SEÇÃO VI - MANEJO E CONSERVAÇÃO DO SOLO E DA ÁGUA

PHYSICAL QUALITY OF AN OXISOL CULTIVATED WITH MAIZE SUBMITED TO COVER CROPS IN THE PRE-CROPPING PERIOD[1]

Fabiana de Souza Pereira[2], Itamar Andrioli[3], Amauri Nelson Beutler[4], Cinara Xavier de Almeida[2] & Faber de Souza Pereira[5]

SUMMARY

The intensive use of land alters the distribution of the pore size which imparts consequences on the soil physical quality. The Least Limiting Water Range (LLWR) allows for the visualization of the effects of management systems upon either the improvement or the degradation of the soil physical quality. The objective of this study was to evaluate the physical quality of a Red Latosol (Oxisol) submited to cover crops in the period prior to the maize crop in a no-tillage and conventional tillage system, using porosity, soil bulk density and the LLWR as attributes. The treatments were: conventional tillage (CT) and a no-tillage system with the following cover crops: sunn hemp (*Crotalaria juncea* L.) (NS), pearl millet (*Pennisetum americanum* (L.) Leeke) (NP) and lablab (*Dolichos lablab* L.) (NL). The experimental design was randomized blocks in subdivided plots with six replications, with the plots being constituted by the treatments and the subplots by the layers analyzed. The no-tillage systems showed higher total porosity and soil organic matter at the 0–0.5 m layer for the CT. The CT did not differ from the NL or NS in relation to macroporosity. The NP showed the greater porosity, while CT and NS presented lower soil bulk density. No ≤ 10 % airing porosity was found for the treatments evaluated, and value for water content where soil aeration is critical (θ_{PA}) was found above estimated water content at field capacity (θ_{FC}) for all densities. Critical soil bulk density was of 1.36 and 1.43 Mg m^{-3} for NP and CT, respectively. The LLWR in the no-tillage systems was limited in the upper part by the θ_{FC}, and in the bottom part, by the water content from which soil resistance to penetration is limiting (θ_{PR}). By means of LLWR it was observed that the soil presented good physical quality.

Index terms: management systems; physical attributes; least limiting water range.

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[2] Doutoranda do Departamento de Solos e Adubos da Faculdade de Ciências Agrárias e Veterinárias, Universidade Estadual Paulista – FCAV/UNESP. Via de Acesso Professor Paulo Donato Castellane s/n, CEP 14884-900 Jaboticabal (SP). E-mail: fabianadsp@hotmail.com

[3] Professor Adjunto do Departamento de Solos e Adubos, FCAV/UNESP. E-mail: itamar@fcav.unesp.br

[4] Professor Adjunto da Universidade Federal do Pampa – Unipampa. Rua Luiz Joaquim de Sá Brito s/n, CEP 97650-000 Itaqui (RS). E-mail: amauribeutler@unipampa.edu.br

[5] Engenheiro Agrônomo, Universidade Estadual de Goiás – UEG. Unidade Universitária de Ipameri. Rod. GO-330, km 241 - Anel Viário s/n, CEP 75780-000 Ipameri (GO). E-mail: faberfla@hotmail.com

RESUMO: *QUALIDADE FÍSICA DE UM LATOSSOLO VERMELHO CULTIVADO COM MILHO SUBMETIDO A CULTURAS DE PLANTAS DE COBERTURA EM PRÉ-SAFRA*

*O uso intensivo do solo modifica a distribuição do tamanho de poros, com reflexos na qualidade física do solo. O intervalo hídrico ótimo (IHO) permite visualizar os efeitos dos sistemas de manejo na melhoria ou na degradação da qualidade física do solo. Objetivou-se, com este estudo, avaliar a qualidade física de um Latossolo Vermelho submetido a culturas de plantas de cobertura em pré-safra ao milho, em sistema de semeadura direta e em sistema convencional, utilizando como atributos a porosidade, a densidade do solo e o IHO. Os tratamentos foram: plantio convencional (PC) e sistema de semeadura direta com as seguintes plantas de cobertura: crotalária (*Crotalaria juncea *L.) (SC), milheto (*Pennisetum americanum *(L.) Leeke) (SM) e lab lab (*Dolichos lablab *L.) (SL). O delineamento experimental foi o de blocos casualizados em parcelas subdivididas, com seis repetições, sendo as parcelas constituídas pelos tratamentos e as subparcelas pelas camadas analisadas. O cultivo do solo em sistema de semeadura direta apresentou maior valor de porosidade total e conteúdo de matéria orgânica na camada de 0–0,05 m em relação ao PC. Este não diferiu do SL e do SC quanto à macroporosidade. O SM apresentou maior microporosidade. O PC e o SC apresentaram menor densidade do solo. Não houve porosidade de aeração ≤ 10 % nos tratamentos avaliados, e o valor do conteúdo de água no solo em que a porosidade de aeração é crítica (θ_{PA}) manteve-se acima do conteúdo de água estimado na capacidade de campo (θ_{CC}), para todas as densidades. A densidade do solo crítica foi de 1,36 e 1,43 Mg m^{-3} para SM e PC, respectivamente. Os IHOs nos sistemas de semeadura direta foram limitados na parte superior pelo θ_{CC} e, na parte inferior, pelos valores de conteúdo de água em que a resistência do solo à penetração atinge valores críticos (θ_{RP}). Verificou-se por meio do IHO que o solo apresentou boa qualidade física.*

Termos de indexação: sistemas de manejo, atributos físicos, intervalo hídrico ótimo.

INTRODUCTION

The adoption of adequate systems for the use and management of agricultural soils is essential for their conservation, contributing to an increase in crop yield, as well as preserving the environment.

Among the management systems used in the cultivation of annual crops, the no-tillage system grows year by year and has been consolidated as a model for economically sustainable agriculture. In the agricultural, no-tillage has been one of the best alternatives for natural resources sustainability maintenance in the use of soils (Oliveira et al., 2002).

However, northern and northeastern of São Paulo State, as well as the Cerrado (tropical savanna), involving other States, present dry winter, which places some endangerment to the top-soil planting aimed at the production of phytomass as well as the improvement of the soil attributes, the way it has been successfully performed in the south of the country. According to Andrioli (2004), one of the alternatives is the planting of cover crops at the beginning of spring, taking advantage of the first rains and part of the summer, prior to the planting of the commercial crops. In addition to these benefits, cover crops grown in the pre-cropping time can provide N and make for an increase in the maize yield, as seen by Bertin et al. (2005). Nevertheless, there is the need to refine studies regarding the use of cover crops in the pre-cropping period under the conditions of a tropical climate with a hot and rainy summer and dry winter.

Growth of the root system and the above ground part of the plants is influenced by various physical attributes of the soil and by the complex interaction which involves soil water potential, O_2 content and soil resistance to root penetration (Tormena et al., 1998), thus being factors which create difficulties in obtaining the critical values for crop development and yield (Beutler et al., 2004a).

In the State of São Paulo, with the use of the cover crops pearl millet, pigeon pea, velvet bean, sunn hemp and brachiaria grass, prior to the corn crop, alterations in the values of bulk density were not observed compared to the no-tillage system after laying fallow (Pelá, 2002). Cruz et al. (2003) observed that conventional tillage presented greater macroporosity than the conservationist systems. Silva et al. (2008) showed that the period of six years of adoption of the no-tillage system was not sufficient to alter some physical attributes and the organic matter content of a clay Oxisol.

Adding to the physical attributes used for monitoring the physical quality of the soil, the Least Limiting Water Range (LLWR) has been suggested. According to Letey (1985), the growth of the plants is directly related to four physical factors: water, airing, the soil resistance to penetration and temperature. Based on this, Silva et al. (1994) improved the LLWR, which came to be part of the three first attributes for the soil bulk density. The LLWR is so defined as the range of water content in which the limitations to the plants due to water, soil resistance to penetration and airing are minimal. The LLWR has been evaluated in a number of works as the proper index for the assessment of the physical quality of the soil, and many researches highlight its importance for the decision making on soil management (Tormena et al., 1999; Beutler et al., 2004a; Freddi et al., 2007).

Soil resistance to penetration is one of the physical attributes to be taken into account in the modeling of LLWR, whose value of 2.0 MPa, commonly used, has been questioned as a limiting value to the growth of the roots as well as the aerial part for different cultures, management systems and soil classes, suggesting the need for more studies that relate the LLWR with crop production in Brazilian tropical soils (Beutler et al., 2004a). According to Silva et al. (1994) and Beutler (2003), the asserting of a limiting soil resistance to penetration for each culture and its insertion in the LLWR would increase its exactness for monitoring of soil physical quality.

Cavalieri et al. (2006) have observed that soil, under different tillage systems, presented different values in relation to LLWR. Tormena et al. (1998), Beutler et al. (2004a) and Freddi et al. (2007) verified that in tropical soils, the LLWR was limited in the upper part by water content at field capacity, and in the lower part by soil resistance to penetration.

According to Camargo & Alleoni (1997), values of soil bulk density greater than 1.55 Mg m^{-3} are considered critical for clay loam soils. Archer & Smith (1972) and Silva et al. (1994) observed that with the increase of density, aeration porosity is reduced. Nevertheless, studies that evaluate the physical quality of the soil, by means of LLWR, in management systems with the use of cover crops are rare, although they are highly useful, since soil coverage promotes the consolidation and sustainability of the no-tillage system for annual crops.

The objective of this study was to evaluate the soil physical quality, using as attributes the porosity, soil bulk density and the LLWR in a Red Latosol (Oxisol), after eleven years of cultivation of cover crops prior to the maize crop in the no-tillage system and in the conventional tillage system.

MATERIAL AND METHODS

The study took place in the city of Jaboticabal-SP (21 ° 15 ' S and 48 ° 18 ' W; 595 m altitude), in an area having an eleven-year period of different soil management systems. The climate is type Cwa, according to Köppen classification, with moderate temperatures (mean 22.4 °C), hot and rainy summer, and annual mean rainfall of 1,285 mm.

The experimental area is represented by a Red Latosol (Oxisol) with medium texture (Embrapa, 2006). The grain-size composition was determined in samples deformed by means of dispersion with NaOH (0.1 mol L^{-1}) and slow vibration for 16 h, being the clay content obtained by pipette means (Gee & Bauder, 1986). The 0–0.20 m layer contained 642 g kg^{-1} sand, 48 g kg^{-1} silt and 310 g kg^{-1} clay.

The experimental design was of random plots of 4.5 m wide and 20 m long, which underwent four treatments and six replications in split plots, the latter formed by the analyzed layers.

The experimental area had been cultivated since 1995 under conventional tillage and no-tillage as well as coverage plants at the pre-harvest (September through December). The annual cultures were maize, during the years 1995 to 1997; soy, between 1998 and 2000, and maize, from 2001 to 2007. Since the year 2001, the area has been cultivated with maize in the no-tillage at the following pre-harvest coverage planting: sunn hemp (*Crotalaria juncea* L.) (NS), pearl millet (*Pennisetum americanum* (L.) Leeke) (NP), lablab (*Dolichos lablab* L.) (NL) and conventional tillage (one disk ploughing and two leverers) (CT).

The tillage of the coverage plants was performed at the beginning of the first rainfalls up to the second fortnight of September, carried out by means of no-tillage using a furrower, at 0.45 m between lines, with 20, 30 and 50 kg ha^{-1} of pearl millet, lablab and sunn hemp seeds, respectively. In the beginning of December, desiccation was performed using glyphosate herbicide (2.4 kg ha^{-1} of i.a.), followed by maize planting both by no-tillage and conventional tillage.

Soil samples, for determination of physical attributes, were collected during the first fortnight of March 2007, approximately three months after maize tillage, in two replications of six non-deformed samples of soil, by means of cylinders with volumetric rings of 0.03 m high and 0.048 m diameter, at layers 0.0–0.05; 0.05–0.10; 0.10–0.15 and 0.15–0.20 m, a total of 48 samples per treatment. The samples were saturated and submitted to tensions of 0.006; 0.01; 0.033; 0.06; 0.1 and 0.3 MPa, in Richards cameras (Klute, 1986). When balance was reached, they were weighed, and the soil resistance to penetration (PR) was determined in two replications for each sample, coming to a total of 100 readings per replication, used for obtaining the mean PR. The PR in each tension was determined by using a static electronic penetrometer, at a penetration constant speed of 0.01 m min^{-1}, equipped with a linear actuator and load cell of 20 kg, coupled to a microcomputer for data input, as described by Tormena et al. (1998).

Following, the samples undisturbed by the PR were stove-dried at 105 °C for 24 h, for determination of both water content and soil bulk density in each tension (Blake & Hartge, 1986). Microporosity was determined by drying at a 0.01 MPa tension; in Richards pressure chambers with a porous plate (Klute, 1986); total porosity, according to Danielson & Sutherland (1986), as well as the macroporosity, were obtained from the difference between the total porosity and the microporosity.

Deformed samples, at the same layers, were also collected for determining of the soil organic matter, according to method described by Raij et al. (1987).

For the finding of the LLWR, the curve of water retention was adjusted, using the non-linear model described by Silva et al. (1994), in log-transformed way, as follows:

$$\ln\theta = \ln a + b \ln Db = c \ln\psi \quad (1)$$

where θ is the volumetric water content ($m^3\ m^{-3}$); Db is the soil bulk density ($Mg\ m^{-3}$); ψ is the water tension in the soil (hPa), and a, b, c, are the coefficients found by means of the model adjustment.

The soil penetration resistance curve was adjusted using the non-linear model proposed by Busscher (1990) in the log-transformed form which follows:

$$\ln PR = \ln d + e \ln\theta + f \ln Db \quad (2)$$

in which PR is the soil resistance to penetration, d, e, and f are coefficients obtained by means of the model adjustment.

From the estimated values of the parameters, the anti-logarithm was applied, and the estimated values of the physical attributes were obtained. Thus, assuming the content of water in the field capacity being equivalent to a 100 hPa tension and the permanent wilting point being at 15,000 hPa, the θ_{FC} and θ_{PWP} were estimated by the equations 3 and 4, respectively, derived from equation (1):

$$\theta_{FC} = \exp^a * Db^b * 100^c \quad (3)$$

$$\theta_{PWP} = \exp^a * Db^b * 15000^c \quad (4)$$

The water content, from which PR is limiting, was obtained by means of equation 5, from equation (2):

$$\theta_{PR} = (PR_{crít} / (\exp^d * (Db^e))^{1/f} \quad (5)$$

Water content, of which the airing porosity is equal to 10 %, was calculated by the following equation 6:

$$\theta_{PA} = 1 (Db/Dp)) - 0.1 \quad (6)$$

Adjustments of curve models of soil water retention and soil resistance to penetration were found by means of statistical software SAS (SAS, 1999).

RESULTS AND DISCUSSION

The no-tillage system with cultivation of sunn hemp (NS), millet (NP) and lablab (NL), prior to maize cropping, presented a greater value of organic matter in the layer from 0–0.05 m, not differing among themselves (Table 1). According to Sousa Neto et al. (2008), less soil turnover in the no-tillage system reduced soil contact with the plant residues, thus diminishing the speed of decomposition when compared to the CT, in which there is soil turnover, fragmentation, incorporation and exposure of plant remains to more intense activity of the microorganisms that act in their decomposition. Albuquerque et al. (2005) verified in a highly clayey Oxisol that the utilization of cover crops resulted in an increase in the soil organic matter content. According to the authors, over longer periods, the cover crops associated with conservationist management forms, through the increase of organic matter, can improve the physical characteristics of the soil.

The treatments differed in regard to macroporosity only in the layer from 0–0.05 m. The greatest values

Table 1. Soil organic matter assessed at management systems and layers of a Red Latosol (Oxisol)

Soil layer	CT	NS	NP	NL	Mean
m			Organic matter, g dm^{-3}		
0–0.05	16.33 Ba	22.50 Aa	24.16 Aa	22.66 Aa	21.41
0.05–0.10	15.33 Ab	15.83 Ab	16.16 Ab	15.16 Ab	15.62
0.10–0.15	13.83 Abc	14.33 Abc	14.66 Abc	13.83 Ab	14.16
0.15–0.20	12.83 Ac	13.50 Ac	13.00 Ac	13.50 Ab	13.20
Mean	14.58	16.54	17.00	16.29	
	CV (%) plot: 13.51			CV (%) subplot : 8.16	

CT: conventional tillage; NS: sunn hemp no-tillage; NP: pearl millet no-tillage; NL: lablab no-tillage. Means followed by the same letter have no statiscal difference by Tukey test ($p < 0.05$). Capital letters compare the means in lines, and small letters, in columns.

were seen in the NL and in CT, which did not differ from the NS (Table 2). High values of macroporosity in the CT are related to greater mobilization in the surface layer. Nevertheless, in the other layers, the treatments did not differ, because, according to Klein (2008), the organic matter, together with the oxides and hydroxides, act as cementing agents, both of the primary soil particles and the secondary particles, thus increasing their aggregation and structuring.

The NL presented lower macroporosity in the lower layers in relation to the layer from 0–0.05 m. However, the NP did not present differences among the layers, and the NS presented a difference only in the layer from 0–0.05 m. In spite of the greater organic matter content of the no-tillage system, in the layer from 0–0.05 m, this did not result in an improvement in macroporosity, except for the NL.

The CT presented greater macroporosity in the two first layers (0–0.05 and 0.05–0.10 m). According to Cruz et al. (2003), this fact is probably due to the soil tillage operations. Schäfer et al. (2001) observed that the use of heavy disking resulted in apparent reduction of macroporosity and in an increase of densification at the soil surface, giving evidence of a "hardpan".

Microporosity was greater in the NP in relation to the other treatments in the layer from 0–0.05 m and contributed to this system presenting the lowest value of macroporosity in this layer. The CT presented a significant increase of microporosity in the layer from 0–0.05 m in relation to the layer from 0.15–0.20 m. The NS and the NP presented reduction of microporosity by 10 and 24 %, respectively, among these layers.

Total porosity was greater in the no-tillage system, such that with increasing depth its values were reduced in these treatments. According to Spera et al. (2004), the greater value for total porosity in the surface layer reflects lower bulk density.

There was no significant interaction between the management systems and the layers analyzed in relation to soil bulk density (Table 3). The CT presented the lowest value of soil bulk density in relation to the no-tillage systems, not differing from the NS. The lower values of bulk density may be attributed to the intense soil tillage and to the incorporation of crop residues. Centurion & Demattê (1985) also observed a greater value of bulk density in the no-tillage system compared to other tillage systems. Among the management systems studied, the layer from 0-0.05 m was that which presented the lowest bulk density, with the layer from 0.05–0.10 m not differing from the layer from 0.15–0.20 m.

In figure 1 is presented the estimated least limiting water range (LLWR) for the management systems. In all the treatments, to the extent that there is an increase in soil bulk density, there is a simultaneous increase in water retention at the tension of 0.01 MPa, and in lower intensity at the tension of 1.5 MPa, as

Table 2. Soil total porosity, macro- and microporosity in the management systems for layer 0–0.20 m

Soil layer	CT	NS	NP	NL	Mean
m			$m^3 m^{-3}$		
			Macroporosity		
0.0 –0.05	0.15 ABa	0.12 BCab	0.10 Ca	0.18 Aa	0.14
0.05 –0.10	0.14 Aa	0.15 Aa	0.14 Aa	0.12 Ab	0.14
0.10 –0.15	0.09 Ab	0.11 Ab	0.10 Aa	0.08 Ab	0.09
0.15 –0.20	0.09 Ab	0.13 Aab	0.12 Aa	0.11 Ab	0.11
Mean	0.12	0.13	0.11	0.12	
	CV (%) plot: 15.88			CV (%) subplot : 22.3	
			Microporosity		
0.0 –0.05	0.25 Cb	0.30 Ba	0.33 Aa	0.27 Cb	0.29
0.05 –0.10	0.25 Ab	0.26 Ab	0.25 Ac	0.26 Ab	0.25
0.10 –0.15	0.30 Aa	0.30 Aa	0.30 Ab	0.29 Aa	0.30
0.15 –0.20	0.28 Aa	0.27 ABb	0.25 Bc	0.27 ABb	0.27
Mean	0.27	0.28	0.28	0.27	
	CV (%) plot: 5.07			CV (%) subplot : 5.42	
			Total porosity		
0.0 –0.05	0.37 Bb	0.43 Aa	0.44 Aa	0.45 Aa	0.42
0.05 –0.10	0.41 Aa	0.40 ABab	0.40 ABb	0.37 Bb	0.39
0.10 –0.15	0.39 Aab	0.38 Ab	0.39 Ab	0.38 Ab	0.38
0.15 –0.20	0.37 Ab	0.40 Aab	0.38 Ab	0.37 Ab	0.38
Mean	0.38	0.40	0.40	0.39	
	CV (%) plot: 3.81			CV (%) subplot : 5.96	

CT: conventional tillage; NS: sunn hemp no-tillage; NP: pearl millet no-tillage; NL: lablab no-tillage. Means followed by the same letter have no statiscal difference by Tukey test ($p < 0.05$). Capital letters compare the Means in lines, and small letters, in columns.

Table 3. Soil bulk density in the management systems for layer 0–0.20 m

Management systems (S)	Soil bulk density
CT	1.26 b
NS	1.28 ab
NP	1.32 a
NL	1.31 a
F-test	5.84**
LSD (5 %)	0.045
Soil layer (L)	
0.0 –0.05	1.15 c
0.05 –0.10	1.33 ab
0.10 –0.15	1.32 b
0.15 –0.20	1.38 a
F-test	40.06**
LSD (5 %)	0.060
Interaction S x L	0.82 ns

CT: conventional tillage; NS: sunn hemp no-tillage; NP: pearl millet no-tillage; NL: lablab no-tillage. LSD: least significant difference. Means followed by the same letter have no statistical difference by Tukey test ($p < 0.05$).

can be seen by their respective θ_{FC} and θ_{PWP} curves, corroborating the results obtained by Tormena et al. (1998) and Beutler et al. (2004a,b). Klein (2008) affirms that the soil, the water reservoir for plants, is affected by crop management and practices, undergoing alteration of the dynamic and water retention in its pores as a consequence of the alterations in its structure. With an increase in density, there is also an increase in water content for the soil critical resistance to penetration of 2 MPa (θ_{PR}). Nevertheless, the water content for the air-filled porosity (θ_{PA}) considered as limiting (>10 %) is reduced, as observed by Archer & Smith (1972) and Silva et al. (1994).

There was no air-filled porosity ≤ 10 % in the evaluated treatments, indicating that the plants did not have their development limited by O_2 diffusion and gas exchanges. Thus, the value of θ_{PA} remained above that of θ_{FC} for all the densities.

In the conservationist management system, the θ_{PR} was greater than the θ_{PWP} throughout the extension of values for soil bulk density. Similar results were found by Imhoff et al. (2001) and Benjamin et al. (2003), in which soil resistance to penetration was the factor which most often reduced the LLWR in soils of varied granulometry, subjected to different management systems.

In the CT, the θ_{PR} substituted the θ_{PWP} in the values of soil bulk density less than 0.97 Mg m^{-3}; in other words, in this system, the soil resistance to penetration was not limiting with the soil having lower densities. Such results are similar to those obtained by Silva et al. (1994) and Tormena et al. (1998). According to Almeida et al. (2008), soil resistance to penetration is greatly influenced by the water content and the soil bulk density.

Critical soil bulk density (C_{bd}) is defined as the value of bulk density in which the upper limit of the LLWR is equal to the lower limit; in other words, when the LLWR is equal to zero (Silva et al., 1994). In this study, the C_{bd} was 1.36 and 1.43 Mg m^{-3} for NP and CT, respectively. According to Camargo & Alleoni (1997), values greater than 1.55 Mg m^{-3} are considered critical for clay loam soils.

Soil bulk density values greater than the C_{bd} indicate severely restrictive physical conditions for root development and, consequently, for crop productivity. As can be observed (Figure 1), the NS and the NL did not present C_{bd}, showing that the maize roots did not

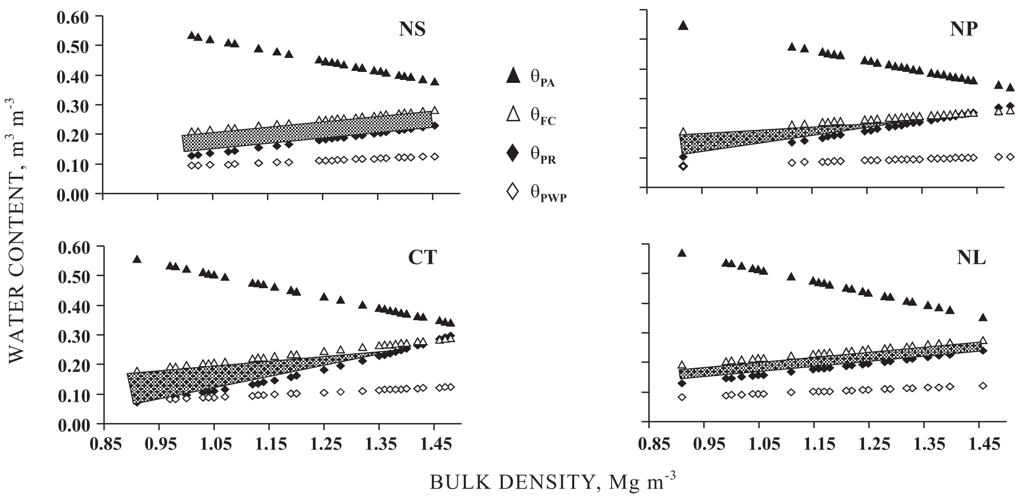

Figure 1. Volumetric water content variation (θ) with soil bulk density for the critical porosity limits for airing (θ_{PA}), field capacity (θ_{FC}), soil resistance to penetration of 2.0 MPa (θ_{PR}) and permanent wilting point (θ_{PWP}) in a Red Latosol (Oxisol), in the management systems: sunn hemp no-tillage (NS), pearl millet no-tillage (NP), lablab no-tillage (NL) and conventional tillage (CT).

have their growth limited through this attribute. Thus, in accordance with Freddi et al. (2007), the structural modifications caused in the soil by the different management systems can result in greater or lesser compaction, which may have an impact on soil resistance to penetration, bulk density and soil porosity, influencing root growth and, in the end, crop productivity.

That way, the LLWR allows one to identify, by means of quantification and integration of the data related to available water, aeration and soil resistance to penetration, and the restrictions imposed by structural degradation to the physical quality of the soil for plant growth.

CONCLUSIONS

1. Soil cultivation in the no-tillage system presented a greater value of total porosity and organic matter content in the layer from 0–0.05 m in relation to conventional tillage.

2. The system of conventional tillage did not differ from the no-tillage system with lablab plants and from the no-tillage system with sunn hemp in regard to macroporosity in the layer from 0–0.05 m.

3. The conventional tillage system and the no-tillage system with sunn hemp presented lower soil bulk density.

4. The treatments studied showed that the soil has good physical quality, as seen through the LLWR.

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