Ciência Rural, Santa Maria, v.47: 12, e20160762, 2017

http://dx.doi.org/10.1590/0103-8478cr20160762

ISSNe 1678-4596

SOIL SCIENCE

Maximum soil density of Entisols as a function of silt content

Djulia Taís Broch[1*] **Vilson Antonio Klein**[2]

---

[1]Programa de Pós-graduação em Agronomia, Universidade de Passo Fundo (UPF), Campus Universitário, Bairro São José, 99001-970, Passo Fundo, RS, Brasil. E-mail: djuliataisbroch@hotmail.com. *Corresponding author.

[2]Universidade de Passo Fundo (UPF), Passo Fundo, RS, Brasil.

ABSTRACT: *Degradation that occursin agricultural soils causes compaction.Soil density (DS) analysis has been reported to be an unreliable method of measuring the extent of soil compaction, because it varies with the soil granulometric composition and organic matter (OM)content. However, soil relative density (DR) is a good indicator that facilitates the measurement of the degree of compaction and thus, soil comparison and management techniques. Quotient between the DS and its maximum density (Dsmax) gives the DR. This study aimed to assess the effect of the granulometric composition on the physical-hydrological properties of the high-silt containing soils,under no tillage. Samples from disturbed and undisturbed structures of 18 soils were collected from the state of Rio Grandedo Sul following the no-tillage system. Once the granulometric size, OM content, soil density, maximum soil density and relative density were determined,the results indicated a drop in the Dsmax value when silt and MO were added;however, the addition of clay and clay-plus-silt revealed no significant effect. When the silt and MO content increased the soil density decreased. The DR, however, was not affected by either the granulometric composition or OM content. A difference was observed between the DR calculated from the determined Dsmax and that estimated by the Dsmax assessed based on the clay levels.Silt content was reported to exert a different influence on the physical-water properties of the silt soils than the clayey ones.*

Key words: *Proctor test, silt, relative density.*

Densidade máxima de Neossolos em função do teor de silte

RESUMO: *A compactação é causa de degradação em solos agrícolas. Para mensuração do grau de compactação de um solo a análise da densidade do solo (DS) é insuficiente por ser variável em função da sua composição granulométrica e do seu teor de matéria orgânica do solo (MO). Porém, a densidade relativa (DR) do solo é um indicador que permite a identificação do grau de compactação e, assim, comparar solos e manejos. A DR é obtida pelo quociente entre a DS e a sua densidade máxima (Dsmáx). O objetivo desse trabalho foi avaliar o efeito da composição granulométrica, sobre as propriedades físico-hídricas de solos sob plantio direto com elevado teor de silte. Foram coletadas amostras com estrutura preservada e não preservada de 18 solos do estado do Rio Grande do Sul, sob sistema plantio direto. Determinou-se a composição granulométrica, o teor de MO, a densidade do solo, a densidade do solo máxima e a densidade relativa. Os resultados mostraram que a Dsmáx decresceu com o acréscimo de silte e MO, enquanto argila e argila+silte não tiveram efeito significativo. A densidade do solo diminuiu com o aumento de silte e MO. A DR não foi influenciada pela composição granulométrica e teor de MO. Houve diferença entre a DR determinada a partir da Dsmáx determinada e da calculada pela Dsmáx estimada pelo teor de argila. O teor de silte afeta as propriedades físico-hídricas de solos siltosos de forma distinta do que em solos argilosos.*

Palavras-chave: *Ensaio de Proctor, silte, densidade relativa.*

INTRODUCTION

The set of physical, chemical and biological properties essential for the maintenanceof the productivity and sustainability of agricultural systems determines the soil quality. One of the causes for agricultural soil degradation is compaction which affects plant development, with the resultant effect on crop productivity (KORMANEK et al., 2015). This research proposed a technique that can minimize the soil pore volume and reduce soil pore volume, lower the hydraulic conductivity, raise the water erosionlevel and reduce the root system (SHI et al., 2012). When inappropriate management methodsare adopted, the soil structure can get altered and produce compacted layers (LIMA et al., 2013). Different soil types may reveal higher or lower susceptibility to compaction, which makes it mandatory to assess the soil compaction levels, enabling the critical levels to be identified and a comparison ofvarious soils and management methods to be made.

Soil textures are related to the relative dispersal of the mineral content of the soil based on their size, enabling them to be classified as sand, silt and clay. Agricultural soils reveal a wide variety in density because of their unique physical

Received 08.15.16 Approved 09.05.17 Returned by the author 10.06.17
CR-2016-0762.R3

characteristics, including texture and OM composition (MARCOLIN & KLEIN, 2011). Normally, the proportions of silt and clay possess greater specific surface areas in comparison with the sand fraction, and this increases the soil reactivity. Only the soil density (DS) variations make it hard to utilize them to quantify the soil compaction levels (BRADY & WEIL, 2008).

Soil compaction level, excluding the characteristics of soil texture and degree of soil moisture,was identified by soil relative density (DR) (BEUTLER et al., 2005), which is the quotient of DS with its Dsmax, drawn from Proctor's essay. Study of DR was initiated to find an indicator that could identify the level of compaction, which was simple to use and able to standardize and delimit the critical limits.

The Proctor test is the common method employed to identify the maximum soil density. From the equation of the compaction curve of the normal Proctor assay, mathematically it is easy to derive the Dsmax and optimal humidity for compaction. However, this test is highly labor intensive and hard to perform as it necessitates great quantities of soil to establish the compaction curve (FIGUEIREDO et al., 2000).

It was MARCOLIN & KLEIN (2011) who provided the pedotransference equation to identify the maximum soil density for Oxisols, using the OM and clay levels, concluding that the relative density of the soil can be estimated through the use of the estimated maximum soil density. However, for silt soils, this equation poses difficulties as it over estimates the Dsmax in such soils; this occurs because the silt content is excluded from the calculation, which fraction is evident in greater amounts in silt soils. Thus, the application of the Dsmax determined by the pedo function of MARCOLIN & KLEIN (2011) in these soils provides low DR values, underestimating the real level of compaction.

This study aimed to assessing the degree of influence exerted by the granulometric soil composition on the physical-hydrological properties of high silt containing soils under a no-tillage system, establishing a pedotransfer function for the maximum density of the same.

MATERIALS AND METHODS

Samples were drawn from 18 high silt-soils, under a no-tillage system from the state of Rio Grande do Sul and categorized as Litholic and Regolith Entisols (EMBRAPA, 2013). These are young, poorly weathered and shallow soils, characteristically reported in sharp reliefs. Greater research is essential for effective management of such soils, due to the paucity of studies regarding their behavior. They continue to be used even more popularly for agricultural purposes, as there is a steadily rising pressure for land use.

Locations for the soil sample collection were identified by analyzing the particle size, which was done at the physics and soil water laboratory, UPF (LAFAS). Here the counties having the highest frequency of high silt-containing samples were identified and recorded in table 1 with the respective geographical coordinates of the collection sites. Soil samples with preserved structure were collected preserved with five replicates (cylinders) from each soil type, and about 15kg of soil with a non-preserved structure was taken. Collection was performed at a depth of 0-10cm.

Employing the pipette method the granulometric analysis was done (EMBRAPA, 2011) using 40g of dry soil, which was subjected to chemical and mechanical dispersion. Using two 25mL pipettes the granulometric fractions were separated. The degree of organic matter contained in the soil was established using the Walkley Black method (TEDESCO, 1995).

Soil density was determined by the volumetric cylinder technique. Volumetric stainless steel cylinders, roughly 100cm^3, were utilized by adjusting the soil volume to the cylinder volume. Density was calculated with the soil dry matter quotient by the cylinder volume (EMBRAPA, 2011).

Using the normal Proctor test with 560kPa of applied energy, the maximum soil density for each soil was established (NOGUEIRA, 1998). This test involves compaction of the soil samples, using varying degrees of humidity. They were passed through a sieve having a 4.8mm mesh, in three layers, roughly 4cm thick in a 1.000cm^3 cylinder, using a socket of 2.5kg mass, with 26 strokes per layer, at a 30cm drop height. From the data thus derived, a polynomial equation of the second degree of DS was adjusted as a function of the soil water for each soil sample collected. The first derivative of the function enables the optimal compaction humidity (UOC) to be estimated, while the second helps to determine the Dsmax. Relative density was calculated by the quotient between the DS and Dsmax.

Influence exerted by soil texture on the maximum soil density was determined and results were adjusted through linear regression and significance analysis employing the F test.

Table 1 - Location of the 18 soils sampled under the no-tillage system.

Soil	County (RS)	Geographical coordinates	Elevation (m)
1	Rondinha	S 27° 49´04.7´´ O 52° 51´18.4´´	540
2	Rondinha	S 27° 52´19.5´´ O 52° 54´53.1´´	532
3	Sarandi	S 27° 57´19.5´´ O 52° 56´57.1´´	532
4	Sarandi	S 27° 57´43.8´´ O 52° 56´56.9´´	518
5	Sarandi	S 27° 57´53.6´´ O 52° 56´57.0´´	479
6	Sarandi	S 27° 58´43.0´´ O 52° 56´31.4´´	509
7	Marau	S 28° 20´27.68´´ O 52°18´00.98´´	650
8	Alto Alegre	S 28° 49´11.44´´ O 53°00´39.46´´	402
9	Alto Alegre	S 28° 49´16.49´´ O 53°00´43.81´´	430
10	Alto Alegre	S 28° 49´59.40´´ O 52°59´23.99´´	483
11	Alto Alegre	S 28° 49´52.70´´ O 52°59´30.04´´	507
12	Alto Alegre	S 28° 49´42.28´´ O 52°58´09.86´´	428
13	David Canabarro	S 28° 22´47.69´´ O 52°50´30.61´´	793
14	Arvorezinha	S 28° 51´40.14´´ O 52°07´34.54´´	730
15	Arvorezinha	S 28° 51´17.51´´ O 52°08´36.60´´	753
16	Arvorezinha	S 28° 51´11.29´´ O 52°08´25.65´´	760
17	Arvorezinha	S 28° 54´19.86´´ O 52°05´14.08´´	728
18	Arvorezinha	S 28° 53´33.81´´ O 52°07´45.66´´	680

RESULTS AND DISCUSSION

Table 2 shows the granulometric composition and MO constituent. The silt content ranged from 350g kg^{-1} to 175g kg^{-1}, with the highest value of 532g kg^{-1}. Greater silt levels in these soils were mostly from their lower degree of weathering, a characteristic feature of the Entisols.

The OM levels recorded revealed the amplitude ranging from 17 to 51g kg^{-1}. This occurred as they came from a variety of locations, all under the SPD, but under different degrees of management.

Soil density (Table 2B) hovered from 1.09 to 1.46g cm^{-3}. When compared with the conventional values of density, viz., for sandy soils the range was from 1.2 to 1.8g cm^{-3} whereas for clayey soils was 1.0 to 1.6g cm^{-3}, being the values reported e intermediate. The drop in the DS as the OM levels in the soil increased (Figure 1a),

Table 2 - A) Granulometric composition, organic matter (OM) and textural class. B) Optimum compaction humidity (UOC), maximum density (Dsmax) and equation obtained from the Proctor test, soil density (DS) and soil relative density (DR) of the 18 soilsamplesthat experienced no tillage.

A) Soil	Clay	Silt	Sand	Relation Silt/clay	MO	Textural class
----------------	----------------	----------------	----------------	g kg^{-1}	----------------	----------------
1	248.12	316.36	435.39	1.28	17.67	Loam
2	191.94	326.41	481.47	1.70	17.00	Loam
3	238.28	372.58	388.57	1.56	17.67	Loam
4	224.45	308.43	466.55	1.37	18.67	Loam
5	310.18	356.29	333.52	1.15	24.17	Clay loam
6	465.54	354.48	179.83	0.76	32.50	Clay
7	539.20	175.62	284.86	0.33	33.17	Clay
8	349.54	380.96	269.41	1.09	27.50	Clay loam
9	443.03	255.35	300.88	0.58	32.17	Clay
10	238.91	506.60	253.58	2.12	23.50	Silty loam
11	244.87	441.99	312.89	1.81	43.00	Loam
12	250.62	377.24	371.98	1.51	51.00	Loam
13	211.41	396.13	392.09	1.87	26.83	Loam
14	374.67	532.51	92.62	1.42	36.33	Silty clay loam
15	321.49	483.26	195.03	1.50	35.00	Silty clay loam
16	319.42	449.42	228.59	1.41	42.00	Clay loam
17	503.23	292.47	204.22	0.58	30.00	Clay
18	421.84	474.84	103.10	1.13	39.83	Silty clay
CV(%)	1.92	1.85	2.94	-	7.19	

B)Solo	UOC	Dsmáx	Equation	R²	DS	DR
	g g^{-1}	g cm^{-3}			g cm^{-3}	
1	0.235	1.622	$y=-23.139x^2 + 10.879x + 0.343$	0.78	1.34	0.83
2	0.218	1.673	y = -39.438x2 + 17.224x - 0.207	0.97	1.36	0.81
3	0.293	1.424	y = -16.582x2 + 9.730x - 0.003	0.96	1.39	0.98
4	0.270	1.474	y = -17.986x2 + 9.718x + 0.162	0.97	1.30	0.88
5	0.257	1.594	y = -40.975x2 + 21.074x - 1.116	0.98	1.38	0.87
6	0.274	1.549	y = -35.875x2 + 19.639x - 1.139	0.91	1.33	0.86
7	0.256	1.477	y = -21.868x2 + 11.188x + 0.046	0.99	1.46	0.99
8	0.328	1.334	y = -20.269x2 + 13.311x - 0.852	0.96	1.09	0.82
9	0.286	1.419	y = -31.798x2 + 18.196x - 1.184	1.00	1.26	0.89
10	0.306	1.339	y = -11.426x2 + 6.997x + 0.267	0.97	1.05	0.78
11	0.308	1.311	y = -10.965x2 + 6.752x + 0.271	0.94	1.15	0.87
12	0.303	1.330	y = -11.872x2 + 7.192x + 0.240	0.97	1.18	0.89
13	0.369	1.294	y = -19.626x2 + 14.500x - 1.384	0.98	1.18	0.91
14	0.273	1.418	y = -16.605x2 + 9.052x + 0.184	0.97	1.38	0.98
15	0.285	1.341	y = -7.463x2 + 4.258x + 0.734	0.92	1.29	0.97
16	0.321	1.274	y = -8.377x2 + 5.379x + 0.410	0.99	1.20	0.94
17	0.279	1.411	y = -28.248x2 + 15.786x - 0.795	0.99	1.25	0.88
18	0.299	1.356	y = -18.481x2 + 11.051x - 0.296	0.98	1.19	0.88

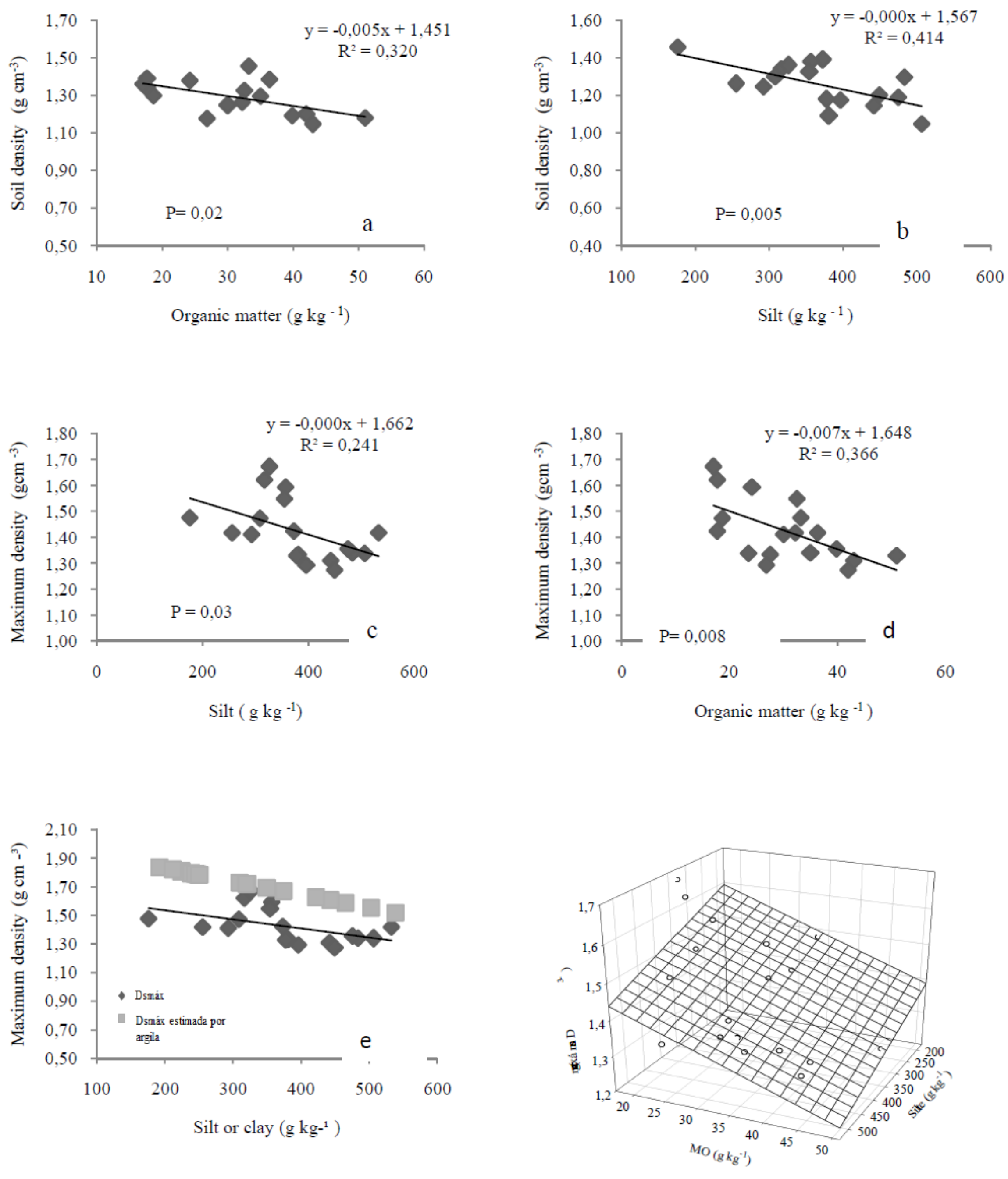

Figure 1 - Soil density as a function of the organic matter content (a) and as a function of silt content (b). maximum soil density as a function of silt content (c) and soil organic matter (d). Maximum soil density as a function of the silage content obtained using the Proctor test and assessed by the clay content (e). maximum soil density as a function of the silt and organic matter content (f).

was attributed to the positive effect on the structural stability of the soil (ARAGÓN et al., 2000). The DS was also influenced by the soil silt levels (Figure 1b) - with the DS decreasing as the silt concentration increased. As the soil density varies depending on the mineral content, texture and organic matter constituents, it easier to quantify the intensity of soil compaction (BRADY & WEIL, 2008).

The second-order polynomial equations of the soil density pair adjustment as a function of gravimetric moisture was derived from the data drawn from the Proctor test (Table 2B). Determination indices higher than 0.77 were noted, which clearly described the Dsmax phenomenon in these soils.

The rise in the silt concentration (Figure 1c) caused the maximum density values to drop; although,the clay and the clay plus silt did not reveal any notable influence on the Dsmax. These results differed from the findings of MARCOLIN & KLEIN (2011), in their research on the Latosols. They reported that the increase in clay concentration decreased the maximum soil density. However, in this study, due to the higher silt content in their granulometric composition, the soils exerted a higher influence on the Dsmax than did the clay.

When OM was added, the Dsmax values (Figure 1d) decreased because of the dissipation effect of the energy on the soil by the same, by its water retention capacity, stopping the water from revealing its lubricating capacity between the mineral particles as well as by the lower density of the MO (BRAIDA et al., 2006). Identical findings of negative correlation between MO and Dsmax were also reported by ROSSETTI et al. (2012), OLIVEIRA et al. (2010) and LUCIANO et al. (2012).

When the Dsmaxvalues recorded for the soil samples studied were compared with the Dsmax when it had been assessed by the equation for the clay levels (MARCOLIN & KLEIN, 2011) (Figure 1e), the lines revealed similar tendencies, the difference being that the maximum density values were less; in fact, they were lower than those reported by the Dsmaxpedotransfer equation as a function of the clay content.

The pedotumn function that most clearly described the density phenomenon in these soil samples, and which enabled the estimation of the Dsmaxin order to establish the DR, is as given: Dsmax = 1.774- (0.000434 * silt) - (0.00610 * MO), (P = 0.005). MO was identified as the most influential factor of the Dsmax in these soils. It is evident in the function and obvious in Figure 1f, as it showed a higher coefficient (0.00610) than the silt (0.000434).

The UOC values were observed in the range of 0.218 and 0.369g g^{-1}, increasing as the soil OM levels rose. According to LUCIANO et al., (2012), the influence of MO on the UOC was confirmed, a result of the great ability of the organic matter to retain water.

Table 2B shows the soil DR values ranging between 0.783 and 0.978. As the values 0.90 to 0.95 were regarded as compacted soils (MARCOLIN, 2009), soil samples 13 and 16 were considered compacted, while soils 3, 7, and 15 with values higher than 0.95 were categorized as very compacted. BONINI et al. (2011) reported that the DR which induced the highest wheat grain harvest was 0.83; earlier, SUZUKI et al. (2007) reported DR values of 0.86 for the soybean crop, both for Oxisols.

In the soil samples studied in this research, when the relative density was calculated applying the equation estimated by the clay levels, the values which were less than those reported were calculated by assessing the maximum density attained in the Proctor's test. This implied that when the DR calculated for these soils was determined at Dsmax solely by the clay content the true degree of compaction was understated as it leaned towards classifying these soils as noncompacted; this was a faulty evaluation, because when the calculation was performed by the Dsmax determined in the Proctor's test, the values showed that the soils were compacted. The T test done between the means of the DR calculated from these soils and the means of the DR derived from the estimated Dsmax indicated a noteworthy dissimilarity among the groups (P=<0.001). This highlighted the fact that the equation for the clay content was deficient for these soils. Unlike the Dsmax and the UOC, no relationship was reported between the DR and MO concentration or the granulometric soil fractions, as this is an index and was unaffected by these factors. The potential use of the DR as a soil quality indicator was reinforced, irrespective of the textural class, when compared solely with soil density assessment, which is closely connected with soil granulometric composition(REICHERT et al., 2009) and organic matter (BRAIDA et al., 2010).

As each soil type possesses specific Ds, Dsmax and UOC, the use of these values for other soil classes can result in huge errors in the identification of the best management humidity or the assessment of the present level of compaction in a specific site (LUCIANO et al. al., 2012). It is thus significant that more studies are required using the soils of the present research, as the same ones continue to be utilized for agricultural purposes; however, knowledge is limited regarding its behavior in specific conditions.

CONCLUSION

The silt and organicconstituents of matter influence the physical-hydrologic properties of theEntisols. The pedotransfer equation that best fits these soils is Dsmax = 1.774- (0.000434* silt)- (0.00610 * MO); however, the equation used to assess the density using the clay content is not suitable.

ACKNOWLEDGMENTS

We are grateful to the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), and Universidade de Passo Fundo (UPF).

REFERENCES

ARAGÓN, A. et al. Maximum compactibility of Argentine soils from the Proctor test: the relationship with organic carbon and water content. **Soil and Tillage Research**, v.56, n.3, p.197-204,2000.Available from: <http://directory.umm.ac.id/Data%20Elmu/jurnal/S/Soil%20&%20Tillage%20Research/Vol56.Issue3-4.Aug2000/1526.pdf>. Accessed: Feb. 10, 2016.

BEUTLER, A.N. et al. Optimal relative bulk density for soybean yield in oxisols. **Revista Brasileira de Ciência do Solo**, v.29, n.6, p.843-849, 2005. Available from: <http://www.scielo.br/pdf/rbcs/v29n6/28953.pdf>. Accessed: Dec. 15, 2015.

BONINI, A.K. et al. Physical-hydraulic attributes and wheat yield in an oxisol under compaction states. **Ciência Rural**, v.41, n.9, p.1543-1548, 2011. Available from: <http://www.scielo.br/scielo.php?script=sci_arttext&pid=S010384782011000900009>. Accessed:Mar.30, 2016.

BRADY, N.C.; WEIL, R.R. **The nature and properties of soils**. 14th .ed. New Jersey: Prentice Hall, 2008.975p.

BRAIDA, J.A. et al. Mulch and soil organic carbon content and their relationship with the maximum soil density obtained in the proctor test. **Revista Brasileira de Ciência do Solo**, v.30, n.4, p.605-614, 2006.Available from: <http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0100-06832006000400001>. Accessed: Feb. 10, 2016.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA (EMBRAPA Centro Nacional de Pesquisa de Solos). **Manual de métodos de análise de solo**. 2.ed. Rio de Janeiro, 1997. p.212.

FIGUEIREDO, L.H.A. et al.Critical moisture content and maximum dry bulk density in response to soil management systems in a dusky red latosol. **Revista Brasileira de Ciência do Solo**, v.24, n.2, p.487-493, 2000. Available from: <http://www.scielo.br/pdf/rbcs/v24n3/02.pdf>. Accessed: Dec. 15, 2015.

KORMANEK, M. et al. Effects of soil bulk density on sessile oak *Quercus petraea* Liebl. **European Journal of Forest Research**,v.134, p.969-979, 2015. Available from: <http://link.springer.com/article/10.1007%2Fs10342-015-0902-2>. Accessed: Mar.30, 2016.

LIMA, R.P. et al. Soil compaction of different textural classes in areas of sugarcane production. **Revista Ceres**, v.60, p.16-20, 2013. Available from: <http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0034-737X2013000100003>. Accessed: Dec.10, 2015.

LUCIANO, R.V. et al. Physical attributes related to soil compaction under native vegetation of southern brazil. **Revista Brasileira Ciência do Solo**, v.36, p.1733-1744, 2012. Available from: <http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0100-06832012000600007>. Accessed: Feb. 10, 2016.

MARCOLIN, C.D. **Uso de funções de pedotransferência entre atributos físicos de solos sob plantio direto**. 187f. 2009. (PhD Thesis) – Universityof Passo Fundo.

MARCOLIN, C.D.; KLEIN, V.A. Determination of relative soil density through a pedotransfer function of maximum bulk density. **Acta Science Agronomy**, v.33, p.349-354, 2011. Available from: <http://www.scielo.br/scielo.php?pid=S1807-86212011000200022&script=sci_abstract&tlng=pt>. Accessed: Jan. 10, 2016.

NOGUEIRA, J.B. Mecânica dos solos. In: **Ensaios de laboratório**.São Carlos: Eesc-USP, 1998. p.248.

OLIVEIRA, V.S. et al. Compaction of a ultisol submitted to different managements. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v.14, n.9, p.914-920, 2010. Available from: <http://www.scielo.br/scielo.php?script=sci_arttext&pid=S1415-43662010000900002>. Accessed: Jan.13, 2016.

ROSSETTI, K.V. et al. Physical properties of an oxisol as affected by soybean management systems. **Revista Brasileira de Ciência do Solo**, v.36, p.367-376, 2012. Available from: <http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0100-06832012000200006>. Accessed: Jan.13, 2016.

REICHERT, J.M. et al. Reference bulk density and critical degree compactness for no-till crop production in subtropical highly weathered soils. **Soil & Tillage Research**, v.102, p.242-254, 2009. Available from: <http://www.sciencedirect.com/science/article/pii/S0167198708001025>. Accessed: Dec.20, 2015.

SHI, X.H. et al. Impact of ridge tillage on soil organic carbon and selected physical properties of a clay loam in southwestern Ontario. **Soil & Tillage Research**, v.120, p.1-7, 2012. Available from: <http://www.sciencedirect.com/science/article/pii/S0167198712000050>. Accessed: Jan. 21, 2016.

SUZUKI, L.E.A.S. et al. Relative compaction, physical properties and crop yield in Oxisol and Alfisol. **Pesquisa Agropecuária Brasileira**, v.42, p.1159-1167, 2007.Available from: <http://www.scielo.br/pdf/pab/v42n8/a13v42n8.pdf>. Accessed: Mar.19, 2016.

TEDESCO, M.J.et al. **Análise de solo, plantas e outros materiais**. 2.ed. Porto Alegre: Universidade Federal do Rio Grande do Sul, 1995.147p. (Technical Bulletin).