Original Article

LEAST LIMITING WATER RANGE AND DEGREE OF COMPACTNESS OF SOILS UNDER NO-TILLAGE

INTERVALO HÍDRICO ÓTIMO E GRAU DE COMPACTAÇÃO DE SOLOS SOB PLANTIO DIRETO

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ABSTRACT: The least limiting water range (LLWR) and degree of compactness (DC) can be useful indicators of soil physical quality and crop yield. This study focused on assessing of LLWR, DC and evaluation of critical values to crop growth of an Alfisol and Oxisol under no-till management. Undisturbed soil cores were taken from the layer 0.00 - 0.20 m depth. Soil water retention curve, soil penetration resistance curve, air-filled porosity and bulk density (Bd) were measured. The range of LLWR variation was limited by volumetric water content at field capacity and penetration resistance. Values of LLWR varied from 0.00 - 0.14 m^3 m^{-3} to Alfisol and 0.00 - 0.04 m^3 m^{-3} to Oxisol. The critical values of the Bd and DC for crop development were 1.79 Mg m^{-3} and 1.35 Mg m^{-3} and 96% and 74% to Alfisol and Oxisol, respectively. Further researches relating LLWR, DC and crop response are still required in soils with different conditions and management.

KEYWORDS: Soil quality. Bulk density. Soil strength. Porosity.

INTRODUCTION

Soil quality has been influenced by indicators that reflect the environmental sustainable and management practice. The understanding and quantification of the impact caused by soil management on the soil physical quality are fundamental for the development of sustainable agricultural systems.

The structural quality has been evaluated by different soil parameters. Soil physical attributes associate to soil water potential, soil oxygen, and soil strength, directly affect plant growth (LETEY, 1985). The single parameter that describes the range of soil water content in which limitations to plant growth associated with matric pressure, aeration, porosity and mechanical resistance was defined as non limiting water range, by Letey (1985) and improved by Silva et al. (1994). It represents the interval of soil water content in wich limitations to crops development will occur. The least limiting water range (LLWR) indicate the range of soil water content with upper limit defined by field capacity or aeration and lower limit defined by permanent wilt point or penetration resistance is limiting (KAY et al., 1997).

The LLWR has been proposed as an index of soil structural quality and has been utilized in estimate of others soil attributes associated to plant growth (MEDEIROS et al., 2011; GUIMARÃES et al., 2013, GUBIANI et al., 2013; GUEDES FILHO et al. 2013).

In Brazil, Tormena et al. (1998) conducted the first study of LLWR in Oxisol. Other studies has been realized to modifies the conventional system of water management utilized (VERMA; SHARMA, 2008; FREDDI et al., 2009), with decrease of costs in the irrigated areas. In non irrigated systems, the LLWR also has been a basic indicator of management system and crop development with positive impact on structural quality and agricultural productivity (LIMA et al., 2009; LIMA et al., 2012).

The compaction has reduced the LLWR by usually alters the pore size distribution of the bulk soil with a decline of macroporosity and an increase of microporosity, and is reflected by an increase in soil bulk density and soil strength (CHEN et al., 2014).

Thus associated to the LLWR, the degree of compactness or relative compaction (REICHERT et al., 2009) have been sensitive parameters for quantification and prediction of soil physical attributes and quantification of soil structural quality.

The degree of compactness is defined by relationship between bulk density in the field and reference bulk density at static and normal load of 200 kPa (HÄKANSSON, 1990; SILVA et al., 1997) and 1.600 kPa (REICHERT et al., 2009) or others amount of impacting energy utilizing disturbed or undisturbed soil samples. Reichert et al. (2009) were

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postulated the efficiency of this parameter associate with evaluations of penetration resistance, hydraulic conductivity, porosity and development crops in an Alfisol and Oxisol under no-till.

The knowledge of the critical values related with LLWR and DC or soil compression parameters would help obtain decisions about adequate soil management and consequently improvements in soil quality for crop growth and yield.

Further studies are needed to estimate the degree degradation of soil structure and to guide adequate practices of soil and water management. However, is necessary to indicate subsidies to contribute to knowledge of physical quality and development crops. The main of this study was quantified the least limiting water range, degree compactness and indicated restrictive values for development crops in representative soils of Rio Grande do Sul state (Alfisol and Oxisol) under no-till management.

MATERIAL AND METHODS

This study was established in two experimental areas with different compaction levels. The first one about 504 m^2 belongs to Department of Soils, Federal University of Santa Maria Brazil (29^o 45' S; 53^o 42'' W; 95 m). The soil is classified as an Alfisol (NRCS, 2010), with particle-size distribution consisting of 81 g kg^{-1} clay, 291 g kg^{-1} silt and 628 g kg^{-1} clay (sandy loam texture). The study was perfomed using 36 plots (7 x 6 m) in different levels of soil compaction under no-till system during fifteen years with crop rotation of soybean and bean in summer and oats and wheat in winter.

Undisturbed samples (0.076 m diameter, 0.076 m, length) were taken from the layer 0.00 - 0.20 m depth. The samples were divided into eight groups, saturated with water and equilibrated on pressure plates (KLUTE, 1986) and tension tables (TOPP; ZEBCHUK, 1979) at matric pressures: - 0.001; -0.004; -0.006; -0.033; -0.07 and -0.1 MPa. In the laboratory, for a period of seven and nine days, for the obtaining of lower soil water content, two groups of soil samples were maintained in to perforated boxes for releasing water.

During seventeen days, the volumetric water content at field capacity was measured in area about 1 m^2 obtaining constant value of 0.14 g kg^{-1} in the layer 0.00 – 0.20 m. The permanent wilt point was evaluated into pots with soybean, soy and sunflower development by Collares et al. (2006) in the layer 0.00 – 0.20 m depth. In this study, the permanent wilt point obtained was of 0.051 g kg^{-1}.

The second study was in an area about 2.500 m^2 established in experimental area of University of Cruz Alta, Brazil (28° 33' 35"S; 53° 37' 19"W, 450 m). The soil is classified as Oxisol (NRCS, 2010), with particle-size distribution consisting of 607 g kg^{-1} clay, 176 g kg^{-1} silt and 217 g kg^{-1} clay (clay texture). The study was perfomed using 9 plots (16.67 x 16.67 m) cultivated under no-till system in different levels of soil compaction during six years with soy in the summer and oats and wheat in winter.

Undisturbed samples (0.076 m, diameter, 0.076 m, length) were taken from the layer 0.00 - 0.20 m depth. The soil samples were divided into eight groups, saturated with water and equilibrated on pressure plates (KLUTE, 1986) and tension tables (TOPP; ZEBCHUK, 1979) at matric pressures: - 0.001; -0.004; -0.006; -0.01; -0.033; - 0.07 and -0.12 MPa. In this study, for volumetric water content at field capacity (θcc), was adopted a matric potential of - 0.033 MPa and volumetric water content at permanent wilt point (θ_{PMP}) was utilized a matric potential of -1.5 MPa.

The soil water release data for two experimental areas were fitted using a function employed by Ross et al. (1991) and soil resistance data were regressed against volumetric water content (θ) and bulk density (Db) using model proposed by Busscher (1990).

The resistance to soil penetration was measured using an electronic penetrometer with a cone of 12.83 mm diameter and semi angle of 30^0 to constant rate of penetration.

The LLWR was determined for each core by the method of Leão; Silva (2004). Critical values for crop growth associated with soil resistance and air porosity were selected from the literature, i.e., soil resistance at 2 MPa (TAYLOR et al., 1966) and air-filled porosity at 10% (GRABLE; SIEMER, 1968).

The relative compaction or degree compaction (DC) was evaluated with undisturbed soil samples. This soil samples (0.025 m diameter, 0.061 m, length) were taken of layer 0.08 - 0.13 m depth. After the saturation, the soil samples were equilibrated on pressure plate at matric pressure of - 0,033 MPa and conducted to uniaxial soil compression test using S-450 Terraload consolidometer. This test was established using pressures of 12.5; 25; 50; 100; 200; 400; 800 e 1.600 kPa. Each pressure was applied to five minutes following the procedure described by Silva et al. (2000). The relative compaction was calculated using the following equation:

$$DC = \frac{Bd}{Bdref} \times 100$$

where: Bd is the bulk density (Mg m^{-3}) determined in the field for each core by method of Blake; Hartge (1986) and Bdref is the reference bulk density calculated according to Suzuki et al. (2007) obtained in the laboratory with static load of 1.600 kPa.

The results were evaluated using the software Statistical Analysis System (SAS INSTITUTE, INC., 1991) and $P < 0.05$ probability level.

RESULTS AND DISCUSSION

The amplitude of variation of penetration resistance (PR) and least limiting water range (LLWR) was associated with variation of soil water content (Table 1). Differences of RP variation were due to the variations in bulk density (Bd) and θv values. Similar Bd (1.15 Mg m^{-3}) and penetration resistance (PR) (1.43 MPa) values of an Oxisol with similar characteristics under no-till have been postulated by Tormena et al. (1999c).

Table 1. Bulk density (Bd, Mg m^{-3}), soil volumetric water content (θv, m^3 m^{-3}), penetration resistance (PR, MPa), least limiting water range (LLWR, m^3 m^{-3}) and degree of compactness (DC, %) of an Alfisol and Oxisol under no-till system at a depth 0.00 – 0.20 m.

Variables	Mean	Minimum	Maximum	CV, %
		Alfisol		
Bd	1.60	1.28	1.86	6.56
θv	0.19	0.09	0.38	35.14
PR	1.50	0.00	4.78	61.05
LLWR	0.08	0.00	0.14	48.51
DC	85.84	68.64	99.38	6.55
		Oxisol		
Bd	1.27	1.17	1.41	4.58
θv	0.34	0.28	0.45	11.91
PR	1.50	0.40	3.39	50.14
LLWR	0.02	0.00	0.04	66.49
DC	70.37	64.33	78.38	5.59

CV: coefficient of variation.

The fitted models (Table 2) explained 91% and 72%, of volumetric water content (θv) and PR variability, respectively to Alfisol and 85% and 91%, of θv and PR variation to Oxisol respectively. The adjusted parameters were demonstrated positive relationship between PR and Bd and negatively with θv, according to Tormena et al. (1999c).

The positive value of coefficient f (Table 2) indicated that water retention increased with Bd. Similar results were observed by Beltz et al. (1998) and Tormena et al. (1999b). According to these researchers, the Bd was influenced by soil water retention and soil porous size distribution.

In the Alfisol, the lowest variation of Bd was observed in field capacity (FC) and permanent wilt point (PWP) (Figure 1a). In the Oxisol, the FC and permanent PWP were positively related with Bd, i.e., the Bd was influenced by water retention similarly to Tormena et al. (1999a).

An increase in Bd was related with a decrease of aeration porosity (AFP) and increase in penetration resistance (PR) (Figures 1a and 2a) as results presented by Tormena et al. (1999c).

The AFP and PR were more influenced by Bd than limitations related by matric potential. It indicated that LLWR was more sensible the alterations of soil structural quality than the soil water availability as suggested by Silva et al. (1994) and Tormena et al. (1999b). Tormena et al. (1999c); Beutler et al. (2004) and Medeiros et al. (2011) postulated that PR is a parameter that more influenced the LLWR of soil under conventional and no-till system.

By relationship between LLWR and Bd was indicated the value when LLWR is null, (Bd_{LLWR}=0) (Figures 1b and 2b). The $Bd_{LLWR} = 0$ is defined as critical bulk density, when upper and lower limits are equal (MOREIRA, et al., 2014b) in which limitations for crop development associated the physical quality may occurred (SILVA; KAY, 1997; HÄKANSSON; 2000)

The functional relationship between LLWR and Bd had a similar effect by the soils studied. The

LLWR was negatively related with higher Bd than about 1.40 Mg m^{-3} and 1.12 Mg for Alfisol and Oxisol, respectively (Figures 1b and 2b).

Significant differences no were presented in soils studied. Similar critical Bd was observed in soils under no-till with different compaction levels by Klein; Camara (2007) and Tormena et al. (2007).

Soil texture probably was related with critical bulk density values to crop development. The Alfisol presented critical Bd of 1.79 Mg m^{-3} that agrees with values postulated by Lima et al. (2007) (1.44 – 1.76 Mg m^{-3}). Furthermore, observed that critical Bd for Oxisol was of 1.35 Mg m^{-3}. Considering the average Bd values (Table 1) and the critical Bd values obtained (Figures 1b and 2b), no observed critical values for plant growth in this soil. The LLWR in both soils was limited by field capacity water content (upper limit) corroborate with Klein; Libardi (2000) and penetration resistance (lower limit) (Figures 1a and 2a) similarly observed by Tormena et al. (1998), Cavalieri et al. (2006) and Freddi et al. (2007).

The Alfisol presented the highest amplitude of LLWR (0.00 – 0.14 m^3 m^{-3}) and higher value of critical bulk density in relationship to Oxisol (Figures 1a and 2a).

Although more influenced by water content, soils of fine texture have lowest LLWR when compared with soils of coarse texture (DRURY et al., 2003). This means that the Alfisol, in this study, may have higher resistance the external factors and compaction and in turn presented increase in the plant yield (ZOU et al., 2000). Letey (1985) indicated lowest LLWR by soils that requiring more care for maintenance of adequate environment for plant growth.

The critical degree of compactness (DC) for crops development obtained by LLWR for Alfisol and Oxisol were respectively 96% and 74% (Figures 1d and 2d). Similar value (DC=0.93) was obtained by Suzuki et al. (2007), considering PR = 2 MPa.

Carter (1990) related the DC with relative productivity of cereals and indicated that the productivity was reduced to DC=0.90. Twerdoff et al. (1999) were indicated DC=0.90 (corresponding to a volume 10% macropores) as a critical value for crops growth.

Table 2. Results of the multiple regression analysis of the soil volumetric water content release curve (a, b, c) and soil penetration resistance curve (d, e , f) by models of Ross et al. (1991) and Busscher (1990), respectively of an Alfisol and Oxisol under no-till system at a depth 0.00 – 0.20 m.

Parâmetros	Adjusted value	Standard Error	Confidence interval	
			Limite inferior	Limite superior
		Alfisol		
		θv		
a	-1.932	0.082	-2.093	-1.771
b	-0.282	0.051	-0.383	-0.182
c	-0.182	0.003	-0.188	-0.176
		PR		
d	0.012	0.002	0.0079	0.017
e	-1.317	0.057	-1.429	-1.205
f	5.111	0.249	4.620	5.602
		Oxisol		
		θv		
a	-2.1369	0.1583	-2.4559	-1.8179
b	0.6199	0.1197	0.3786	0.8612
c	-0.0680	0.00417	-0.0764	-0.0596
		PR		
d	0.00365	0.00134	0.000943	0.00635
e	-3.8700	0.2847	-4.4439	-3.2961
f	7.2848	0.4029	6.4728	8.0968

θv: soil volumetric water content; PR: penetration resistance.

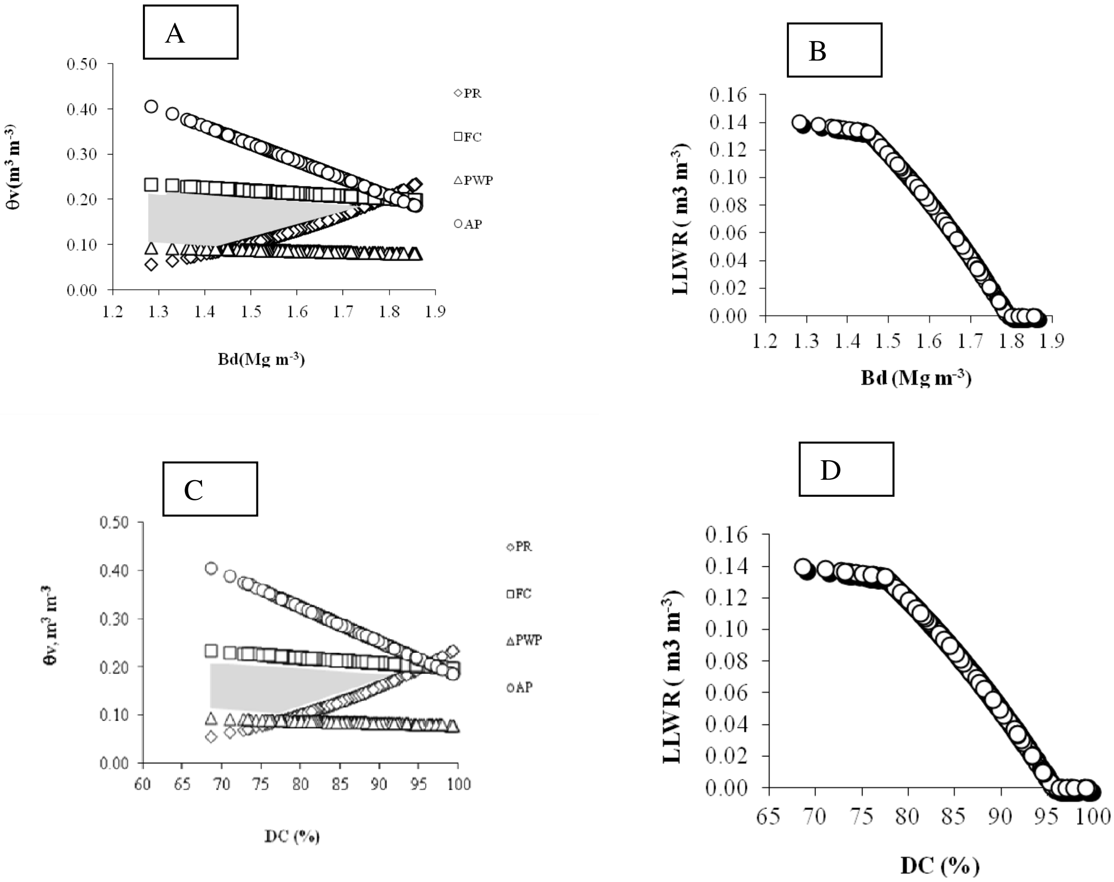

Figure 1. Soil water content variation (θv) with bulk density (Bd) (A) and with degree compactness (DC) (C) at critical levels of field capacity (0.01 MPa, FC), at permanent wilting point (1.5 MPa, PWP), at air filled porosity of 10% (AP) and at penetration resistance (PR) of 2 MPa and variation of least limiting water range (LLWR) with Bd (B) and with DC (D) in an Alfisol under no-till at a depth 0.00 – 0.20 m. The shaded area represents the LLWR.

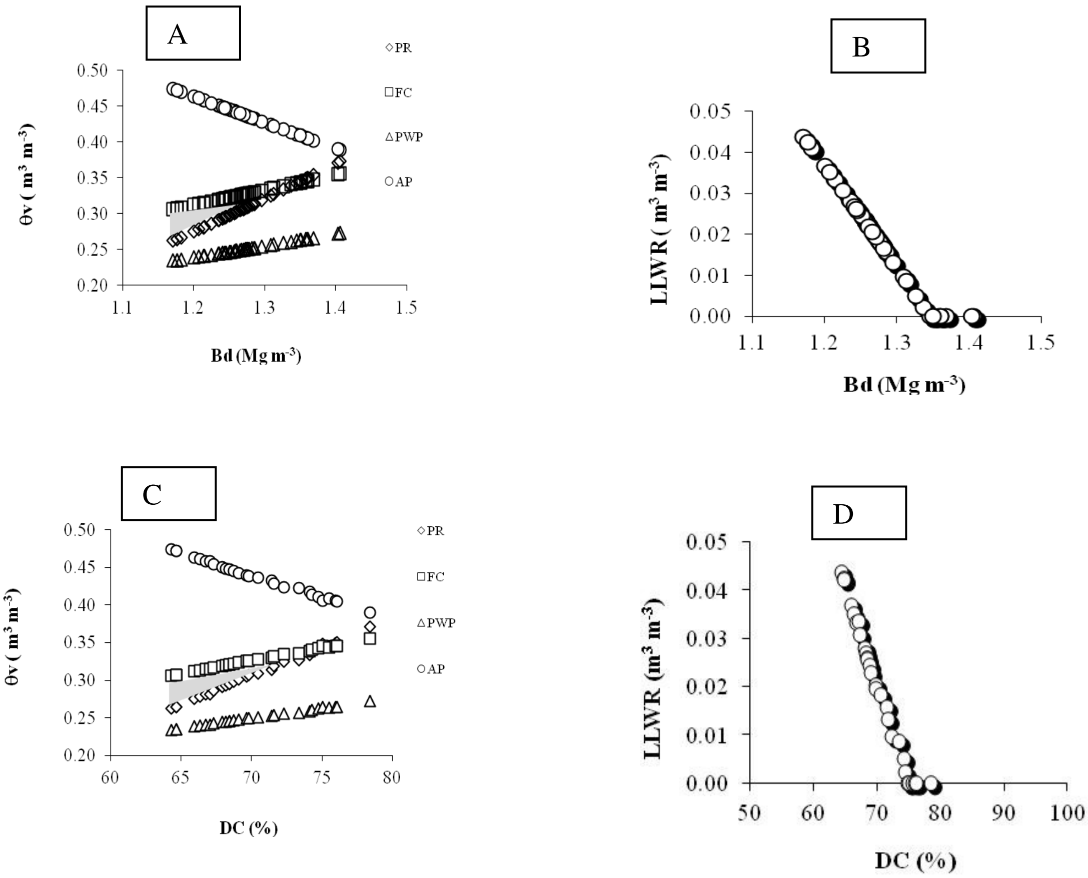

Figure 2. Soil water content variation (θv) with bulk density (Bd) (A) and with degree compactness (DC) (C) at critical levels of field capacity (0.01 MPa, FC), at permanent wilting point (1.5 MPa, PWP), at air filled porosity if 10% (AP) and at penetration resistance (PR) of 2 MPa and variation of least limiting water range (LLWR) with Bd (B) and with DC (D) in an Oxisol under no-till system at a depth 0.00 – 0.20 m. The shaded area represents the LLWR.

The establishment for limiting values has complexity resulting for soil, climate and crop interactions. There are still doubts in evaluations of the water availability for crops of the air filled porosity and PR values for adequate root development (ABERCROMBIE; PLESSIS, 1995). Nevertheless the LLWR can be used satisfactorily for indicated critical values for plants development (KAY, 1990) associated to parameters of soil compressibility and the air filled porosity of soils (KELLER et al., 2011).

The use of LLWR to determine points at which it is higher than critical bulk density aids decision making for intervention or modification of soil tillage while the selection criterion of the critical value of penetration resistance can contribute to the interpretation of field results (MOREIRA et al., 2014a).

However, other soil parameters should be considered in future studies for better understanding the behavior of LLWR associated with the compressibility in other agricultural soils.

CONCLUSIONS

The amplitude of the variation of least limiting water range was limited by field capacity water content and penetration resistance values. The interval of least limiting water range was 0.00 - 0.14 $m^3\ m^{-3}$ to Alfisol and 0.00 - 0.04 $m^3\ m^{-3}$ to Oxisol.

The critical bulk density values were 1.79 and 1.35 Mg m^{-3} to Alfisol and Oxisol, respectively. The critical degree of compactness values of crop development were 96% and 74% to Alfisol and Oxisol, respectively.

RESUMO: O intervalo hídrico ótimo (IHO) e o grau de compactação (GC) são indicadores úteis da qualidade física do solo e produção de culturas. Objetivou-se avaliar o IHO, o GC e valores críticos do crescimento de plantas de um Argissolo e Latossolo sob semeadura direta. Amostras indeformadas de solo foram coletadas na camada de 0,00 a 0,20 m. Avaliou-se a curva de retenção de água e de resistência à penetração, a porosidade de aeração e a densidade do solo (Ds). A amplitude de variação do IHO foi limitada pela umidade na capacidade de campo e pela resistência à penetração com valores de 0,00 a 0,14 e de 0,00 a 0,04 e m^3 m^{-3} para o Argissolo e Latossolo, respectivamente. Os valores críticos ao desenvolvimento de plantas de Ds e GC foram 1,79 e 1,35 Mg m^{-3} e 96% e 74%, respectivos para o Argissolo e Latossolo. Pesquisas futuras relacionando IHO, GC e resposta das culturas são ainda necessárias em solos com condições e manejos diferenciados.

PALAVRAS- CHAVE: Qualidade do solo. Densidade do solo. Resistência à penetração. Porosidade do solo.

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