Evaluation of Soil Physical Indices Under Different Uses in River Basin
Avaliação de Índices Físicos do Solo sob Diferentes Usos em uma Bacia Hidrográfica

Pedro Daniel da Cunha Kemerich[1]; Sergio Roberto Martins[2]; Masato Kobiyama[3];
Vanderlei Rodrigues da Silva[4]; Ezequiel Koppe[5]; Willian Fernando de Borba[6];
Carlos Eduardo Balestrin Flores[7]; Gabriel D'Ávila Fernandes[8] & Cristiane Heredia Gomes[9]

[1] *Fundação Universidade Federal do Pampa, Departamento de Engenharia Sanitária e Ambiental (DESA),*
Avenida Pedro Anunciação, Vila Batista, 96570-000, Caçapava do Sul, Rio Grande do Sul
[2] *Universidade Federal de Santa Catarina, Departamento de Engenharia Sanitária e Ambiental, 88040-900, Florianópolis, Santa Catarina*
[3] *Universidade Federal do Rio Grande do Sul, Departamento de Obras Hidráulicas,*
91501-970, Porto Alegre, Rio Grande do Sul
[4] *Universidade Federal de Santa Maria, Departamento de Ciências Agronômicas e Ambientais,*
98400-000, Frederico Westphalen, Rio Grande do Sul
[5] *Universidade Federal de Santa Maria, Departamento de Solos, 97105-900, Santa Maria, Rio Grande do Sul*
[6] *Universidade Federal de Santa Maria, Departamento de Engenharia e Tecnologia Ambiental,*
98400-000, Frederico Westphalen, Rio Grande do Sul
[7] *Universidade de Passo Fundo, Departamento de Engenharia Civil, 99052-900, Passo Fundo, Rio Grande do Sul*
[8] *Universidade Federal de Santa Maria, Departamento de Engenharia Sanitária e Ambiental, 97105-900, Santa Maria, Rio Grande do Sul*
[9] *Fundação Universidade Federal do Pampa, Departamento de Engenharia Sanitária e Ambiental,*
96570-000, Caçapava do Sul, Rio Grande do Sul
E-mails: eng.kemerich@yahoo.com.br; sergio@ens.ufsc.br; masato.kobiyama@ufrgs.br; vanderlei@ufsm.br; koppe03@hotmail.com; borbawf@gmail.com; carlos.ebf@hotmail.com; enggabrielfernandes@gmail.com; crisheredigomes@gmail.com
Recebido em: 26/07/2017   Aprovado em: 18/06/2018
DOI: http://dx.doi.org/10.11137/2018_2_66_73

Abstract

The present study aimed to analyze the changes in the physical properties of the soil under different uses in a watershed. The undisturbed soil samples were collected in 26 different locations and analyzed at the Federal University of Santa Maria, RS – Campus Frederico Westphalen, following the methodologies proposed by Klein (2008) and Embrapa (1997). The penetrometer Penetrolog 1020 was used to determine the Penetration Resistance (PR). The PR values range from 2752 (pasture soil) to 9612 kPa (native forest soil). Regarding the physical parameters, the Permanent Wilting Point (PWP) parameter shows that soils occupied by rice cultivation, urban occupation, pasture and native field presented a higher influence on this parameter (higher mean values). The soils occupied by soybean cultivation and native forest have not shown a significant difference between them per this parameter. The other parameters didn't show a significant difference for the utilized test. The PWP parameter shows a positive correlation with Clay, Penetration Resistance, Field Capacity and Micro Porosity. This is an evidence of the physics parameter's influence, such as density and porosity, in water storage. As for Density and Macro Porosity parameters showed an inverse correlation which indicates that with the increase of the soil's density there is a smaller storage of water. Therefore, a smaller amount of water is confined in the PWP. Based on this, it was possible to conclude that the soil's uses alter the physical properties of it, especially those that suffer anthropic alterations, such as rice cultivation (density and penetration resistance) and soybean (field capacity and permanent wilt point).
Keywords: Clay; Resistance to penetration; Vacacaí-Mirim

Resumo

O presente estudo teve como objetivo analisar as mudanças nas propriedades físicas do solo sob diferentes usos em uma bacia hidrográfica. As amostras de solo indeformadas foram coletadas em 26 locais diferentes e analisadas na Universidade Federal de Santa Maria, RS - Campus Frederico Westphalen, seguindo as metodologias propostas por Klein (2008) e Embrapa (1997). O penetrômetro Penetrolog 1020 foi usado para determinar a resistência à penetração (RP). Os valores de RP variam de 2752 (solo de pastagem) a 9612 kPa (solo florestal nativo). Em relação aos parâmetros físicos, o parâmetro Ponto de Murcha Permanente (PMP) mostra que os solos ocupados pelo cultivo de arroz, ocupação urbana, pastagem e campo nativo apresentaram maior influência sobre este parâmetro (maiores valores médios). Os solos ocupados pelo cultivo de soja e floresta nativa não mostraram diferença significativa entre eles por esse parâmetro. Os outros parâmetros não mostraram diferença significativa para o teste utilizado. O parâmetro PMP mostra uma correlação positiva com argila, resistência a penetração, capacidade de campo e microsidade. esta é uma evidência da influência do parâmetro físico, como densidade e porosidade, no armazenamento de água. Quanto aos parâmetros de densidade e macroporosidade macro mostraram uma correlação inversa que indica que com o aumento da densidade do solo há um menor armazenamento de água. Portanto, uma quantidade menor de água é confinada no PMP. Com base nisso, foi possível concluir que os usos do solo alteram suas propriedades físicas, especialmente aqueles que sofrem alterações antrópicas, como cultivo de arroz (densidade e resistência à penetração) e soja (capacidade de campo e ponto de marchas permanente).
Palavras-chave: Argila; Resistência a penetração; Vacacaí-Mirim

Evaluation of Soil Physical Indices Under Different Uses in River Basin
Pedro Daniel da Cunha Kemerich; Sergio Roberto Martins; Masato Kobiyama; Vanderlei Rodrigues da Silva;
Ezequiel Koppe; Willian Fernando de Borba; Carlos Eduardo Balestrin Flores; Gabriel D'Ávila Fernandes & Cristiane Heredia Gomes

1 Introduction

The soil is a natural resource slowly renewable, found in different locations on the landscape. Its origin is a result of rock and sediments weathering by climate (rain intensity, temperature variation) and biological beings (fauna and flora), in the most diverse situations of the landscape through the time (Streck, 2008). Lima *et al*. (2009) affirms that one of the main reasons for soil degradation is the compaction caused by the increase in soil's density and the penetration resistance, derived from anthropic actions.

Several authors affirm that the soil's compaction causes many damages to the soil, among them Soares Filho (1992) and Cunha *et al.* (2002), mentioning that the compaction is one of the most serious damages due to the agricultural exploration of the land, by the compaction caused by the animal trampling or by traffic of machinery on the ground, exerting great pressure on it. This basically occurs due the arrangement and reduction of soil voids, modifying its properties and causing damages, Lima *et al.* (2009) affirm that with the increase of the soil's penetration resistance, the plants' radicular systems reduce its developing, resulting in a loss to the plants.

This compaction process is intensified by the need for increased tractive effort and the search for greater efficiency in farming operations, aiming for a better use of climate windows, are arguments for the fabrication and utilization of extremely heavy equipment, particularly for operations of sowing and harvesting. If the equipment has a weight greater than the load carrying capacity of the ground, which is lower especially when the traffic happens under high humid conditions, it's more susceptible to compaction (Gubiani, 2008).

Moreira *et al.* (2012) show that different soil's physical attributes have been used to characterize the modifications resulting from the soil's compaction, occurred by the pressure exerted by the wheels of harvesting machinery, by the animals' hulls or by the different systems of preparation and handling of the soil. In this context, there are equipment that allow us to know the resistance to penetration, one of the most used being the Penetrometer.

In a way, there is a relationship between resistance to penetration and the soil density. This relationship is affected mainly by the texture and humidity content of the soil. Lima et al. (2009) relate the influence of soil's density in the radicular development of the plants. Based on this, this study aims to analyze the alterations of soil's physical parameters under different uses and occupation in the watershed of Vacacaí-Mirim River, at the central region of Rio Grande do Sul state.

2 Materials and Methods
2.1 Characterization of the Study Area

The Vacacaí-Mirim basin is located in the central region of Rio Grande do Sul state, between the latitudes of 29º36′55″S e 29°39′50″S and longitude of 53º46′30″O e 53°49′29″O, covering a total area of 1.145,7 km^2 (Casagrande, 2004; Figure 1).
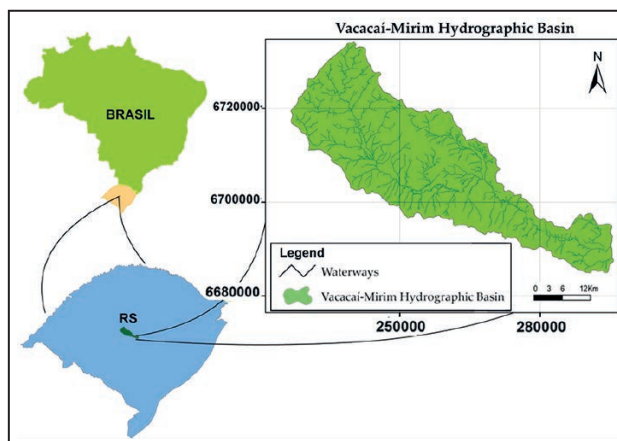

Figure 1 Location of Vacacaí-Mirim Basin in the Rio Grande do Sul.

In the region of springs of this basin, in its portion of higher altimetric values, occurs the Serra Geral Formation. According to the Geological Map of CPRM (2008) this consists of basic volcanic rocks (basalts, SiO^2 content between 45-52%) and acidic rocks (riolites, riodacite, granophylls with $SiO2$ content between 52-55%) Leinz and Amaral (1989).

In this unit, there are soybean, native forest and pasture areas. In the west region, there are lowland regions dominated by rice cultivation, comprised by formation from current sediments (alluviums).

Evaluation of Soil Physical Indices Under Different Uses in River Basin
Pedro Daniel da Cunha Kemerich; Sergio Roberto Martins; Masato Kobiyama; Vanderlei Rodrigues da Silva;
Ezequiel Koppe; Willian Fernando de Borba; Carlos Eduardo Balestrin Flores; Gabriel D'Ávila Fernandes & Cristiane Heredia Gomes

2.2 Location of Sampling Points

To carry out this present study, the sampling and measuring points were chosen aiming at a uniform spatial distribution in the basin, covering different types of existing soils, as well as their predominant uses in the region under study. In this way, 26 sites (points) were sampled, receiving the nomenclature ranging from P1 to P26 (Figure 2).

Figure 2 shows the planialtimetric map of the Vacacaí-Mirim Basin, which shows the occurrence of areas with altitudes equal to or less than 50 m in the SE region, mainly occupied by rice cultivation (Vacacaí-Mirim River floodplain). Altitudes in order of 100 m occur mainly in the central region and W, the highest altitudes are in the NW region of the watershed varying between 150 and 450 m.

Tables 1 and 2 show the use of soil's type and the soil's type in each of the sampling points, respectively.

Soil Use	Sampling Points
Native forest	1,2,3,10,26
Native field	5,12,22,23
Pasture	11,15,20
Soy	4,6,7,8,9
Rice	16,17,18,19,21,24,25
Urban area	13,14

Table 1 Use and Occupation of the soil at the Vacacaí Mirim Basin -RS.

Soil's type	Sampling Points
Claysoil Bruno-Alic gray or rich in aluminum	20,21
Claysoil Bruno-Alic gray	8
Neosoil Litholic normal and dystrophic	2,7,9,10
Claysoil Alic red and dystrophic	1,3,4,5,6,13,14,15,22,23
Planossoil haplic eutrophic	11,12,16,17,18,19,24,25,26

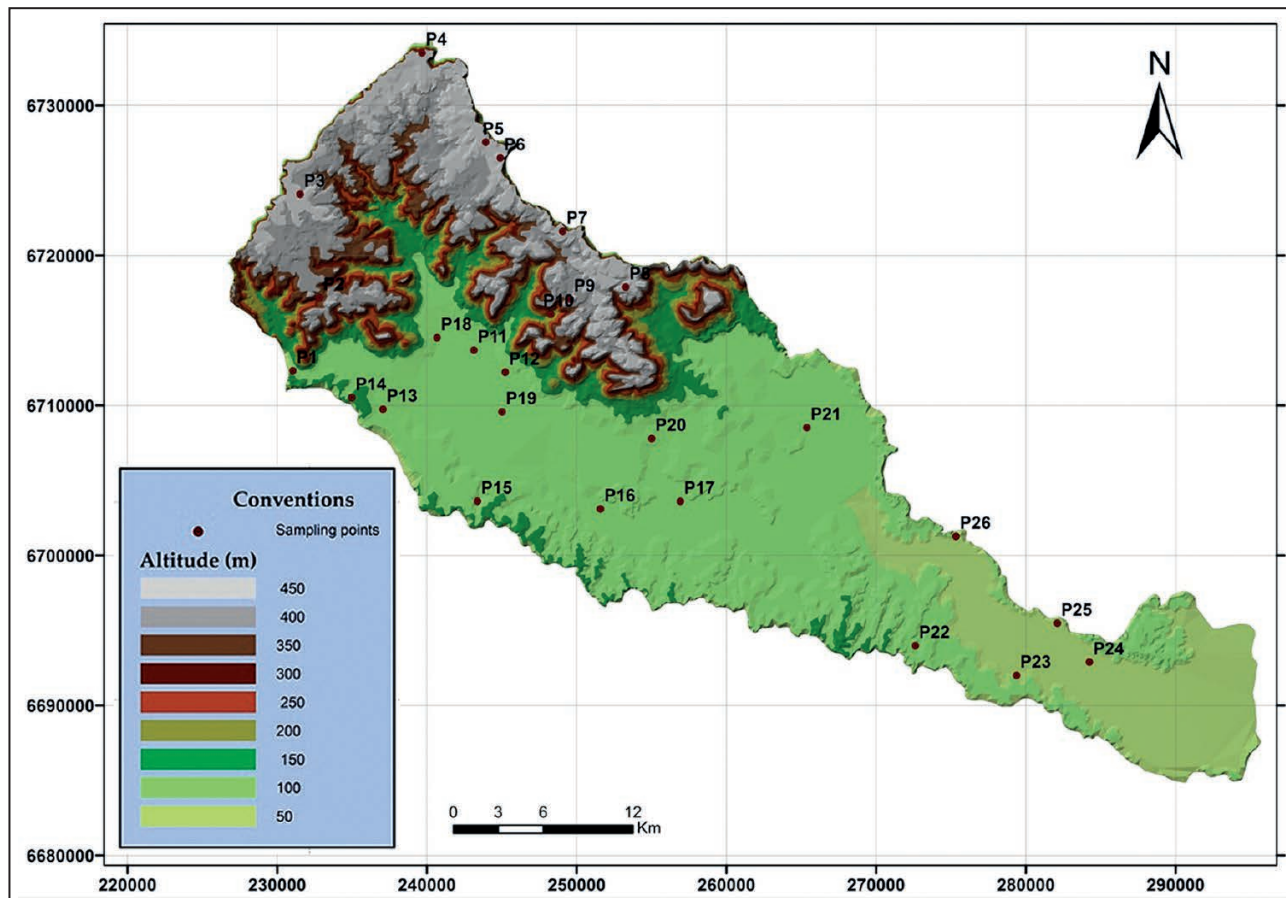Table 2 Soil's type at the Vacacaí Mirim Basin - RS.

Figure 2 Planialtimetric map with the location of the 26 points used for the tests of resistance to penetration and sample collection in the Vacacaí Mirim Basin - RS.

Evaluation of Soil Physical Indices Under Different Uses in River Basin
Pedro Daniel da Cunha Kemerich; Sergio Roberto Martins; Masato Kobiyama; Vanderlei Rodrigues da Silva;
Ezequiel Koppe; Willian Fernando de Borba; Carlos Eduardo Balestrin Flores; Gabriel D'Ávila Fernandes & Cristiane Heredia Gomes

2.3 Determination of Soil Physical Indexes

Undisturbed soil samples were collected by rings with dimensions of 5 cm in diameter, 3 cm in height and 3 cm deep. The values for dry soil density (Dens), total porosity, macro porosity (Macro), micro porosity (Micro), volumetric moisture conditions in field capacity (FC) and permanent wilting point (PWP), and saturated hydraulic conductivity (Ksat) were determined for these samples.

The porosity was determined by the Tension Table method, where the cylinders are submitted to a tension of 6 kPa for the drainage of the water in the macro pores (Embrapa, 1977). Then the field capacity determination was performed and the samples were submitted to a voltage of 10 kPa (Klein, 2008), in Richard's chamber. After the weighing, the samples were re-saturated and in constant load permeameter, the saturated hydraulic conductivity was determined. After determination of the saturated hydraulic conductivity load, the samples were oven-dried at 105 ° C for dry weight determination. With the weight obtained of 6 to 10 kPa, the dry weight values were determined for porosity, field capacity, and density.

2.4 Penetration Resistance (PR)

For penetration resistance tests a penetrometer FALKER PenetroLOG – PLG 1020 was used, with the same methodology used by Camargo and Alleoni (1997) and later by Melo (2011), however the present study evaluated in the layer from 0 to 0.40 m.

3 Results and Discussion

Figure 3 shows the average values for penetration resistance of the soil in the 0-40 cm layer, at the Vacacaí-Mirim Basin.

The highest value of PR was found in a soil with native forest presence, this factor may be related to the presence of decomposing rock material along the section. Mota *et al*. (2011) found, for the same type of soil, average values for the 0 to 30 cm layer of 1880 kPa. These values are lower than those found in this present study, which shows that it may contain rocky material that may have interfered with the results because the soil where the point is located is a Lithic Neosols with a large presence of decomposing rock material.
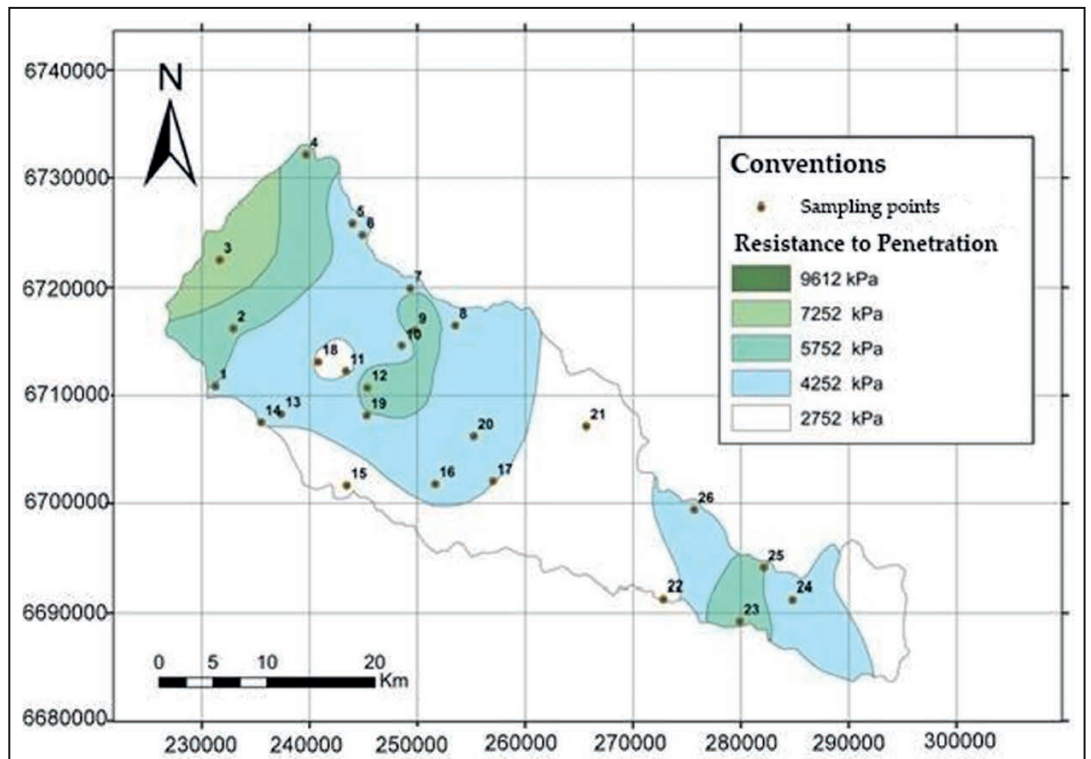

Figure 3 Penetration Resistance in the 0 to 40 cm layer at the Vacacaí Mirim basin -RS, 2013.

Evaluation of Soil Physical Indices Under Different Uses in River Basin
Pedro Daniel da Cunha Kemerich; Sergio Roberto Martins; Masato Kobiyama; Vanderlei Rodrigues da Silva;
Ezequiel Koppe; Willian Fernando de Borba; Carlos Eduardo Balestrin Flores; Gabriel D'Ávila Fernandes & Cristiane Heredia Gomes

In pasture areas, Palma et al. (2010) and Mota et al. (2011) found PR values of 2500 and 4370 kPa respectively, these values are higher than the ones found in this present study, this can be explained by the practice of extensive livestock breeding developed in the watershed region. Brasil et al. (2011) in the Rio Grande do Sul state found in the layer from 0 to 10 cm PR values close to 2000 kPa, these values are lower than the ones found in this present study. This fact can be explained by the number of animals, specifically cattle, in the study area or by the type of soil. Trein et al. (1991) observed that the intense grazing of cattle in a pasture caused an increase in PR from 840 to 4030 kPa in the 0.0 to 0.07 m depth, Rodrigues Júnior et al. (2011) found similar values to that in the 0.0 to 10 cm layer (4460 kPa).

Several factors influence soil compaction. In areas of soybean cultivation, the traffic of agricultural machinery is one of the main agents causing compaction. In the present study, it can highlight the point P7 that presented 6956 kPa of penetration resistance, which is higher than the others under same the use. This fact can be related to the large machinery traffic onsite, which increases the PR of the ground. Santi *et al.* (2006) in studies carried out in areas of soybean cultivation in the northern RS region, found maximum PR values of 4200 kPa. The same occurred with studies developed by Stürmer (2012), which found PR rates close to 4000 kPa. These values are well below those found in the present study. The same was identified by Xavier (2005), where variation occurred from 1469 to 2039 kPa.

Tables 3 and 4 show the parameters for PWP, CC, Arg, Ksat, Dens, Micro, Macro and PR for urban area use, rice cultivation, native field, native forest, soybean and pasture, average compared by Tukey test at the 5% error probability level. The influence of land use on PWP was observed, with the soils occupied by rice cultivation, urban area, pasture and native field had a greater influence on PWP (higher mean values), and soils occupied by soybean and native areas presented no difference for this parameter. The other parameters did not present significant differences between different soil uses.

Paiva *et al.* (2003) in a native field area in the same watershed under study, found PWP value of 11.1%, which is different from the one found in this

Use	PWP (%)	Clay (%)	Ksat (%)	CC (%)
Soy	17.1 a*	33.2 ns	2.4 ns	24.9 ns
Native pasture	7.6 b	30.5	9.0	19.5
Native forest	17.0 a	25.0	4.2	34.5
Rice	8.0 b	19.0	1.4	23.9
Urban area	7.8 b	17.5	0.6	23.5
Pasture	7.7 b	13.6	4.7	16.0

Table 3 Statistical comparison of PWP, Arg, Ksat and CC parameters in different soil uses.

*Averages followed by the same letter do not differ statiscally by the Tukey test at the 5% level of error probability. ns not significant.

study (7.6%). In the same watershed, Dias (2003), in native forest soil, found PWP values of 9.3%, different from the one found in this paper (17%).

In the present study made in the Vacacaí-Mirim Basin, Rizzardi (2010) in 9 sampling points of the same watershed found average values of clay soil's varying between 3 to 60% (both in soils occupied by native forest). These values were higher than those found in the present study since the soil occupied by soybean cultivation had the highest average value (33.2%) and the lowest value (13.6%) was found in a native field soil. With respect to the clay contents, Primel *et al.* (2005) found average values of 15 to 25% in a rice crop soil, values close to those found (19%).

In relation to Ksat, Beling *et al.* (2011), found values of 7.3 cm h^{-1} in a native forest area, which is much higher than that found in the present study (4,2 cm h^{-1}). This fact can be explained by Pérez *et al.* (1998), who claims that some soils have the property of repelling water, not easily being wetted by rainwater or irrigation, and then are called hydrophobic soils. According to these authors, the soils ability to repel water would be caused by the covering of soil particles by hydrophobic organic substances. Many can be the origins of the organic substances responsible for repellency. The local vegetation, due to its chemical decomposition, can contribute hydrophobic organic compounds, through decomposition covering the soil particles, creates the character of water repellency.

Rizzardi (2010) in 9 sampling points from the same watershed, found average values of soil density varying between 1.12 (soil occupied by native fo-

Evaluation of Soil Physical Indices Under Different Uses in River Basin
Pedro Daniel da Cunha Kemerich; Sergio Roberto Martins; Masato Kobiyama; Vanderlei Rodrigues da Silva;
Ezequiel Koppe; Willian Fernando de Borba; Carlos Eduardo Balestrin Flores; Gabriel D'Ávila Fernandes & Cristiane Heredia Gomes

Use	Dens. (g cm^{-3})	Micro (%)	Macro (%)	PR
Soy	1.3[ns]	35[ns]	13[ns]	7135[ns]
Native field	1.2	24	28	3456
Native forest	1.1	38	18	3012
Rice	1.4	33	12	5963
Urban area	1.3	31	16	3849
Pasture	1.3	22	25	2762

Table 4 Statistical comparisons of Dens, Micro, Macro and PR parameters of different soil uses.
[ns] not significant.

rest) to 1.8 g cm^{-3} (soil occupied by pasture), values like those were found in the present study, since the native forest soil had the lowest mean value (1.1 g cm^{-3}), but the highest value (1.4 g cm^{-3}) was found in a rice cultivation soil. Santos *et al.* (2009) in native forest soil found a soil density of 1.28 g cm^{-3}, a value similar to the one found in this present study. Different values of orders were found in the state of Tocantins, by Rachwal *et al.* (2007) where the density value was 1.54 g cm^{-3}, Soares (2011) and Bortoluzzi *et al.* (2008) in the city of Santa Maria-RS found values in the order of 1.54 and 1.31 g cm^{-3}, respectively.

For native field use, values in different orders were found by Potes (2009) and Bortoluzzi *et al.* (2008), where the values were 0.81 and 1.82 g cm^{-3}, in fields from the Serra and Santa Maria-RS, respectively. For pasture soil use, Uhde (2009) in Santa Maria city found similar values to those found in the present study (1,39 g cm^{-3}), Silva Neto (2010) and Pizzani (2008), found values in different orders for the same use (1,5 g cm^{-3}) in regions of Porto Alegre and Mata-RS, respectively. For the rice cultivation areas, Roth *et al.* (2009) found values well below (0,88 g cm^{-3}) those found in the present study (1,4 g cm^{-3}).

For the micro porosity variable, Rizzardi (2010) found similar values for native forest soil use (values varying between 37 and 45%), the same happened with the study of Ceconi (2010) and Rachwal *et al.* (2007) when the values were 35%. For soybean use, Rizzardi (2010) found Micro Porosity of 39%. Soils used as native field, urban area and pasture were found to have different orders of values

(41%, values between 32 and 38% and between 19 and 24%, respectively). For soybean use, Wink (2009) also found different values, varying between 19 and 38%.

For the macro porosity parameter, Rizzardi (2010), Cecconi (2010) and Wink (2009) found similar values for pasture use (19%, 13% and 6 to 24%, respectively). For the native forest, native field, soybean, and urban area use, Rizzardi (2010) found mean values of different orders (7%, 3%, 8% and 8.3%, respectively).

As it can be observed in table 4 the use system that showed a higher value for the variable PWP was the soybean use, followed by native forest. There was no statistical between these two systems. The lowest value found for PWP was the native field, which presented a water content of 7.6%. This use does not present statistical difference from the uses of rice cultivation, pasture, and urban area.

Regarding the clay contents, the area that presented the highest values was soybean, although it is numerically higher, it did not obtain significant differences between the treatments. For the penetration resistance, the soybean system of soil use presented higher values. Although it is higher, this did not have statistical difference from the others.

When we evaluated the field capacity, although there was no statistical difference between the systems of land use, numerically the native forest had a greater amount of water retained in field capacity. The cultivated pasture was the one that presented the lowest values numerically.

Table 5 show the statistical correlation between the analyzed parameters in the Vacacaí-Mirim Basin.

	PWP	Clay	PR	CC	Dens.	Micro	Macro
PWP							
Clay	0.49*						
PR	0.10*	0.28*					
CC	0.62*	0.20*	ns				
Dens.	-0.43*	ns	ns	-0.68*			
Micro	0.60*	0.27*	ns	0.90*	-0.35*		
Macro	-0.23*	-0.21*	ns	-0.22*	-0.51*	-0.59*	
Ksat	ns	ns	ns	ns	-0.31*	-0.25*	0.51*

Table 5 Pearson Correlation Matrix between the variables PWP, Clay, PR, CC, Dens., Micro, Macro and Ksat.
*: significative to 5% of probability; ns: not significative.

Evaluation of Soil Physical Indices Under Different Uses in River Basin
Pedro Daniel da Cunha Kemerich; Sergio Roberto Martins; Masato Kobiyama; Vanderlei Rodrigues da Silva;
Ezequiel Koppe; Willian Fernando de Borba; Carlos Eduardo Balestrin Flores; Gabriel D'Ávila Fernandes & Cristiane Heredia Gomes

Based on table 5, it can be affirmed that the PWP variable presents a positive correlation with clay, Penetration Resistance, Field Capacity and Micro Porosity. This is evidence of the influence of physical parameters, such as density and porosity, in water storage. Parameters as Density and Macro Porosity presented inverse correlation, which indicates that with the increase of the soil's density there is a smaller storage of water, consequently, a smaller quantity of water retained in the PWP.

According to Moraes (2012), the larger the pore diameter the smaller its capacity to retain water, thus confirming the results obtained in the correlation, which shows that with the increase of macro porosity there is a reduction in the humidity values for PWP. Regarding Clay, it showed a direct correlation with PR, CC, and Micro, but presented an inverse correlation with Macro porosity. The CC parameter showed an inverse correlation with Macro porosity and density, although the micro porosity showed a direct correlation because it is retained mainly by the micropores.

The values for density presented inverse correlation with the variables Micro porosity, macro porosity and Ksat. The Micro porosity parameter presented a inverse correlation with macro porosity and Ksat. Macro porosity presented a direct correlation with Ksat. Schaffrath *et al.* (2008) found a direct correlation between Field Capacity and Micro Porosity and between Field Capacity and Density, which was different from the present study where an inverse correlation was found. Alvarenga *et al.* (2010) found an inverse correlation for the variables of Field Capacity and Density.

The direct correlation between Ksat and Macro Porosity provides evidence that pores with larger diameters (macropores) allow higher hydraulic conductivity of soil values (Mesquita & Moraes, 2014). For Hurtado (2004) many physical properties of the soil are responsible for the variability of hydraulic conductivity, since this is influenced by the properties that affect the distribution, size and form of the soil pores, such as density, structure, and porosity.

4 Conclusions

Based on what was exposed in this present study, it is possible to identify that the physical properties of the soil suffer influences with respect to the use to which they are subjected. Changes in properties such as density and penetration resistance occurred where soils were under rice cultivation use having higher average values, thus directly influencing the dynamics of water infiltration in the soil. Regarding the statistical analysis, the PWP parameter presented a positive correlation with Clay, Penetration Resistance, Field Capacity and Micro porosity. This is evidence of the influence of physical parameters, such as density and porosity in water storage. On the other hand, parameters such as Density and Macro Porosity presented an inverse correlation, which indicates that with an increase of soil density there is, consequently, lower water storage and a smaller amount of water retained in the PWP.

5 Acknowledgments

6 References

Alvarenga, C.C.; Mello, C.R.; Ávila, L.F.; Côrrea, M.P. & Borges, L.A. 2010. Determinação da umidade do solo na capacidade de campo e no ponto de murcha permanente com base em atributos físicos do solo. *In*: CONGRESSO DE PÓS-GRADUAÇÃO DA UNIVERSIDADE FEDERAL DE LAVRAS, 19, Lavras, 2010. *Trabalho completo*, Lavras, UFLA.

Behling, F.A.; Paiva, J.B.D. & Paiva, E.M.C.D. 2011. Avaliação do Modelo Kineros na Estimativa do Hidrograma de Projeto para uma Pequena Bacia Característica de Mata Atlântica. *In:* SIMPÓSIO BRASILEIRO DE RECURSOS HÍDRICOS, 19, Maceió, 2011. *Trabalho completo*, Maceió, ABAS.

Bortoluzzi, E.C.; Pernes, M. & Tessier, D. 2008. Mineralogia de Partículas Envolvidas na Formação de Gradiente Textural em um Argissolo Subtropical. *Revista Brasileira de Ciência do Solo*, *32*(3): 997 - 1007.

Camargo, O.A. & Alleoni, L.R.F. 1997. *Compactação do solo e o desenvolvimento das plantas*. Piracicaba, ESALQ/USP.

Casagrande, L. 2000. *Avaliação do parâmetro de propagação de sedimentos do Modelo de Williams (1975) na Bacia do Rio Vacacaí-Mirim com o auxílio de técnicas de geoprocessamento*. Programa de Pós-Graduação em Engenharia Civil, Universidade Federal de Santa Maria, Dissertação de Mestrado, 242p.

Ceconi, D.E. 2010. *Diagnóstico e recuperação da mata ciliar da Sanga Lagoão do Ouro na Microbacia Hidrográfica do Vacacaí-Mirim, Santa Maria – RS*. Programa de Pós-Graduação em Ciência do Solo, Universidade Federal de Santa Maria, Tese de Doutorado, 132p.

COMPANHIA DE PESQUISA EM RECURSOS MINERAIS – CPRM. 2008. *Mapa hidrogeológico da folha de Santa Maria, SH.22-V-C-IV. escala 1:100.000*. Porto Alegre, CPRM.

Cunha, J.P.A.R.; Vieira, L.B. & Magalhães, A.C. 2002. Resistência

Evaluation of Soil Physical Indices Under Different Uses in River Basin
Pedro Daniel da Cunha Kemerich; Sergio Roberto Martins; Masato Kobiyama; Vanderlei Rodrigues da Silva;
Ezequiel Koppe; Willian Fernando de Borba; Carlos Eduardo Balestrin Flores; Gabriel D'Ávila Fernandes & Cristiane Heredia Gomes

mecânica do solo à penetração sob diferentes densidades e teores de água. *Revista Engenharia Agrícola*, *10*(1):1-7.

Dias, J.R. 2003. *Aplicação do modelo hidrológico agnps2001 utilizando dados observados na Bacia do Arroio Vacacaí-Mirim*. Programa de Pós-Graduação em Engenharia Civil, Universidade Federal de Santa Maria, Dissertação de Mestrado, 142p.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA - EMBRAPA. 1999. *Sistema Brasileiro de classificação de solos*. Brasília, EMBRAPA.

Gubiani, P.I. 2008. *Tempo para a ocorrência da resistência a penetração restritiva ao feijoeiro em solo com diferentes estados de compactação*. Programa de Pós-Graduação em Ciência do Solo, Universidade Federal de Santa Maria, Dissertação de Mestrado, 110p.

Hurtado, A.L.B. 2004. *Variabilidade da condutividade hidráulica do solo em valores fixos de umidade e de potencial matricial*. Programa de Pós-Graduação em Agronomia, Universidade de São Paulo, Dissertação de Mestrado, 119p.

Klein, V.A. 2008. *Física do solo*. Passo Fundo, Ed. UPF. 253p.

Leinz, V. & Amaral, S.E. 1989. *Geologia geral*. São Paulo, Editora Nacional. 543p.

Lima, R.P.; Leon, M.J.; Gonzaga, B.AB.S. & Santos, R.F. 2009. Resistência a penetração e densidade do solo como indicativos de compactação do solo em área de cultivo da cana-de-açúcar. *In*: CONGRESSO BRASILEIRO DE CIÊNCIA DO SOLO, 32, Fortaleza, 2009. *Trabalho completo*, Fortaleza, SBCS.

Melo, R.T. 2011. *Uso de sistema de integração lavoura - pecuária na recuperação de áreas compactadas: Riacho dos Cavalos – PB*. Programa de Pós-Graduação em Ciência do Solo, Universidade Federal do Semi - Árido, Dissertação de Mestrado, 100p.

Mesquita, M.G,B.F. & Moraes, S.O. 2004. A dependência entre a condutividade hidráulica saturada e atributos físicos do solo. *Revista Ciência Rural*, *34*(3): 963 - 969.

Moreira, W.H.; Betioli Júnior, E.; Petean, L.P.; Tormena, C.A.; Alves, S.J.; Costa, M.A.T. & Franco, H.H.S. 2012. Atributos Físicos de um Latossolo Vermelho Distroférrico após oito anos de Integração Lavoura-Pecuária. *Revista Brasileira de Ciência do Solo*, *36* (2): 389-400.

Mota, M.S.; Cremon, C.; Mapeli, N.C.; Silva, W.M.; Magalhaes, W.A & Cremon, T.Q. 2011. Qualidade e atributos físicos de um Latossolo Vermelho Distroférrico Típico em diferentes sistemas de manejo. *Rev. Agrar*. 12:105-115.

Palma, M.A.Z.; Volpato, C.E.S.; Barbosa, J.A.; Spagnolo, R.T.; Barros, M.M. & Vilas Boas, L.A. 2010. Efeito da profundidade de trabalho das hastes sulcadoras de uma semeadora-adubadora na patinagem, na força de tração e no consumo de combustível de um trator agrícola. *Revista Ciência e Agrotecnologia, 34*(5): 1320-1326.

Pérez, D.V.; Simão, S.M. & Salatino, A. 1998. Identificação e caracterização da repelência à água em alguns solos brasileiros. *Revista Brasileira de Ciência do Solo*, 22: 197-207.

Pizzani, R. 2008. *Produção e qualidade de forragens e atributos de um Argissolo Vermelho*. Programa de Pós-Graduação em Ciência do Solo, Universidade Federal de Santa Maria, Dissertação de Mestrado, 94p.

Primel, E.G.; Zanella R.; Kurz M.H.S.; Gonçalves F.F.; Machado S.O. & Marchezan E. 2005. Poluição das águas por herbicidas utilizados no cultivo do arroz irrigado na região central do Estado do Rio Grande do Sul, Brasil: predição teórica e monitoramento. *Revista Química Nova, 28*(4): 605-609.

Potes, M.L. 2009. *Matéria Orgânica e sua distribuição em compartimentos físicos em Neossolo Litólico sob pastagem e mata nativa nos campos de cima da serra no Rio Grande do Sul*. Programa de Pós-Graduação em Ciência do Solo, Universidade Federal do Rio Grande do Sul, Dissertação de Mestrado, 101p.

Rachwal, M.F.G.; Dedecek R.A.; Curcio G.R. & Simon A.A. 2007. Manejo dos resíduos de Acácia Negra (Acaciamearnsii De Wild) e a sustentabilidade do sítio. *Revista Ciência Florestal*, *17*(2): 137-144.

Rizzardi, A.S. 2010. *Atributos físicos e fluxo de água em solos da Bacia Hidrográfica do Rio Vacacaí - Mirim RS*. Graduação em Engenharia Ambiental, Centro Universitário Franciscano, Trabalho de Conclusão de Curso, 40p.

Rodrigues Júnior, D.J.; Torres, J.L.R., Sene, G.A.; Jaime, D.G.; Vieira, D.M.S. & Henrique, F.L.A. 2011. Compactação do solo e o pisoteio bovino numa pastagem com e sem irrigação. *In:* CONGRESSO DE FORRIGICULTURA E PASTAGENS, 4, Lavras, 2011. *Trabalho completo*. Lavras, UFMG.

Roth, A.; Sechi, T.; Vivan, G.A.; Barboza, F.; Collares, G.L.; Nebel, A.L.C. & Tavares, V.E.Q. 2009. Desenvolvimento de um permeâmetro de carga constante e condutividade hidráulica em diferentes camadas de um Planossolo Háplico Eutrófico Gleissólico. *In*: CONGRESSO DE INICIAÇÃO CIENTÍFICA, 18, Pelotas, 2009. *Trabalho completo*. Pelotas, UFPEL.

Santi, A.L.; Flora, L.P.D.; Buaes, A.G.; Albuquerque, M.; Martins, F.R.A. & Machado, F.C. 2006. Monitoramento da compactação do solo através do mapeamento da resistência do solo a penetração. *Revista Plantio Direto*, *96*(1): 15-20.

Santos, A.C.; Ferreira, E.M. & Araújo, L.C. 2009. Propriedades químicas e físicas de solos em áreas sob pastagens em Cerrado do Norte do Tocantins. *Revista Acadêmica Ciências Agrárias e Ambientais*, *7*(1): 55-63.

Schaffrath, V.; Tormena, C.A.; Fidalski, J. & Goncalves, A.C.A. 2008. Variabilidade e correlação espacial de propriedades físicas de solo sob plantio direto e preparo convencional. *Revista Brasileira de Ciência do Solo*, *32*(4): 1369-1377.

Silva Neto, L.F. 2010. *Pedogênese e matéria orgânica de solos hidromórficos da Região Metropolitana de Porto Alegre*. Programa de Pós-Graduação em Ciência do Solo, Universidade Federal do Rio Grande do Sul, Tese de Doutorado, 117p.

Soares, J.S.W. 2011. *Matéria orgânica de um Argissolo Vermelho Distrófico Úmbrico após a introdução de fitofisionomias antrópicas*. Programa de Pós-Graduação em Ciência do Solo, Universidade Federal de Santa Maria, Dissertação de Mestrado, 64p.

Soares Filho, R. 1992. *Identificação e avaliação dos sistemas motomecanizados de preparo periódico do solo, usados no Município de Rio Verde-GO*. Programa de Pós-Graduação em Engenharia Agrícola, Universidade Federal de Viçosa, Dissertação de Mestrado, 80p.

Streck, E.V.; Kämpf, N.; Dalmolin, R.S.D.; Klamt, E.; Nascimento, P.C; Schneider, P.; Giasson, E. & Pinto, L.F.S. 2008. *Solos do Rio Grande do Sul*. Porto Alegre: EMATER/RS-ASCAR.

Stürmer, S.L.K. 2012. *Atributos químicos, físico-mecânicos e mineralógicos de um Argissolo Vermelho submetido a manejos de solo sob plantio direto*. Programa de Pós-Graduação em Ciência do Solo, Universidade Federal do Rio Grande do Sul, Tese de Doutorado, 184p.

Trein, C.R.; Cogo, N.P. & Levien, R. 1991. Métodos de preparo do solo na cultura do milho e ressemeadura do trevo, na rotação aveia + trevo/milho, após pastejo intensivo. *Revista Brasileira de Ciência do Solo, 15*(19): 105-111.

Uhde, L.T. 2009. *Sistema pedológico em um ambiente antropizado da Depressão Central do RS*. Programa de Pós-Graduação em Ciência do Solo, Universidade Federal de Santa Maria, Tese de Doutorado, 226p.

Xavier, A. 2005. *Comportamento da cultura da soja em função de resíduos culturais, mobilização do solo e irrigação, em semeadura direta*. Programa de Pós-Graduação em Ciência do Solo, Universidade Federal do Rio Grande do Sul, Dissertação de Mestrado, 113p.

Wink, C. 2009. *Estoque de carbono em plantações de Eucalyptus Sp. implantados em campo nativo*. Programa de Pós-Graduação em Engenharia Florestal, Universidade Federal de Santa Maria, Dissertação de Mestrado, 132p.