SEÇÃO VI - MANEJO E CONSERVAÇÃO DO SOLO E DA ÁGUA

EFFECTS OF DIFFERENT MANAGEMENT SYSTEMS ON POROSITY OF OXISOLS IN PARANÁ, BRAZIL(1)

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SUMMARY

Soils play a fundamental role in the production of human foods. The Oxisols in the state of Paraná are among the richest and most productive soils in Brazil, but degradation and low porosity are frequently documented, due to intensive farming involving various management strategies and the application of high-tech solutions. This study aims to investigate changes in the porosity of two Red Oxisols (Latossolos Vermelhos), denoted LVef (eutroferric) and LVdf (dystroferric) under conventional and no-tillage soil management, with a succession of annual crops of soybean, maize and wheat over a continuous period of more than 20 years. After describing the soil profiles under native forest, no-tillage management and conventional tillage using the crop profile method, deformed and non-deformed soil samples were collected from the volumes most compacted by human intervention and the physical, chemical and mineralogical properties analyzed. The various porosity classes (total pore volume, inter-aggregate porosity between channels and biological cavities) and intra-aggregate porosity (determined in 10 cm^3 saturated clods subjected to a pressure of -10 kPa to obtain a pore volume with a radius (r_{eq}), ≥ 15 µm and < 15 µm). The results showed that the effects of no-tillage farming on porosity are more pronounced in both soil types. Porosity of the LVdf was higher than pf the LVef soil, whatever the management type. In the LVdf soil, only pores with a radius of > 15 µm were affected by farming whereas in the LVef soil, pores with a radius of < 15 µm were affected as well.

Index terms: soil structure, crop profile method, no-tillage, conventional tillage.

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RESUMO: *POROSIDADE DE LATOSSOLOS DO PARANÁ INFLUENCIADA POR DIFERENTES MANEJOS*

Sabe-se que os solos têm função primordial na produção de alimentos para a humanidade. No Estado do Paraná, os Latossolos Vermelhos estão entre os mais produtivos do Brasil; devido à utilização intensa deles com diferentes práticas culturais e a uma agricultura altamente tecnificada, são comuns relatos de sua degradação física, com redução da porosidade. Dessa forma, o objetivo deste trabalho consistiu em estudar a modificação da porosidade de Latossolos Vermelho eutroférrico (LVef) e distroférrico (LVdf) cultivados sob plantio direto e convencional, com sucessão das culturas anuais soja, milho e trigo por mais de 20 anos consecutivos. Após uma descrição dos perfis de solo sob mata, plantio direto e preparo convencional pelo método do perfil cultural, coletaram-se amostras de solo deformadas e indeformadas nos volumes de solo antropizados mais compactos, para as análises físicas, químicas, mineralógicas e estudo das diferentes classes de poros (volume total de poros, poros entre (canais e cavidades biológicas) e intra-agregados (determinada em torrões de 10 cm^3 *saturados e submetidos à tensão de -10 kPa, para obtenção do volume de poros de* $r_{eq.} \geq 15\ \mu m$ $r_{eq.} < 15\ \mu m$*). Os resultados permitiram concluir que o efeito da exploração agrícola sobre a porosidade é evidenciado principalmente no plantio direto nos dois solos estudados. O LVdf apresentou porosidade superior à de LVef, qualquer que seja o manejo considerado; no LVdf, somente os poros de raio equivalente > 15 μm foram alterados pela exploração agrícola; e no LVef, além dos macroporos, também os poros de raio equivalente < 15 μm foram afetados pelo manejo.*

Termos de indexação: estrutura do solo, perfil cultural, plantio direto, preparo convencional.

INTRODUCTION

Soils play a fundamental role in the production of human foods (Lesturgez, 2005). Farming a given soil type in a reasonable manner depends directly on the availability of scientific data, since the pressure to meet the ever-increasing demand while ensuring sustainable development and respecting the environment is rarely compatible with the soils of complex ecosystems. This applies especially to tropical regions and in particular to Brazil (Leprun, 1994).

Thus, the soil must be studied with a view to comprehend the effects of large and small-scale agriculture on the soil characteristics and physical, chemical and biological properties in an integrated, rather than isolated manner. The effects of interactions and operation of the soil as a whole are important for the crop (Nicolodi et al., 2007) because agricultural practices are reflected in both the socio-economic sustainability of agriculture and in the harmony of the production system (Lal, 2000).

In the State of Paraná, Red Oxisols derived from basalt are among the most productive in Brazil. They are of fundamental importance to the State and the whole country, since they are used for both subsistence and cash crop agriculture. The agricultural use of these soils has been going on for some 70 years, and nowadays discussions regarding soil compaction have become quite common, regardless of the system employed (conventional or no-tillage).

According to Lal & Stewart (1990), although problems of compaction-induced soil degradation have probably existed since the beginning of agriculture, modern farming methods based on the use of heavy machinery and implements have aggravated the situation and seem to be causing changes in soil structure and consequently in porosity, influencing water infiltration, water availability to plants and aeration of the root system considerably. They are also causing a reduction in the soil volume exploited by the root system of cultivated crops, with significant implications on soil degradation, which may lead to a drop in agricultural productivity (Tavares-Filho et al., 2001; Neves et al., 2003; Tavares-Filho et al., 2006; Barbosa et al., 2007; De Maria et al., 2008). It is worth pointing out that, according to some authors (Benito et al., 2008; Ralisch et al., 2008; Cortez et al., 2009; Torres, 2009), productivity in long-standing no-tillage areas tends to be better than in conventionally tilled areas, mainly in years with uneven rainfall distribution. However, Carvalho et al. (2004) found that in years with normal rainfall, conventional methods of soil tillage tend to enhance productivity.

According to Letey (1985) and Lesturgez (2005), the effects of using agricultural machinery and implements are very significant in soil fertility assessments. The quantity of nutrients is not the only important factor, but also the physical conditions under which root systems develop. According to Collares et al., 2006, soil physical conditions can enhance the nutrient use, since they directly affect the flow of water, heat and gases in the soil and the mechanical resistance, which in turn are affected by soil density and pore size and distribution. These physical factors interact and regulate root growth and functionality, influencing crop growth and productivity.

Studies on the morphology and compaction of Red Oxisols (Latossolos Vermelhos) based on soil profiling (Tavares-Filho et al., 1999) show that the phenomenon of soil compaction does not affect only the top few centimeters, since compaction was observed to depths of 50 cm in many cases (Tavares-Filho & Tessier, 1998; Tavares-Filho et al., 1999; Tavares-Filho et al., 2001). According to Assouline et al. (1997), very clayey Red Oxisols originating from basalt, common in the study region, are highly susceptible to compaction when worked under moisture conditions above the friability point.

Soil management is intended to create favorable physical conditions for crop development, but the proper management causes modifications in the soil structure, according to the type of soil tillage (Tavares Filho et al., 2001; Assis & Lanças, 2005). It is believed that so-called conventional systems cause the greatest structural modifications in the soil, whereas the so-called conservationist systems, such as no-tillage, cause less significant structural modifications since the soil is not moved around. However, according to some authors (Tavares Filho et al., 2001; Collares et al., 2006), not turning over the soil, along with the more intensive use, exposes it to intense machinery traffic, often under inappropriate moisture conditions, contributing to increased soil compaction (Tavares Filho et al., 2001).

According to Ivo & Mielniczuk (1999), soil management methods in which the soil is not turned over can lead to other structures in the profile than those induced by conventional tillage, which can influence the development of plant root systems and consequently crop yields. According to Tavares-Filho et al. (2001), a significant feature of the structural modifications induced by no-tillage is a web of cracks in the soil leading to higher root abundance, higher biological activity and higher moisture content in the soil profile.

Since porosity is a direct result of the organization of soil minerals, according to Kilasara & Tessier (1991) it can be considered one of the best quantitative properties for revealing and assessing the soil structural degradation. Thus, the aim of this study was to investigate changes in the porosity of eutroferric and dystroferric Red Oxisols under conventional and no-tillage management, with a of annual crop succession of soybean, maize and wheat over more than 20 consecutive years.

MATERIALS AND METHODS

The sites chosen for this study are two "mesoregions" (Brazilian regional subdivisions), in northern-central and west Paraná, both on the Third Paraná Plateau. The geology is characterized by the Serra Geral Formation highlands, belonging to the São Bento Group, with fertile soils formed from a basalt volcanic eruption (Derrame de Trapp) which occurred in the Mesozoic era.

Four agricultural areas cultivated for more than 20 years with soybean or maize in the summer and wheat in winter were chosen for the study. Two consisted of eutroferric Oxisol (LVef) and two of dystrophic Oxisol (LVdf). In each pair, one area was cultivated under conventional tillage and the other under no-tillage, all in regions of subtropical climate classified Cfa. In each mesoregion, the LVdf samples were collected in Cascavel (24 º 57 ' 21 " S, 53 º 27 ' 18 " O; 781 m asl); Londrina (23 º 18 ' 36 " S, 51 º 09 ' 46 " O; 610 m asl) and LVef samples in Palotina (24 º 12 ' 00 " S, 53 º 50 ' 30 " O; 332 m asl) and Rolândia (23 º 18 ' 36 " S, 51 º 22 ' 08 " O; 730 m asl).

An area of native forest on LVdf and another on the LVef at each sampling site was used as control (C) (reference for the initial state of soil structure and porosity) (Table 1).

The study was initially based on a description of soil profiles under forest (control) and cultivated soils (NT: no-tillage and PC: conventional tillage), following the crop profile method proposed by Tavares Filho et al. (1999). One trench (1.0 x 1.0 x 1.5 m) was used for each soil under native forest and three for each soil and management method. In the cultivated soils, trenches were opened (completely randomized), at a minimum distance of 100 m. After describing the different soil profiles when the soybean crop was in full bloom, 10 deformed soil samples were collected from the volumes most compacted by human intervention for physical and chemical analysis (according to French Standard AFNOR n° X31D, 1994 and Mathieu & Pieltain, 1998) and non-deformed soil samples of varied sizes (to study different pore classes), totaling 10 soil clods of around 10 cm^3 and 10 soil blocks of around 300 cm^3. Samples were always collected under moist conditions (moisture of around 0.22 ± 0.02 kg kg^{-1}). The non-deformed samples were wrapped in laminate paper and packed in foam-lined polystyrene boxes to prevent moisture loss and protect them during transport to the laboratory.

In the laboratory, the non-deformed samples (from 10 to 300 cm^3) were placed in equilibrium in a device developed by Tessier & Berrier (1979) at a pressure of 10 kPa (0.01 MPa), by which according to Tessier (1994), the soil moisture at field capacity, the plant-available water, drainage porosity and aeration porosity can be estimated. This equipment works on the same principle as the Richards (1947) apparatus and is suitable for non-deformed samples of various sizes.

Next, the samples were analyzed according to the methods of Monnier et al. (1973); Tessier & Berrier,

Table 1. Physical and chemical characterization of samples of eutrophic (LVef) and dystrophic (LVdf) Red Oxisols, collected under native forest

	LVef $^{(1)}$	LVdf $^{(1)}$
Sample collection depth	(0-40 cm)	
Clay (g kg^{-1})	762	787
Silt (g kg^{-1})	198	170
Sand (g kg^{-1})	40	43
OM (g dm^{-3})	22.3	20.8
pH (H_2O)	6.1	5.0
$CTC_{pH7,0}$ ($cmol_c$ dm^{-3})	10.1	8.0
V (%)	54.0	40.0
Al ($cmol_c$ dm^{-3})	0.2	1.1
Mineralogy $^{(2)}$	Trace minerals 2:1 $^{(3)}$, kaolinite, iron oxides, gibbsite $^{(4)}$	Trace minerals 2:1, kaolinite, iron oxides, gibbsite

(1) The results are the averages of 20 soil samples (10 samples per profile at each sampling site), collected in LVef and LVdf profiles under native forest at the four study sites. (2) Analysis performed at the French Agronomics Institute (INRA – Versailles). (3) Clearer than in the LVdf. (4) Lower than in the LVdf.

(1979); and Mathieu & Pieltain (1998) and the results expressed in relation to a reference, ie., the solid phase volume, to allow a comparison of results of materials with different solid phase volume (Tavares Filho et al., 2005). Thus, to express the pore volume in the soil, the void index (e) was used and then converted to total pore volume (TPV) by applying the following formula: TPV = e/(e+1). For the 300 cm^3 blocks, TPV1 was calculated and for the 10 cm^3 clods, TPV2. Then a porosity study was conducted (inter and intra-aggregate porosity) with pores that indicate limits for plant-available water, drainage porosity and aeration porosity. The difference between TPV1 and TPV2 was considered as the inter-aggregate porosity (IAP), consisting basically of biological cavities and channels through which the drainage is more intense. The intra-aggregate porosity, determined in saturated 10 cm^3 clods subjected to a pressure of 10 kPa, was considered to be the volumetric moisture content (θ1) (corresponding to the pore volume of $r_{eq.} \geq 15$ μm) and volumetric moisture content (θ2) (corresponding to the pore volume of $r_{eq.} < 15$ μm) (Tessier, 1994).

The results were presented as average values of 10 replications, and the variation coefficient, together with a 95 % confidence interval, were computed.

RESULTS AND DISCUSSION

Soil organization based on profile analysis (Tavares Filho et al., 1999)

Based on a detailed analysis of the organization of the surface and subsurface horizons of the soils under native forest and cropping, it was possible to highlight the most sensitive properties to human intervention: soil structure, porosity, permeability, compaction, and crusting (Bullock et al., 1985).

Observations of these features under native forest provided a reference for comparison with areas exposed to constant human intervention, similar in terms of organization and compaction susceptibility. The soil organization under forest was morphostructural, characterized by the microaggregate state found in the Oxisols (solid microaggregate structure or a "coffee powder structure" according to Pedro et al. (1976)), with weak cohesion between aggregates and clods when dry, structural porosity visible through a magnifying glass and presence of biological activity with no variation along the profiles. By agricultural use, the morphostructural organization of the soil was modified differently according to the type of crop management: under conventional tillage, soils (LVef and LVdf) in the 0–40 cm layer average, a compact morphostructural organization prevailed, with macroscopic discontinuity, subangular polyhedral aggregates and clods clearly separated by cracks (high crack porosity), with predominantly rough fragmentation surfaces; under no-tillage cultivation, soils in the 0–60 cm layer average, a morphostructural organization with continuous compaction (laminar structure) prevailed with little macroscopic discontinuity, and individual aggregates and clods that were difficult to differentiate due to the high level of cohesion between them, but when differentiated, they were normally angular polyhedral with mostly smooth fragmentation surfaces.

These results agree with those presented by Tavares-Filho (1995); Tavares-Filho et al. (2001); Neves et al. (2003); Benito et al. (2008); Ralisch et al. (2008), and show that the soil profiles found under long-term no-tillage management tend to exhibit a "solid" structure, with apparently more compact clods and less visible porosity to the naked eye. In eutroferric soils under no tillage, these structures were more compact than in no-tillage dystroferric soils, extending to a greater depth (up to 50–60 cm). According to some authors (Oliveira et al. (1996); Ferreira et al. (1999a,b); Vidal-Torrado et al. (1999); Resende et al. (2002)), climatic action in terms of weathering, through sunlight, rain and wind, expose the soil to wet/dry cycles, leading to different-sized cracks in the soil. In addition, particle adjustment, clay dispersion and translocation through the soil profile using channels left by soil fauna, and pore clogging by these finer particles can occur.

Changes in porosity in response to soil management

The results are shown for an average of 10 replications per soil and management system (Figure 1). The first observation is that variation coefficients (CV) were not high, indicating that the results obtained are fairly accurate and reliable. Total porosity, whatever the scale (Figure 1a: (TPV1) – 300 cm^3 soil blocks; or figure 1b: (TPV2) – 10 cm^3 soil clods) was always higher in the LVdf than LVef, even under native forest.

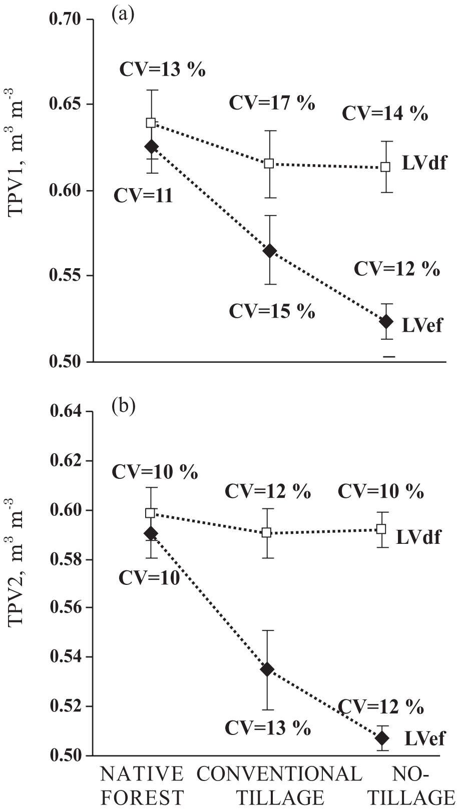

Figure 1. Average values (for 20 replications with 10 samples per profile at each sampling site) and confidence interval (95 %) (a) of the total pore volume of 300 cm^3 soil blocks (TPV1) and (b) of 10 cm^3 soil clods (TPV2), collected in the LVdf and LVef (dystroferric and eutroferric Red Oxisols) in the 5–50 cm layer, representing the crop profile.

A comparison of TPV1 for 300 cm^3 soil blocks (Figure 1a) with TPV for 10 cm^3 soil clods (Figure 1b), under forest and cultivated soils, shows that in the LVdf the values obtained for native forest are lower in the cultivated soils, with no significant differences between samples at 5 %, either for soil blocks (TPV1) or smaller clods (TPV2). The same drop was observed in the LVef, but with significant differences between the management systems in question. This drop in porisity always follows the same sequence: forest → conventional tillage → no-tillage management. In the specific case of the LVef, the differences between no-tillage and conventional tillage indicate that this soil type was more affected by the management system than the LVdf, and no-tillage management most affected porosity at the depth analyzed. These results agree with the soil profile analyses and with the results obtained by Tavares-Filho & Tessier (1998); Tavares-Filho et al. (1999, 2001) and Neves et al. (2003).

To deepen the discussion, we studied distribution of inter-aggregate porosity (biological cavities and channels) (IAP – Figure 2), and intra-aggregate porosity, ie. pores with $r_{eq.} \geq 15$ µm (θ1 – Figure 3a), and pores with $r_{eq.} < 15$ µm (θ2 – Figure 3b), which indicated the limit for plant-available water, drainage porosity and aeration porosity (Tessier, 1994).

The inter-aggregate porosity (IAP) (biological cavities and channels), which is first to be affected by the soil management method according Boone et al (1976), is higher in the LVdf (Figure 2), with a significant difference at 5 % between the two soils under no-tillage management (NT), where inter-aggregate porosity was most affected. This confirms the results obtained using the crop profile method,

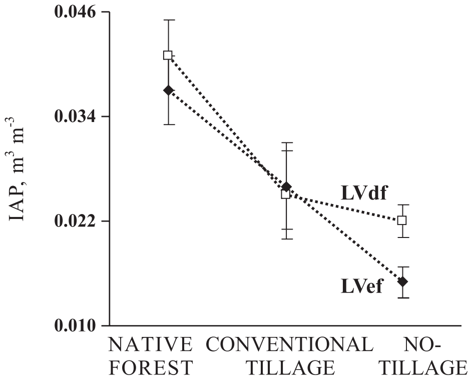

Figure 2. Average values (for 20 replications with 10 samples per profile at each sampling site) and confidence interval (95 %) for inter-aggregate porosity (IAP) of samples collected in the LVdf and LVef (dystroferric and eutroferric red Oxisols) in the 5–50 cm layer, representing the crop profile.

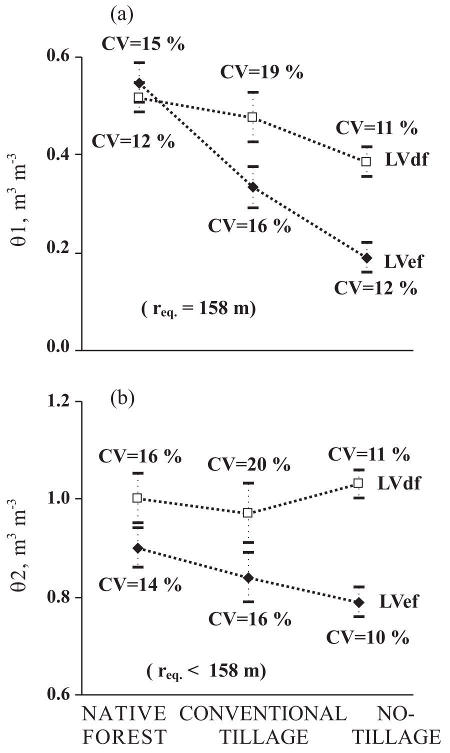

Figure 3. Average values (for 20 replications with 10 samples per profile at each sampling location) and confidence interval (95 %) for intra-aggregate porosity (a) and (b) at a pressure of 10 kPa, determined in 10 cm^3 clods collected in the LVdf and LVef (dystroferric and eutroferric Red Oxisols) in the 5–50 cm layer, representing the crop profile.

where an apparently more compact soil was detected under this management system. In terms of morphostructural organization, macroscopic discontinuity was low (laminar structure), cohesion between clods and aggregates high, normally angular polyhedral, and fragmentation surfaces normally smooth, as described above. These results agree with Tavares-Filho et al. (1999); Tavares-Filho et al. (2001) and Neves et al. (2003).

The pore analysis (radius ≥ 15 µm) (θ1 – Figure 3a) confirmed the previous results, ie., in addition to inter-aggregate porosity (IAP), soil management also affected pore volume more in the LVef than in the LVdf. No-tillage management, irrespective of the analysis scale, caused the strongest structural modifications, with greater changes in soil porosity. These results agree with Pidgeon & Soane, (1977); Derdour et al. (1993); Tavares-Filho (1995); Tavares-Filho & Tessier (1998); Tavares-Filho et al. (1999); Tavares-Filho et al. (2001) and Neves et al. (2003).

The pore analysis (radius $r_{eq.}$ < 15 µm (θ2 – Figure 3b) indicates that pore volume is higher in the LVdf than in the LVef, whatever the soil management system, and that the effects of agricultural use on porosity are more significant for no-tillage systems in both soils studied. For the LVdf, only pores of $r_{eq.}$ > 15 µm were affected by agricultural use; for the LVef, in addition to pores of $r_{eq.}$ > 15 µm, pores of $r_{eq.}$ < 15 µm were also affected by the soil type management. In the LVdf, there was a difference in this porosity type between soils under native forest and under no-tillage management, whereas in the LVef soil, there were differences between soil under native forest and the both management systems studied, showing a drop in porosity as the soil was incorporated into agricultural system. These results agree with those obtained by Tavares-Filho (1995) and Tavares-Filho & Tessier (1998), and show that incorporation of soils into the agricultural system is generally accompanied by compaction, influencing the soil at different levels. Furthermore, they indicate a contrasting change in porosity as a function of the soil type (physical and chemical environment) and the type of farming practices adopted on each soil.

The results shown (Figures 1, 2, and 3) indicate less compaction in the LVdf, with a stronger and more porous structure than the LVef, independent of the pore size and farming practice under study. Because of this more rigid behavior, it seems that conventional tillage of LVdf tends to cause more damage than no-tillage, since the effect of turning over the soil with agricultural implements fragments the typical microaggregate structure of Oxisols, aggravating compaction, whereas in the no-tillage management the soil loses some of its macroporosity due to soil compression, whereas its microaggregate structure remains relatively stable, as shown by the profile analysis. This means that under no-tillage management the structural state of soils with LVdf characteristics is conserved.

Thus, an agricultural use of these more acidic, basalt-based LVdf requires physico-chemical conditions (working at moisture contents as close as possible to the friability point and appropriate liming and fertilization management) that would ensure the soil physical stability (less compaction and higher porosity), without however causing toxicity problems for the crops. According to Hartmann et al. (1994, 1999), Tavares-Filho & Tessier (1998) and Lesturgez (2005), the pH of these soils must be sufficiently low to ensure that there are cohesive forces among the soil constituents to guarantee its physical stability, since an excessive rise in pH and cation saturation can adversely affect soil structure.

These comments on LVdf do however not apply to the LVef, since in this case, land use under no-tillage management for more than 20 years compacted the soil (Figures 1, 2 and 3). On the other hand, under the conditions described, conventional tillage maintained better porosity for plant growth in the LVef.

According to Hartmann et al. (1994, 1999), Tavares-Filho & Tessier (1998) and Lesturgez (2005), these differences between LVdf and LVef may be due to soil mineralogy, since LVdf (higher acidity, richer in exchangeable Al and gibbsite – see Table 1) was more weathered than LVef, which is probably the reason for the differences in terms of organization of soil constituents, with probable differences in cohesive forces between the constituents. In addition, the hypothesis presented above in the section *"Soil organization based on crop profile analysis"*, relating to different climatic action according to study locations and predisposition of the soil to wet/dry cycling could also help to understand the results in figures 1, 2 and 3.

CONCLUSIONS

1. In both soils studied, the effect of agricultural activity on soil porosity was more pronounced under no-tillage management.

2. The porosity of the LVdf was higher than of the LVef, whatever the management system. In the LVdf, only pores with a radius of > 15 µm were affected by agricultural use, whereas in the LVef, effects were evident not only on macropores but also on pores with a radius of < 15 µm.

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