, when these values are used to correct the stocking rate, there are signs that under irrigated and non-irrigated managements, the stocking rate needs no correction to prevent soil compaction in the situation under study. According to soil physics, the stocking rate can still be increased in the areas studied, as long as the quantity of plant mass produced to feed animals allows a continuous monitoring of soil structural alterations.

CONCLUSIONS

1. The rupture lines of the LVAd in the water retention tension of 6 kPa in irrigated pasture and in natural forest did not differ, but the apparent cohesion value were higher than for non-irrigated pasture.

2. At at a water retention tension of 6 kPa, the apparent cohesion was responsible for the possible alterations in the soil structure.

3. At a tension of 33 kPa, no statistical differences in shear strength were found between the soil samples collected in areas of irrigated pasture, non-irrigated pasture and natural forest.

4. The correction factors calculated approached 1, which indicated that there was no significant structural alteration in the soil, however, the values found for the correction factors indicate a possible initial compaction that could be intensified in long-term management.

LITERATURE CITED

AZEVEDO, M.A.A. Contribuição ao estudo geotécnico de solos de Viçosa-MG. Viçosa, MG, Universidade Federal de Viçosa, 1999. 169p. (Tese de Mestrado)

BETTERIDGE, K.; MACKAY, A.D.; SHEPHEN, T.G.; BARKER,D.J.; BUDDING, P.J.; DEVANTIER, B.P. & COSTALL, D.A. Effect of cattle and sheep treading on surface configuration of a sedimentary hill soil. Austr. J. Soil Res., 37:743-760, 1999.

BERTOL, I.; GOMES, K.E.; DENARDIN, R.B.N.; ZAGO, L.A. & MARASCHIN, G.E. Propriedades físicas do solo relacionadas a diferentes níveis de oferta de forragem numa pastagem natural. Pesq. Agropec. Bras., 33:779-786, 1998.

BLAKE, G.R. & HARTGE, K.H. Particle density, In: KLUTE, A., ed. Methods of soil analysis. 2.ed. Madison, Soil Science Society of America, 1986. Part 1. p.377-382.

DAY, P.R. Particle fractionation and particle-size analysis. In: BLACK, C.A., ed. Methods of soil analysis. Madison, American Society of Agronomy, 1965.v.1. p.544-566.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA – EMBRAPA. Centro Nacional de Pesquisa de Solos. Sistema brasileiro de classificação de solos. 2.ed. Rio de Janeiro, 2006. 306p.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA - EMBRAPA. Centro Nacional de Pesquisas de Solos. Manual de métodos de análises de solo. 2.ed. Rio de Janeiro, 1997. 212p.

KONDO, M.K. & DIAS JUNIOR, M.S. Compressibilidade de três Latossolos em função da umidade e uso. R. Bras. Ci. Solo, 23:211-218, 1999.

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. R. Bras. Ci. Solo, 28:945-951, 2004.

MORAES, M.F.; OLIVEIRA, G.C.; KLIEMANN, H.J.; SEVERIANO, E.C.; SARMENTO, P.H.L. & NASCIMENTO, M.O. Densidade e porosidade do solo como diagnóstico do estado de degradação de solos sob pastagens na região dos cerrados. In: SIMPÓSIO NACIONAL SOBRE RECUPERAÇÃO DE ÁREAS DEGRADADAS, 5., Belo Horizonte, 2002. Anais... Belo Horizonte, MG, SOBRADE, 2002. p.256-258.

OLIVEIRA G.C.; SEVERIANO, E.C. & MELLO, C.R. Dinâmica da resistência à penetração de um Latossolo Vermelho da Microrregião de Goiânia, GO. R. Bras. Eng. Agríc. Amb., 11:265-270, 2007.

PIRES, B.S. Compressibilidade e resistência ao cisalhamento de um Latossolo sob diferentes manejos e intensidades de uso na região de Passos, MG. Lavras, Universidade Federal de Lavras, 2007. 62p. (Tese de Mestrado)

RAIJ, B.van. & QUAGGIO, J.A. Métodos de análise de solo para fins de fertilidade. Campinas, Instituto Agronômico de Campinas, 1983. 16p. (Circular, 63).

RAMAMURTHY, T. Shear strength response of some geological materials in triaxial compression. Intern. J. Rock Mech. Mining Sci., p.1-15, 2001.

ROCHA, W.W. Resistência ao cisalhamento e estabilidade de taludes de voçorocas em solos da região de Lavras, MG. Lavras, Universidade Federal de Lavras, 2003. 101p. (Tese de Doutorado)

ROCHA, W.W.; BORGES, S.R.; VICTÓRIA, E.P. & NUNES, A.B. Resistência ao cisalhamento do solo do ponto de vista ambiental. In. Mauro. Belo Horizonte, Ciência Ambiental, 2007. p.87-124.

ROCHA, W.W.; DIAS JUNIOR, M.S. & LIMA, J.M. Resistência ao cisalhamento e grau de intemperismo de cinco solos da região de Lavras, MG. R. Bras. Ci. Solo,.26:297-303, 2002.

SNEDECOR, G.W. & COCHRAN, W.G. Statistical methods. 8.ed. Ames, Iowa State University, 1989. 503p.