PENETROMETERS TO DETERMINE THE RESISTANCE TO PENETRATION IN OXISOL IN PASTURE LAND IN THE CERRADO

Victor Abadio Martins Franco Ferreira[1]; Indiamara Marasca[2], João Fernandes da Silva Júnior[3], Silvio Vasconcelos de Paiva Filho[1], Rose Luiza Moraes Tavares[1]

RESUMO – A resistência do solo à penetração (RP) é a forma mais comum e prática de estimar o nível de densidade/compactação do solo. O uso de RP é evidente na maioria dos estudos, mas grande parte não explicou os diferentes tipos de penetrômetros capazes de quantificá-lo. Seu princípio é medir a resistência do solo ao inserir uma haste de ponta cônica em uma profundidade específica. Baseado nisso, este estudo teve como objetivo comparar o uso de dois penetrômetros/penetrógrafos para determinar o RP de um solo argiloso: um penetrômetro estático (impacto) e outro dinâmico (digital). Para tanto, três tratamentos que são áreas com plantas forrageiras distintas: *Cynodon nlemfuensis, Cynodon dactylon* e *Cynodon plectostachyus* foram avaliadas. A resistência do solo à penetração e a umidade do solo foram avaliadas nas profundidades de 0–20 cm e 20–40 cm. Os valores de RP variaram de 3,0 a 3,9 MPa entre as áreas e a umidade do solo de 13 a 14%. Encontramos alta correlação entre os resultados dos penetrômetros com R^2 = 0,93 e R^2 = 0,95 em 0-20 e 20-40 cm respectivamente. A ANOVA não mostrou diferenças significativas (p>0,05 no teste de Tukey) para os tratamentos, indicando eficiência semelhante dos penetrômetros para determinação dos valores de RP em solo argiloso do Cerrado. Os métodos de avaliação da resistência do solo à penetração podem apresentar valores iguais por meio de equação de ajuste.

Palavras-chave: compactação, capim cynodon, penetrômetro.

PENETROMETERS FOR DETERMINING PENETRATION RESISTANCE IN OXISOL IN PASTURE LANDS IN CERRADO

ABSTRACT - Soil penetration resistance (PR) is the most common and practical way to estimate the level of soil densification/compaction. The use of PR is evident in most studies, but a large unexplained the different types of penetrometers capable of quantifying it. Their principle is to measure the soil resistance when is inserting a cone-tipped rod to a specific depth. This study aimed to compare the use of two penetrometers/penetrographs to determine the PR of a clayey soil: one static penetrometer (impact) and another dynamic (digital). For this purpose, three treatments in distinct forage plants were evaluated: i) *Cynodon nlemfuensis*, ii) *Cynodon dactylon* and iii) *Cynodon plectostachyus*. Soil penetration resistance and soil moisture were assessed at two depths, i.e., 0–20 cm and 20–40 cm. PR values ranged from 3.0 to 3.9 MPa between the areas, and soil moisture ranged from 13 to 14%. We found a high correlation between the results of penetrometers with R^2=0,93 and R^2=0,95 at 0-20 and 20-40 cm, respect from impact and digital penetrometer. The ANOVA did not show significant differences (0.05 scored in Tukey test) for the three selected treatments, indicating similar efficiency of the penetrometers for determining PR values in clayey soil in Cerrado. The methods for evaluating soil penetration resistance can present equal values through the adjustment equation.

Keywords: compactation, cynodon grass, penetrometer.

[1] Universidade de Rio Verde. Fazenda Fontes do Saber, 75901970, Rio Verde, Goiás, victorabadiom@gmail.com;silviofilho1997@hotmail.com; roseluiza@unirv.edu.br.

[2] Centro Universitário La Salle Lucas do Rio Verde (UnilasalleLucas), Avenida Universitária nº 1000, CEP: 78455-000, Lucas do Rio Verde - MT. E-mail: indiamara.marasca@unilasallelucas.edu.br

[3] Universidade Federal Rural da Amazônia, Campus Capanema/PA, joão.fernandes@ufra.edu.br

INTRODUCTION

Brazil, due to the size of the territorial area and favorable climatic conditions, points to a wide potential for meat production in pastures, with 95% of meat produced in pastures, corresponding to about 167 million hectares (Araújo et al., 2017). Thus, the main source of food for cattle in Brazil has been pasture.

In pastures, grasses are forage plants considered the basis of food for beef and dairy cattle in several countries around the world, especially in Central and South America (Borghi et al., 2018).

In addition to serving as animal feed, they act in important processes in the soil, for example, minimizing the effects of soil compaction. Compaction is the compression of soil as its density increases as a result of the reduction of soil pore spaces, mainly macropores (Gupta; Allmares, 1987).

Soil compaction occurs quite constantly in environments that use machines and implements or in areas where animal trampling is intense, in the case of pasture, thus constituting one of the most serious reasons for restricting the development of plants.

Therefore, grasses with an aggressive root system, reduce compaction rates, helping in the process of water infiltration and structuring of the soil profile. In addition, the dry mass from these plants acts on the energy dissipation resulting from the operation of machines, reducing slippage rates and soil surface runoff (Spliethoff et al., 2019).

The measure considered the most practical and quick to measure soil compaction is the evaluation of soil penetration resistance, as there is no need to open trenches and its result does not require laboratory analysis, the most used equipment being the measurement penetrometer manual and digital.

In general, these equipments are used to assess the soil through agricultural management practices or to investigate the need to turn the soil as a result of compaction, which is currently one of the problems faced by several regions (OLIVEIRA et al., 2014).

Wet soil situations, when subjected to intense machine traffic and recent disturbances, with low vegetation cover, make the soil susceptible to compaction (Vizioli et al., 2021).

The practice of turning the soil is adopted in order to break up compacted layers by reducing the density and resistance of the soil to penetration and by increasing the infiltration of water into the soil (HAQUE et al., 2016). In addition, it helps in the incorporation of correctives and fertilizers, increasing the pore space and thus improving the permeability and storage of air and water, in addition to the growth of plant roots (BONILLA-BEDOYA et al., 2017; RODRIGUES et al., 2017).

Monitoring the level of soil compaction is extremely important and helps in decision making regarding soil management. There is a variety of brands of equipment for this evaluation on the market, called a penetrometer, whose evaluation is carried out in the field, with the introduction of a rod in the soil.

The operation of the penetrometer is based on quantifying the resistance that the soil offers to the penetration of a conical tip, relating the areas in which the roots would find an impediment to their growth (MOLIN et al. 2012; SOUZA et al., 2014), but the evaluation is influenced by factors such as soil texture, soil density and especially soil moisture (CORTEZ et al., 2018).

There are two main types of penetrometer, static and dynamic. Static (usually digital) has as its principle the introduction of a rod with a conical tip and is introduced continuously and slowly (almost static), recording at the same time the reaction force that is equal to the resistance of the soil. While the dynamic (manual), the rod is introduced through the promotion of an impact mass in free fall (STOLF et al., 2014).

There is a reference in the literature that determines critical limits of soil penetration resistance, where a soil penetration resistance <0.01 MPa is considered extremely low; 0.01-0.10 MPa very low; from 0.10-1.00 MPa low; from 1.00-2.00 MPa moderate; 2.00-4.00 MPa high; from 4.00-8.00 MPa very high and >8.00 MPa extremely high, for clayey soils (ARSHAD et al., 1996).

According to Lima et al. (2013), although static and dynamic penetrometers have different operating principles, both have the same purpose. Thus, this work was developed aiming to test the soil penetration resistance (PR) using a static (impact) or dynamic (digital) penetrometer.

MATERIAL AND METHODS

Experimental área

The experiment was conducted at the Haras – "Ubere Ranch", rod. GO 174 km 15, near the city of Rio Verde/GO, at coordinates 17°41'21.47"S and 51° 2'0.15"W, altitude of 788 m (Figure 1), in a soil classified as Red Latosol with texture clayey. According to Koppen, the climate of the region is classified as Aw, characterized by two well-defined seasons: dry in winter and wet in summer. The region's average annual rainfall varies between 1,200 and 1,800 mm. The soil of the areas is classified as Red Latosol, clayey texture.

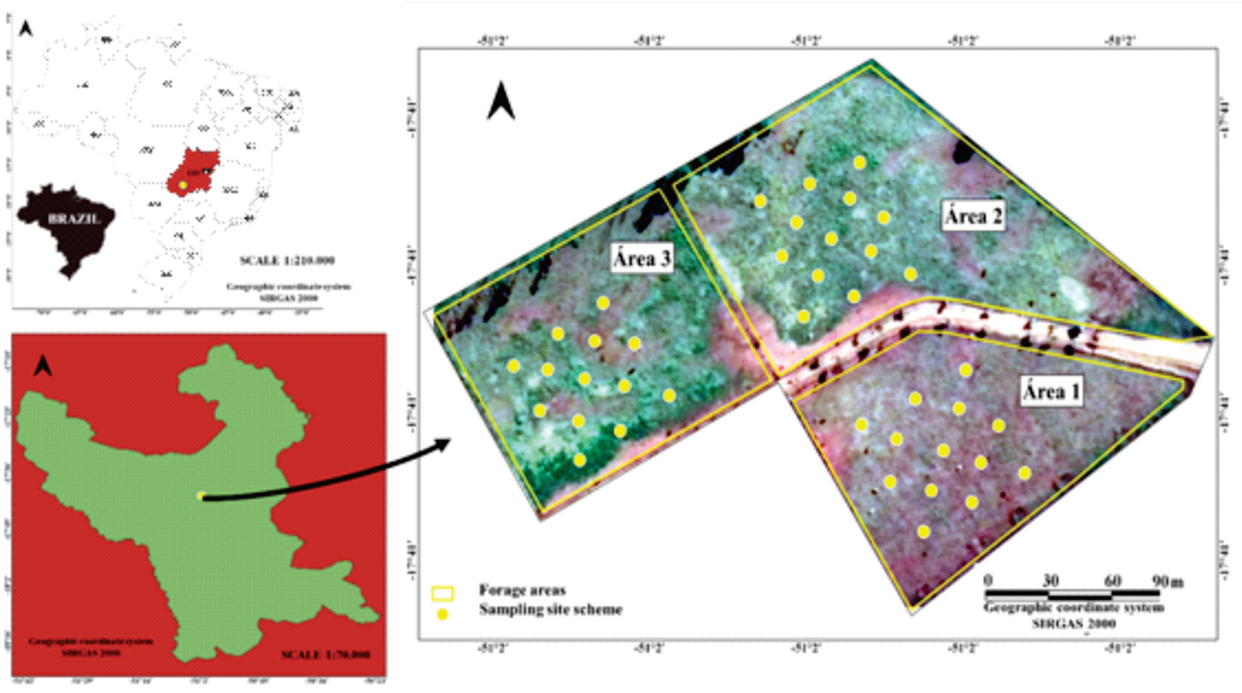


Figure 1 - Map of experiment location and sampling grid in the evaluated areas.

Three areas of 0.5 ha each with different forages were selected: Area 1: Cynodon Niemfluensis (typhton); Area 2: Cynodon Dacylon (cowboy), Area 3: Cynodon Plectostachyus (star).

For the selection of areas, the same type of soil and the same management history were considered as criteria. Thus, all areas were managed in a similar way, where the forages underwent three fertilization in 2017.

The first fertilization was carried out in January, where the formulated NPK 10-20-20 was applied, in the proportion of four bags of 50 kg per paddock. The second fertilization of the year was carried out in April, where a different formulation is used, 20-20-40, with four 50 kg bags per paddock. The third application was made in September, where the formula applied is the same as in January, NPK 10-20-20, applied in the same proportion of 50 kg bags per paddock.

According to the size of the paddocks, an average of 7 animals per paddock was maintained for management. When the forage was overgrazed, that is, the height was much lower than the adequate for grazing, the picket was changed. Due to the size of 1 hectare of each paddock and the amount of 7 mares per paddock, it takes 25 to 30 days for the animals to explore the grass with greater efficiency. For foals up to 2 years old, the management was the same, but with 10 heads per paddock.

PR assessment and soil sampling

In each area, a sampling grid of 0.5 ha was set up, with 13 points spaced at different distances (Figure 1). The points were georeferenced using GPS and demarcated for field analysis and soil collection.

At each sampling point in the three areas, the soil penetration resistance was determined using two field measuring devices.

The evaluations were carried out in October/2017, during the dry period of the year. At each sampling point, resistance to soil penetration to a depth of up to 40 cm was determined using two field measuring instruments: a digital penetrometer and a manually operated penetrometer (Figure 2).

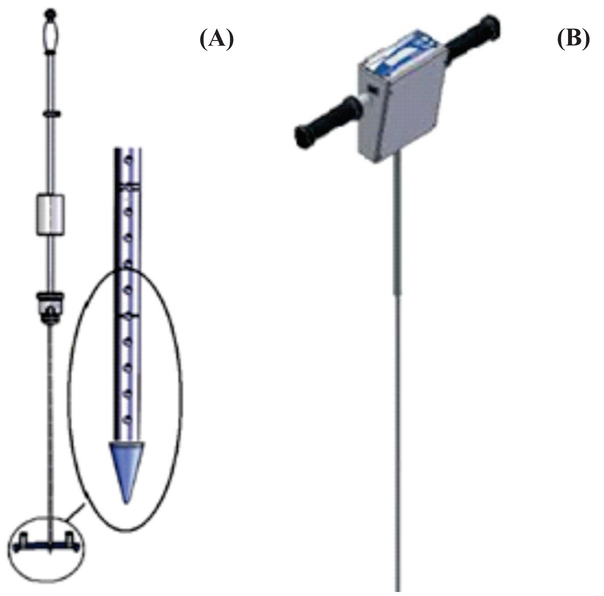


Figure 2 - Schematic representation of the impact (A) and digital (B) penetrometer models used in the work.

Impact penetrometer: it is a dynamic type device for measuring soil resistance to penetration, whose penetration occurs by impact of a flexible plunger coupled to the equipment (STOLF et al., 2014). An impact penetrometer model IAA/Planalsucar with a cone angle of 30° was used. The analysis was carried out up to a soil depth of 40 cm (Figure 2) and, in the field, data on the depth of the rod that entered the soil are recorded as a function of the number of impacts caused by the vertical displacement of the impact weight.

The transformation of the penetration of the device's rod into the ground (cm/impact) in resistance to penetration was obtained by a program that presents RP data in the units: impacts/dm, kgf/cm2 and MPa. The equation for calculating resistance due to impact penetration was developed in Stolf (1991):

$$RP = (5.6 + 6.89 \times ((N/A-A) \times 10) \times 0.0981)$$

Where,

RP: soil penetration resistance (MPa);

N: number of impacts performed to obtain the reading;

A: depth of the shank prior to making the impacts (cm).

D: depth of the stem after the impacts were performed (cm).

Digital penetrometer: A Falker® digital penetrometer was used, whose principle is the measurement of pressure, in MPa, exerted by a conical rod, on the soil up to 40 cm deep. Measurements are taken at every 1 cm of soil depth and the data is stored on a memory card inside the equipment.

The data were downloaded using software from the company Falker®, whose program makes the data available in a quantitative way, obtaining values or using a graph that relates the soil penetration resistance in KPa and the soil depth (cm).

At the points where the RP was determined, soil samples were collected in the 0.20 and 0.20-04 cm layers for moisture assessment, whose samples were stored in aluminum pots and the moisture analysis occurs within 24 hours after collection, following gravimetric moisture methodology (Embrapa, 2017).

Statistical analysis

Analysis of variance

For data interpretation, the RP and soil moisture were evaluated by descriptive statistical analysis, with the mean and coefficient of variation being calculated. The results were submitted to statistical analysis of variance, and the mean values of the treatments were compared by the Tukey test at the level of 5% of probability, using the SISVAR software (Ferreira, 2008).

Relationship between PR and U

To evaluate the relationship between the results obtained by the penetration resistance methodologies via digital and manual penetrometers and soil moisture (U), Pearson's simple linear correction analysis was performed for the three areas at depths of 0.0-20 and 20-40 cm.

Comparison of methods (penetrometers) to determine PR

To evaluate the relationship between the results obtained by the PR evaluation methodologies, Pearson's simple linear correction analysis and regression analysis were performed to obtain the adjustment equations.

RESULTS AND DISCUSSION

The data showed that there was no influence of soil moisture in the treatments in the 0.00-0.20 m layer, which allows us to say that there was no change in the accuracy of the devices in this layer, promoted by soil moisture. As for the 20-40 m layer, there was a difference in soil moisture between the three areas, which may have influenced the RP values in the areas (Table 1).

Table 1 - Analysis of variance with Fc calculated from soil moisture and penetration resistance in a grazing area with different forages.

FV	GL	0,00-0,20 m			0,20-0,40 m		
		Umid	$RP_{digital}$	RP_{manual}	Umid	$RP_{digital}$	RP_{manual}
Rep	12	$1,77^{ns}$	$1,25^{ns}$	$1,16^{ns}$	$2,18^{ns}$	$1,36^{ns}$	$1,24^{ns}$
Área	2	$2,18^{ns}$	5,97**	5,19*	6,57**	7,95**	4,28*
Erro	24	-	-	-	-	-	-
CV	-	19,07	12,15	12,99	5,10	15,70	17,86

Fc: ANAVA statistical parameter. Rep: repetition; Humid: humidity; ns: not significant; *: significant at 5% and **: significant at 1%.

In the soil layer 0.00-.020 m, the area with Cynodon niemfluensis (typhton) presented the lowest values of RP, with the forage being more efficient in reducing soil resistance to penetration and Cynodon dacylon (vaquero) having the highest values of RP (Table 2) for the two equipments, thus evidencing the similarity of results of the two results.

Regarding the RP result between the areas, the tifton grass is characterized by a robust root system with rapid renewal, especially in the 0.00 – 0.20 m layer where there is a higher concentration of roots of this forage (Silva et al., 2020), acting on biological soil decompaction. These factors also allow the use of the species as an instrument for the recovery of physically degraded soils (COLUSSI et. al., 2014).

In the area with vaquero grass (Cynodon dacylon), it is possible that the greater resistance of the soil to penetration occurs due to the greater force on the soil exerted by the animal trampling during grazing due to the physiological aspect of the forage being smaller and not very erect compared to the other evaluated species, thus requiring greater effort and animal presence on the area promoting greater soil compaction.

In the 20-40 cm soil layer, the PR determination methods showed a similar trend in the three areas, with the exception of the area with star grass (Table 2) which, by the digital RP method, showed a statistical difference from the area with vaquero, while the manual PR method there was no significant difference between the two foragers.

Table 2 - Mean values of soil moisture (m-3 m³) and soil penetration resistance (MPa) in the 0.00-0.20 and 0.20-0.40 m layer in a grazing area with different forages.

Tipo de Forrageira	Umid	$RP_{digital}$	RP_{manual}
	0,00-0,20 m		
Cynodon niemfluensis (tífton)	0,120 a	3,307 b	3,371 b
Cynodon dacylon (vaquero)	0,137 a	3,877 a	3,966 a
Cynodon plectostachyus (estrela)	0,137 a	3,476 ab	3,608 ab
	0,20-0,40 m		
Cynodon niemfluensis (tífton)	0,134 ab	3,105 b	2,972 b
Cynodon dacylon (vaquero)	0,140 a	3,823 a	3,555 a
Cynodon plectostachyus (estrela)	0,130 b	3,118 b	3,011 ab

Means followed by the same letter on the line for each soil depth do not differ from each other by the tukey test at 5% probability.

Possibly, this difference was due to the fact that the soil water content in the three areas was statistically different, that is, it is believed that the soil water content influenced the soil RP values, decreasing the resistance values as the increased soil moisture (Rauber et al. 2021).

Therefore, according to Tormena et. al. (2017), the ideal for measuring soil penetration resistance is two days after precipitation for clayey soils and one day for sandy soils, where the soil is at field capacity.

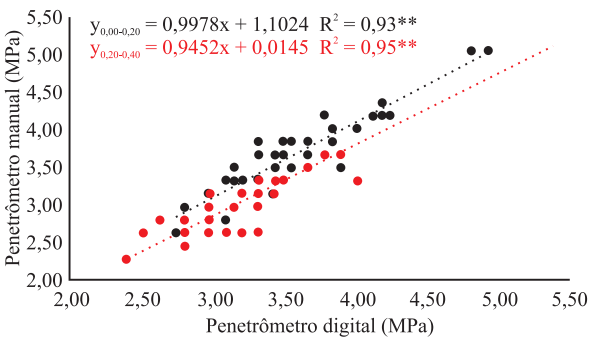
The correlation analysis showed a positive and direct relationship between the PR assessment methods, with a correlation of 0.93 in the 0-20 cm layer and 0.95 in the 20-40 cm layer (Table 3), evidencing the same trend of PR results between the two assessment methods.

Table 3 - Correlation analysis of soil moisture and penetration resistance by digital and manual penetrometers evaluated at depths 0.00-0.20 and 0.20-0.40 m.

	RP_{digita}0,00-0,20	RP_{manual}0,00-0,20	Umid 0,20-0,40	$RP_{digital}$0,20-0,40	RP_{manual}0,20-0,40
Umidade 0,00-0,20	-0,28	-0,18	0,38*	0,004	0,0096
$RP_{digital}$0,00-0,20	-	**0,93****	0,09	0,34*	0,29
RP_{manual}0,00-0,20		-	0,13	0,34*	0,27
Umid0,20-0,40			-	0,18	0,11
$RP_{digital}$0,20-0,40				-	**0,95****
RP_{manual}0,20-0,40					-

Humid: soil moisture,ns: not significant; *: significant at 5% and **: significant at 1%.

Despite the high correlation between the evaluation methods, the regression analysis showed the need to adjust the RP values for the two soil layers evaluated (Figure 3).



Falta Legenda da Figura 3

These results showed that both PR assessment methods tend to present similar results and that they can be adjusted through equations to validate the same value of soil penetration resistance (Baesso et al., 2020; Beckett et al., 2018). ; Vaz et al., 2022).

CONCLUSIONS

The methods used for soil penetration resistance showed the same tendency in the areas evaluated in the 0.00-0.20 m layer.

The methods for evaluating soil penetration resistance can present equal values through an adjustment equation, making both evaluations effective.

LITERATURA CITADA

ARAÚJO, F. R.; ROSINHA, G. M. S.; BIER, D.; CHIARI, L.; FEIJÓ, G. L. D.; GOMES, R. C. *Segurança do Alimento Carne*. Comunicado Técnico. Campo Grande, MS: Embrapa Gado de Corte, 2017.

ARSHAD, M.A.; LOWERY, B.; GROSSMAN, B. Physical tests for monitoring soil quality. In: DORAN, J. W.; JONES, A. J., eds**.** Methods for assessing soil quality**.** *Soil Science Society of America*, v.5, p.123-141, 1996.

BAESSO, M. M.; MENEZES, T. A.; MODOLO, A. J.; ROSA, R. G.; ZUIN, L. F. S. Comparação entre três penetrômetros na avaliação da resistência mecânica do solo à penetração em um latossolo vermelho eutroférrico. *Brazilian Journal of Biosystems Engineering*, v. 14, n. 2, p. 101-110, 2020.

BECKETT, C. T. S.; BEWSHER, S.; GUZZOMI, A. L.; LEHANE, B. M.; FOURIE, A. B.; RIETHMULLER, G.; Evaluation of the dynamic cone penetrometer to detect compaction in ripped soils. *Soil and Tillage Research*, v.175, n. 1, p. 150-157, 2018.

BONILLA-BEDOYA, S.; LÓPEZ-ULLOA, M.; VANWALLEGHEM, T.; HERRERA-MACHUCA, M. A. Effectsofland use changeonsoilqualityindicators in forestlandscapesofthe Western Amazon. *Soil Science*, v. 182, p. 128-136, 2017.

BORGHI, E., GONTIJO NETO, M. M., RESENDE, R. M. S., ZIMMER, A. H., ALMEIDA, R. G., & MACEDO, M. C. M. Recuperação de pastagens degradadas. *Agricultura de baixo carbono: tecnologias e estratégias de implantação. Brasília, DF: Embrapa*, v. 4, p. 105-138, 2018.

COLUSSI, G; SILVA, L. S.; MINATO, E. A.. Escarificação e adubação orgânica: efeito na recuperação estrutural de solo produzindo Tifton 85. *Ciência Rural*, v.44, p.1956-1961.

CORTEZ, J. W.; MATOS, W. P.; ARCOVERDE, A. N. S.; CAVASSINI, V. H.; VALENTE, I. Q. M. Spatialvariabilityofsoilresistancetopenetration in no tillage system. *Engenharia Agrícola*, v. 38, p. 697-704, 2018.

FERREIRA, D.F. SISVAR: um programa para análises e ensino de estatística. *Revista Symposium,* v.6, p.36-41, 2008.

GUPTA, S. C.; *ALLMARAS*, R. R. Models to assess the susceptibility of soils to excessive compaction. *Advances in Soil Science*, v.6, p.65-100, *1987*.

HOFFER, H. et al. Variabilidade espacial do estado de compactação do solo em um sítio experimental de Mimosa scabrellaBenth. *Enciclopédia Biosfera*, v. 11, p. 1903-1914, 2015.

HAQUE, M. E.; BELL, R. W.; ISLAM, M. A.; RAHMAN, M. A. Minimumtillage um puddledtransplanting: analternativecrop establishment strategy for rice in conservationagriculturecropping systems. *Field CropsResearch*, v. 185, p. 31-39, 2016.

LIMA, R. P. de; DE LEÓN, M. J.; SILVA, A. R. da. Comparação entre dois penetrômetros na avaliação da resistência mecânica do solo à penetração. *Revista Ceres*, v. 60, p. 577-581, 2013.

LIMA, R. P.; SILVA, A. R.; OLIVEIRA, D. M. S. Análise de trilha de atributos físicos na resistência à penetração de um Latossolo Amarelo. *Revista de Agricultura Neotropical*, v. 1, p. 65- 74, 2014.

LOPES SOBRINHO, O. P.; SANTOS, L. N. S.; SANTOS, G. O.; CUNHA, F. N.; SOARES, F. A. L.; TEIXEIRA, M. B. Balanço hídrico climatológico mensal e classificação climática de Köppen e Thornthwaite para o município de Rio Verde, Goiás. *Revista Brasileira de Climatologia*, v. 27, n. 2, p. 19-33, 2020.

MOLIN, J. P.; DIAS, C. T. S.; CARBONERA, L. Estudos com penetrometria: Novos equipamentos e amostragem correta. *Revista Brasileira de Engenharia Agrícola e Ambiental,* v. 16, p. 584-590, 2011.

OLIVEIRA, A. P. P.; LIMA, E.; ANJOS, L. H. C. dos.; ZONTA, E.; PEREIRA, M. G. Sistemas de colheita da canade-açúcar: Conhecimento atual sobre modificações em atributos de solos de tabuleiro. *Revista Brasileira de Engenharia Agrícola e Ambiental,* v.18, p. 939–947, 2014.

RAUBER, L. R.; SEQUINATTO, L.; KAISER, D. R.; BERTOL, I.; BALDISSERA, T. C.; GARAGORRY, F. C.; SBRISSIA, A. F.; PEREIRA, G. E.; PINTO, C. E. Soil physical properties in a natural highland grassland in southern Brazil subjected to a range of grazing heights. *Agriculture, Ecosystems and Environment*, v. 319, e107515, 2021.

RODRIGUES, M.; RABÊLO, F. H. S.; CASTRO, H. A.; ROBOREDO, D.; CARVALHO, M. A. C.; ROQUE, C. G. Changes in chemicalpropertiesby use and management of na Oxisol in theAmazonbiome. *Caatinga***,** v. 30, p. 278-286, 2017.

SANTOS, H. G.; JACOMINE, P. K. T.; ANJOS, L. H. C.; OLIVEIRA, V. A.; LUMBRERAS, J. F.; COELHO, M. R.; ALMEIDA, J. A.; ARAÚJO FILHO, J. C.; OLIVEIRA, J. B.; CUNHA, T. J. F. *Sistema Brasileiro de Classificação de Solos*. 5. ed. rev. e ampl. Brasília, DF: Embrapa Solos, 2018. 355p.

SILVA, E. R. O.; BARROS, M. M.; PEREIRA, M. G.; GOMES, J. H. G.; SOARES, S. C. Variabilidade espacial de parâmetros químicos do solo e seus efeitos na produtividade do tifton 85. *Revista Caatinga,* v. 33, n. 1, 2020.

SOUZA, E. B.; PATROCINIO FILHO, A. P.; PIMENTA, W. A.; JESUS NAGAHAMA, H.; CORTEZ, J. W. Resistência mecânica do solo à penetração em função da sua umidade e do tipo de penetrômetro. *Revista Engenharia na Agricultura,* v. 22, p.67-76, 2014.

SPLIETHOFF, J.; RAMPIM, L.; POTT, C. A. Performance of cover and corn plants in different mechanical and biological management associations. *Revista Brasileira de Ciências Agrarias***,** v. 14, n. 4, p. 1–9, 2019.

STOLF, R.; MURAKAMI, J. H.; BRUGNARO, C.; SILVA, L. G.; SILVA, L. C. F.; MARGARIDO, L. A. C. Penetrômetro de impacto stolf - programa computacional de dados em EXCEL-VBA. *Revista Brasileira de Ciência do Solo*, v38, p. 774-782, 2014.

TORMENA, C. A.; ANGHINONI, E.; WATANABE, R.; FERREIRA, C. J. B. *Qualidade física do solo em sistemas intensivos de produção agrícola*. Boletim de Pesquisa. Fundação MT, p.109-124, 2017.

VAZ, C. M. P.; RESNDE, J. M.; FRANCHINI, J. C.; DEBIASI, H.; NUNES, M. R. Evaluation and recommendations for the use of dynamic penetrometers. *Soil and Tillage Research*, v. 220, e105373, 2022.

VIZIOLI, B.; CAVALIERI-POLIZELI, K. M. V.; TORMENA, C. A; BARTH. G. Effects of long-term tillage systems on soil physical quality and crop yield in a Brazilian Ferralsol. *Soil and Tillage Research,* v. 209, n. 1, e104935, 2021.

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