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Weed control methods effect on the hydraulic attributes of a Latosol

Luiz Fernando Pires[1*], Cezar Francisco Araujo-Junior[2], Nivea Maria Piccolomini Dias[1], Moacir de Souza Dias Junior[3] and Elifas Nunes de Alcântara[4]

*[1]Laboratório de Física Aplicada a Solos e Ciências Ambientais, Universidade Estadual de Ponta Grossa, Ponta Grossa, Paraná, Brazil. [2]Instituto Agronômico do Paraná, Pólo de Londrina, Londrina, Paraná, Brazil. [3]Departamento de Ciência do Solo, Universidade Federal de Lavras, Lavras, Minas Gerais, Brazil. [4]Empresa de Pesquisa Agropecuária de Minas Gerais, Lavras, Minas Gerais, Brazil. *Author for correspondence. E-mail: lfpires@uepg.br; luizfpires@gmail.com*

ABSTRACT. Weed management plays a key role in the minimization of soil physical degradation processes such as compaction and hydric erosion. Different weed control managements can induce distinct changes in soil structure. One important soil physical attribute used for the analysis of modifications in soil structure is the soil water retention curve (SWRC). The objective of this work was to verify the use of physico-hydrical attributes to understand the effect of weed control managements on soil structure. Two soil layers (0–0.05 and 0.10–0.15 m) and six weed control managements divided into two groups were analyzed: I. no soil disturbance and ground cover (no weed control, post-emergence herbicide, mechanical mower); and II. soil disturbance and no ground cover (hand-hoe weeding, rotary tiller, pre-emergence herbicide). An area of native forest was used as reference. The results showed that the volumetric water capacity derived from the SWRC can be an interesting tool to evaluate the impact of weed control managements on soil structure. Evaluations of the air-filled porosity variation for different pressure heads also presented interesting findings. Distinct results of the weed control managements were found for the different depths analyzed in relation to the forest.

Keywords: mechanical weed control, interrow area, soil water retention, pore size distribution, air-filled porosity.

Efeito de métodos de controle de plantas invasoras nos atributos hídricos de um Latossolo

RESUMO. O manejo de plantas invasoras exerce papel chave na minimização dos processos de degradação de atributos físicos do solo tais como compactação e erosão hídrica. Diferentes manejos de plantas invasoras podem induzir mudanças distintas na estrutura do solo. Um atributo físico do solo importante na análise de modificações de sua estrutura é a curva de retenção (CRA). O objetivo desse trabalho foi verificar o uso de atributos físico-hídricos para compreender o efeito dos manejos de plantas invasoras na estrutura do solo. Duas camadas (0–0,05 e 0,10–0,15 m) e seis manejos, subdivididos em dois grupos, localizados nas entrelinhas de lavoura cafeeira foram analisados: I. sem distúrbio do solo e cobertura (sem capina, herbicida de pós-emergência, roçadora mecânica); II. distúrbio do solo e sem cobertura (capina manual, enxada rotativa, herbicida de pré-emergência). O solo coletado em mata nativa foi considerado referência. Os resultados mostraram que a função capacidade de água, obtida pela CRA, pode ser uma ferramenta interessante para avaliar o efeito dos métodos de manejo de plantas invasoras na estrutura do solo. Avaliações da porosidade livre de água nos diferentes potenciais mátricos também apresentaram resultados interessantes. Resultados distintos dos manejos de plantas invasoras foram obtidos nas profundidades analisadas em relação à floresta.

Palavras-chave: controle mecânico de plantas invasoras, área entrelinhas, curva de retenção, distribuição de tamanho de poros, porosidade livre de água.

Introduction

Currently, the most important research on weed control management in cash crops emphasizes the agronomic effects of the competition of these weeds for water and nutrients and their relationship with decreases in crop yield. However, weed management plays a key role in minimizing soil physical degradation processes such as compaction and hydric erosion in tropical and subtropical regions (Araujo-Junior, Dias Junior, Guimarães, & Alcântara, 2011a; Araujo-Junior, Dias Junior, Guimarães, & Alcântara, 2011b). Additionally, weed control methods in coffee crop might improve soil organic matter quality and carbon stocks (Alcântara

& Ferreira, 2000; Watanabe et al., 2007; Martins, Araujo-Junior, Miyazawa, Vieira, & Milori, 2015).

Therefore, it is important to study the effects of different methods of weed control on soil structure, in both the row and interrow areas (Trintinalio, Tormena, Oliveira Júnior, Machado, & Constantin, 2005). Integrated management of weeds in coffee plantations is essential to achieve sustainable agricultural production systems. The objectives of integrated management are to reduce the losses caused by invasive plants, to control costs, energy, and other operations, to reduce cultivation, hydric erosion and accelerated wind, ensuring proper food production, to prevent damage by toxic plants and to maintain environmental quality by maximizing profit for the farmer (Victoria Filho, 2000).

The soil water retention curve (SWRC) represents a soil physical attribute that describes the amount of water retained in soil under a series of equilibria between the water in a soil sample and the water at chosen potentials (Klute, 1986). The traditional method of SWRC evaluation involves the establishment of a series of equilibria through a pressure plate apparatus or suction table. After pressure or suction application, at each equilibrium, the soil water content is determined through gravimetry (Libardi, 2005).

The SWRC shape and range are strongly affected by soil texture (Hillel, 1998). Soil structure also strongly affects the SWRC, mainly at high pressure heads (Klute, 1986; Stange & Horn, 2005). Changes in the soil porous system due to management practices or natural processes can lead to modifications in the amount and size of interaggregate pores, which greatly affect the shape and consequently, the slope of the SWRC (Silva, Alves, Sousa, & Fernandes, 2006; Cássaro, Borkowski, Pires, Rosa, & Saab, 2011). The soil organic matter content also influences the water retained at different potentials (Lal & Shukla, 2004).

Compaction is a common process that can occur with respect to the soil structure due to the influence of management systems. The soil volume changes induced by compaction tend to destroy the interaggregate pores and increase the number of pores of intermediate sizes (Hillel, 1998). As a consequence, the SWRC shape will be modified at the intermediate and low suction range.

In addition to the SWRC, the volumetric water capacity (C_θ), derived based on its shape after mathematical adjustment through empirical- or physical-based models, can be an interesting tool to analyze changes in the soil structure related to management systems (Ogunwole, Pires, & Shehu, 2015; Hillel, 1998). Soils with a distinct soil texture or structure will present different C_θ values. Therefore, the volumetric water capacity can be used to assess possible modifications in the soil porous space due to different management systems.

In addition to the fact that the soil porous space affects plant growth and root system development, its characterization can provide valuable information on the effects of weed control methods on the soil structure. Therefore, the aim of this study was to verify the use of physico-hydrical attributes to understand the impact of weed control managements between coffee rows (interrow area) on the soil structure.

Material and methods

Site description, characterization and soil sampling

The soil water retention data used in this study were obtained as part of a weed control methods study in the South of Minas Gerais, Brazil, involving mechanical, chemical and cultural methods (Alcântara & Ferreira, 2000; Araujo-Junior et al., 2011a; 2011b). A long-term field experiment (30 years) was carried out in a coffee plantation in São Sebastião do Paraíso County, State of Minas Gerais, Brazil (20°55'00" S, 47°07'10" W, ≈ 885 m a.s.l.). The average annual temperature of the study area is 20.8°C (27.6°C maximum, 14.1°C minimum), and the average annual rainfall is 1,470 mm (Alcântara & Ferreira, 2000). According to Köppen's classification, the climate of the region is the Cwa type, i.e., tropical highland, mesothermal with a dry winter.

The soil at the site is derived from basalt and is classified as a Dystroferric Red Latosol according to the Brazilian Soil Classification System (Santos et al., 2013), similar to a Ferralsol (FAO, 1998) and a Typic Haplorthox according to the USDA Soil Taxonomy (Soil Survey Staff, 1998).

At the beginning of the experiment in 1977, the field was planted with coffee trees (cultivar Catuaí Vermelho LCH 2077-2-5-99) with a 4 m spacing between coffee rows and a 1 m spacing between coffee plants. In December 2005, due to the decline of the coffee plant yield, the coffee shrubs were replaced with a new cultivar (Paraíso), without disturbing the inter row areas, with the same spacing between coffee rows and 0.70 m spacing between plants.

Analysis of a soil sample collected close to the experimental area under natural forest showed that the Dystroferric Red Latosol contains 570 g kg^{-1} clay, 230 g kg^{-1} silt and 200 g kg^{-1} sand (0 to 0.30 m depth), with a homogeneous structure throughout

the profile. The soil has an average soil bulk density of 988±124 kg m^{-3} (n=9), an average total porosity of 0.676±0.056 m^3 m^{-3} (n=9), an average macroporosity of 0.352±0.086 m^3 m^{-3} (n=9) and exhibits a granular structure similar to coffee powder. Additional details pertaining to the site, soil and trial are provided by Alcântara and Ferreira (2000) and Araujo-Junior et al. (2011a; 2011b).

Experimental design, weed control and cover crops

In 1977, the weed control methods were laid out in a randomized complete block design with three replicates; each plot was 36 m long and 12 m wide. The experimental design was a split-plot with each weed control method used in three interrows as the main-plot factor, and the sampling layers (0–0.05 and 0.10–0.15 m) were used as the split-plot.

In the areas under the coffee canopy, the weeds were managed either by manual hoeing or with the application of herbicides. The type of weed management system, which was adopted satisfactorily in the coffee plantations over the 30-year period, influenced the number of operations needed, as well as the density and diversity of weeds found in the area at the time of the sampling (Araujo-Junior et al., 2011b).

The weed control methods were divided into two groups: I. no soil disturbance and ground cover + forest and II. soil disturbance and no ground cover + forest. The first group consisted of the following weed control: no weeding between coffee rows and under the coffee canopy – weed check (CHECK), post-emergence herbicide (POSH) and mechanical mower (MOW); the second group consisted of the following: hand-hoe weeding (MHW), rotary tiller (RTILL) and pre-emergence herbicide (PREH).

Soil sampling

In December 2007, thirty years after the installation of the experiment, soil samples were collected in the inter row area between coffee rows, 2 m from the stems of the coffee trees at depths of 0–0.05 and 0.10–0.15 m, totaling 180 soil samples (15 samples × 2 depths × 6 management systems). An additional fifteen undisturbed soil samples from each layer were collected from a Dystroferric Red Latosol under native forest (FRT) adjacent to the coffee cultivation. The undisturbed soil samples were collected using a cylindrical Uhland sampler and aluminum cylinders (volumetric rings), with a height of 2.54×10^{-2} m and a diameter of 6.35×10^{-2} m.

Soil water retention curve evaluation

After sample collection, the top and bottom of the samples were trimmed flat. The wetting procedure used to saturate the samples consisted of soaking them in a tray with the water level just below 1/3 of the top of the cylinders. This procedure was carried out over a period of 48 hours to allow saturation of the soil and to avoid the presence of entrapped air bubbles. After the wetting procedure, the soil samples were placed in contact with the porous media inside a suction table and were then placed in a pressure chamber.

The soil samples were subjected to the following pressure heads (h) in the suction table: -2, -4, and -6 kPa (Romano, Hopmans, & Dane, 2002), and they were subjected to -10, -33, -100, -500 and -1,500 kPa in the pressure chambers (Dane & Hopmans, 2002). The choice of h was based on the concepts of pore size to separate macropores and micropores, the water capacity and the permanent wilting point (Lal & Shukla, 2004).

After thermodynamic equilibrium was reached, the moist soil mass was evaluated using a precision balance (0.01×10^{-3} kg). The dry soil mass was obtained at the end of the SWRC evaluation by placing the samples in an oven at 105°C for 48 hours. The volumetric water content was determined by multiplying the gravimetric water content and the soil bulk density (Libardi, 2005). In this study, the water density was considered to equal 1,000 kg m^{-3}.

Data analysis

The SWRC experimental data were adjusted using the mathematical model proposed by van Genuchten (1980) in the SWRC Fit computer program (Seki, 2007):

$$S_e = \frac{1}{\left[1+(-\alpha h)^n\right]^m}, \quad (1)$$

where S_e ($=\theta-\theta_r / \theta_s-\theta_r$) represents the effective soil water saturation and α, n and m ($=1-1/n$) are empirical parameters that govern the SWRC shape. The SWRC adjustments were obtained based on average values of θ (n=3).

To verify the quality of the SWRC mathematical adjustment, the root mean square error (RMSE) and the coefficient of determination (r^2) were analyzed. The highest RMSE and lowest r^2 evaluated for the different layers were obtained for the samples under the native forest, i.e., respective values of 0.034 and

0.994 for 0–0.05 m and 0.034 and 0.992 for 0.10–0.15 m. These results showed that the estimated parameters for the measured SWRCs were an excellent fit.

After the SWRC mathematical adjustments, the volumetric water capacity (C_θ) was obtained using the following equation (Radcliffe & Simùnek, 2010):

$$C_\theta = \frac{\alpha^n(\theta_s - \theta_r)mn(-h)^{n-1}}{\left[1+(-\alpha h)^n\right]^{m+1}}, \quad (2)$$

where θ_r and θ_s denote the soil residual and saturated volumetric water contents, respectively. The equivalent cylindrical soil pore radii (r) were obtained in μm with h in kPa ($=149/h$).

Evaluations of the air-filled porosity (φ) for different h values were also carried out. Air-filled porosity was obtained by relating the difference between the total porosity and θ for each h. These analyses made it possible to verify the influence of the weed control management on the available water at both the low and high pressure heads.

Relative differences (RDs) were also obtained among the SWRCs to evaluate the impact of the different weed control managements in relation to the reference area (FRT). RD was determined using the following equation:

$$RD(\%) = \left(\frac{SWRC_{wcm} - SWRC_{ref}}{SWRC_{ref}}\right).100, \quad (3)$$

where the subscripts *wcm* and *ref* represent the weed control management and reference values, respectively.

The influence of the weed control managements on the structure of the soil was also assessed through soil pore classification systems based on functional characteristics. The system proposed by Greenland (1977) was used for this purpose, in which pores with equivalent cylindrical radii <0.25 μm were considered bonding + residual pores; those from 0.25 to 25 μm were considered storage pores; those from 25–250 μm were considered transmission pores; and those >250 μm were considered fissures.

Results and discussion

In the upper surface layer (0–0.05 m), the weed control methods used in the areas between the coffee rows changed the SWRC behavior in comparison to the reference samples (FRT) (Figure 1). The soil under the native forest was characterized by a high number of transmission and fissure pores, which do not contribute to water retention. On the other hand, they probably increase recharge and minimize the amount of surface water in the watershed (Hillel, 1998).

Changes in the soil structure induced by the weed control methods between the coffee rows affected the distribution of pores, with an increase in the pore contribution related to the storage of water in relation to the FRT samples (Lal & Shukla, 2004).

In the upper surface layer, the MOW weed control method and the chemical POSH method induced modifications in the soil porous system in relation to FRT, resulting in an increase in the water volume retained in the region of small pore sizes (Figures 1a and 1g). The same behavior was observed for CHECK, although with less intensity. This result is an indication of the increase in the volume of storage and residual pores, especially for the former methods.

The CHECK samples (-0.50 kPa) presented a slight difference in the peak position in relation to FRT (-0.42 kPa), as observed in the C_θ results (Figure 1c). On the other hand, for the weed control method with soil disturbance such as hand-hoe weeding, the mechanical action of the hoe caused changes in the soil structure while maintaining the soil without cover on the soil surface. The bare soil contributed negatively to the soil structure and compromised the organic carbon content and protection against water erosion (Faria, Schaefer, Ruiz, & Costa, 1998; Alcântara & Ferreira, 2000; Yang, Wang, Tang, & Chen et al., 2007; Araujo-Junior et al., 2011a; 2011b; Watanabe et al., 2007; Martins et al., 2015). Information on the organic carbon content for the same weed control methods and soil depths analyzed in this study can be found in Araujo-Junior et al. (2011b).

POSH and MOW seemed to cause the same effects with respect to the soil structure (Figure 1g), mainly under high h. The C_θ peak for these two management types was found at -0.30 kPa (MOW) and -0.26 kPa (POSH). A shift toward higher h was observed for these two management types in relation to FRT. It is important to stress that a large number of pores in the region of transmission pores contributes positively to water and air fluxes through the soil profile and directly affects plant growth by facilitating root penetration (Pagliai, Vignozzi, & Pellegrini, 2004).

These changes in the position of the C_θ peak help demonstrate the modifications in the soil structure induced by different management options (Leij, Ghezzehei, & Or, 2002). The C_θ results also demonstrate the differences in the frequency of pores for CHECK, POSH and MOW in relation to FRT (Figure 1c), which indicates important changes in the soil structure induced by the weed control managements (Lal & Shukla, 2004).

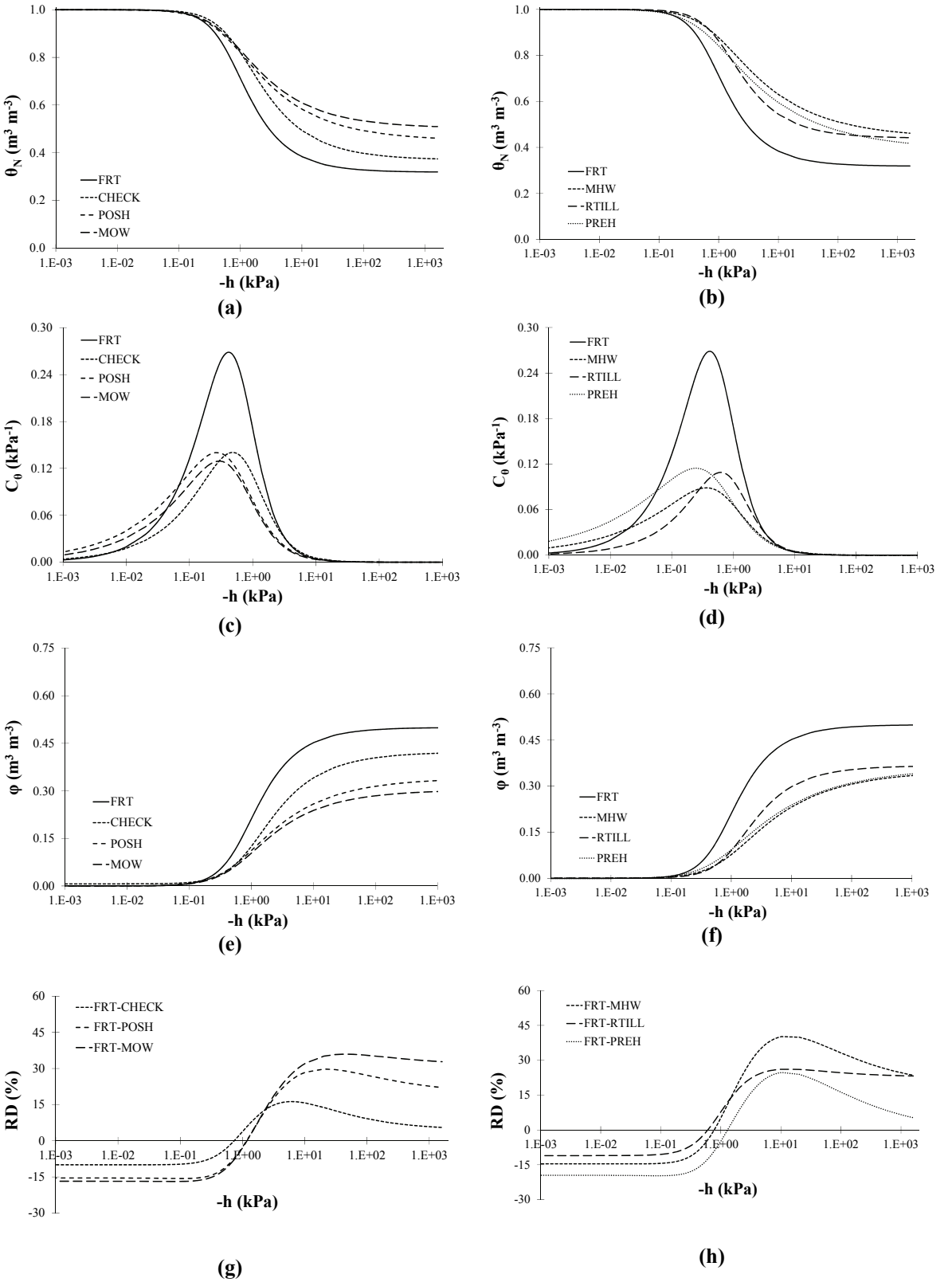

Figure 1. Normalized soil water retention curve (SWRC), volumetric water capacity (C_θ), air-filled porosity (φ) variation and SWRC relative differences (RD) for samples without soil disturbance and with ground cover (a, c, e, g) and with soil disturbance and without ground cover (b, d, f, h) for the 0 to 0.05 m layer. FRT=forest; CHECK=weed check; POSH=post-emergence herbicide; MOW= mechanical mower; MHW=hand-hoe weeding; RTILL=rotary tiller; PREH=pre-emergence herbicide.

By analyzing the SWRC data, it is possible to observe high values of mean soil porosity for FRT (0.733 m^3 m^{-3}) followed by CHECK (0.667 m^3 m^{-3}), POSH (0.620 m^3 m^{-3}) and MOW (0.610 m^3 m^{-3}). FRT retained a large amount of water (~29%) up to an r value of approximately 149 μm in comparison to the other managements (~18% – CHECK and POSH; ~17% – MOW) (Figure 1a). An inversion in the water retention pattern (not shown in the normalized SWRC) was observed for r values smaller than 149 μm among the managements (FRT<CHECK<POSH <MOW) (Figure 1a). This observation is an indication of a large amount of small pores (storage and residual+bonding pores) for MOW and POSH in relation to FRT (Greenland, 1977). The variations in φ with h provide insight about this result (Figure 1e). The smallest value of φ, in the region of small pores (small h), was found for MOW followed by POSH, CHECK and FRT.

In summary, the weed control methods MOW and POSH caused practically the same effects on the structure of the soil (Figures 1a and 1g), and the CHECK method resulted in water retention similar to that of FRT (Figure 1e and g).

Considering the managements with soil disturbance (Figure 1b), MHW and PREH presented a water retention behavior similar to FRT (Figure 1h). RTILL had closer agreement with FRT mainly regarding the region of large macropores. However, this method is not recommended for weed control in tropical regions because it results in damage caused to the soil structure due to aggregate breakage in small fractions as observed in the field. Additionally, the long-term use of this method resulted in the selection of the weed *Cyperus rotundus* ("tiririca"). There are negative aspects associated with the use of certain mechanical weed control methods, e.g., conventional tillage systems, such as the formation of surface crusts and plough pans at the lower cultivation limit (Pagliai, Vignozzi, & Pellegrini, 2004).

Differences in the SWRCs of these managements resulted mainly as a consequence of soil disturbance (Lipiec, Kus, Slowinska-Jurkiewicz, & Nosalewicz, 2006; Ugarte Nano, Nicolardot, Quinche, Munier-Jolain, & Ubertosi, 2016) (Figures 1b and 1h). The C_θ results demonstrate these differences among the weed crop methods (Figure 1d). The peak C_θ value for the different managements was found at -0.62 kPa (RTILL), -0.38 kPa (MHW) and -0.25 kPa (PREH); a shift of the peak toward large h values was observed in relation to FRT (-0.42 kPa), with the exception of RTILL. The C_θ values for MHW and PREH indicated a slightly broad distribution for these managements. FRT had the largest frequency of pores in relation to the other methods (Figure 1d), which is mainly related to the highest total pore volume (Lu, Malik, Chen, & Wu, 2014).

High values of mean soil porosity were found for RTILL (0.653 m^3 m^{-3}) followed by MHW (0.627 m^3 m^{-3}) and PREH (0.590 m^3 m^{-3}). Regarding pores smaller than 15 μm, the soil under MHW retained more water (~63%) than the other managements and the forest (FRT: ~39% < RTILL: ~55% < PREH: ~60%) (Figure 1b). This result indicates a large amount of small sized pores (storage and residual+bonding pores) for this management in relation to the others. Due to this fact, smaller values of φ were found for MHW followed by PREH and RTILL (Figure 1f), which is a consequence of soil disturbance (Lipiec, Hajnos, & Swieboda, 2012).

Regarding the weed control methods that cause soil disturbance, MHW and PREH presented similarities with respect to water retention (Figures 1b and 1f). The former had the smallest volume of pores in relation to the other managements (Figure 1d). RTILL was characterized by the narrowest C_θ distribution, which indicates a concentration of pores of similar sizes (Figure 1d). The air-filled porosity results showed similarities in their values among managements for large h values. On the other hand, MHW presented the smallest φ values and RTILL the largest values for small values of h (small pore sizes).

For the lower layer analyzed (0.10–0.15 m), the results showed similarities in the SWRCs among managements for soil without disturbance, mainly for h < -10 kPa (Figure 2a). Regarding pores larger than 300 μm, only slight differences in the volume of water retained between CHECK (~9% of water retained between 0 and -0.5 kPa) and POSH (~9%), and between MOW (~16%) and FRT (~17%) were observed (Figure 2g).

A large mean soil porosity was found for samples under FRT (0.663 m^3 m^{-3}), and similar values were found for the other managements, which indicates that for this soil layer, CHECK (0.607 m^3 m^{-3}), POSH (0.603 m^3 m^{-3}) and MOW (0.610 m^3 m^{-3}) led to the same type of modification in the soil structure if its porosity is considered as a reference attribute (Moraes et al., 2016).

However, the C_θ results indicated differences in the frequency of pores in the following sequence: FRT>MOW>POSH>CHECK (Figure 2c). The peak C_θ distribution presented a shift toward small h values among the managements in relation to FRT (-0.20 kPa), with MOW being an exception (-0.16 kPa). This result can be an indication that MOW maintained a soil structure more similar to FRT (Figure 2a and e), mainly for high h values (large pore sizes). POSH and CHECK were also characterized by narrow C_θ distributions.

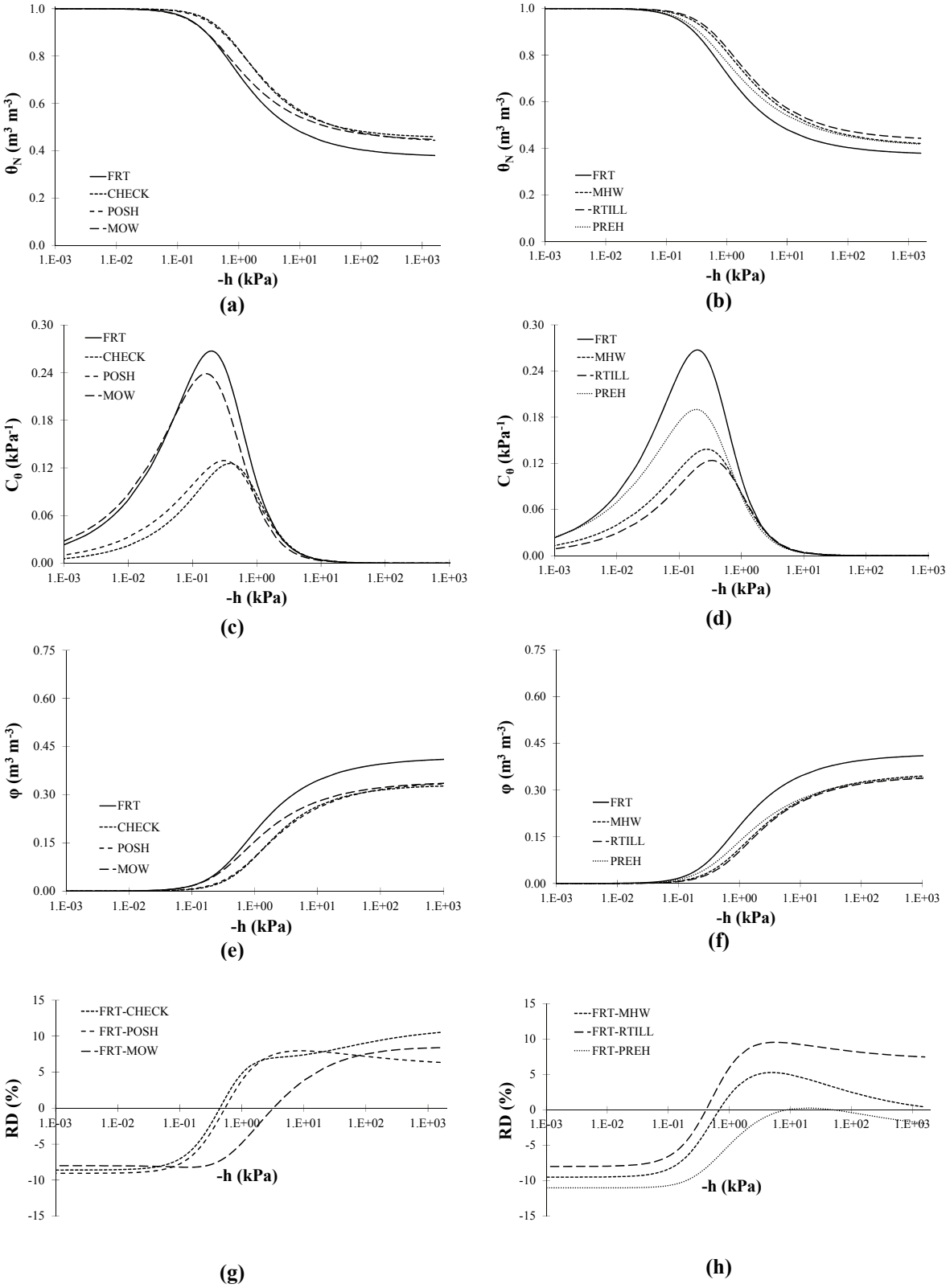

Figure 2. Normalized soil water retention curve (SWRC), volumetric water capacity (C_θ), air-filled porosity (φ) variation and SWRC relative differences (RD) for samples without soil disturbance and with ground cover (a, c, e, g) and with soil disturbance and without ground cover (b, d, f, h) for the 0.10 to 0.15 m layer. FRT=forest; CHECK=weed check; POSH=post-emergence herbicide; MOW= mechanical mower; MHW=hand-hoe weeding; RTILL=rotary tiller; PREH=pre-emergence herbicide.

With respect to the weed control methods that cause soil disturbance, the SWRC results showed similarities among managements for h ranging from 0 to -0.10 kPa (MHW: ~1.3% of water retained in this interval, RTILL: ~1.0%, PREH: ~2.2%) and from -20 to -1500 kPa (MHW: ~9.3%, RTILL: ~8.5%, PREH: ~8.4%) (Figure 2b and h). FRT presented the largest mean soil porosity (0.663 m^3 m^{-3}) followed by RTILL (0.610 m^3 m^{-3}), MHW (0.600 m^3 m^{-3}) and PREH (0.590 m^3 m^{-3}), which differed only slightly.

Regarding pores smaller than 10 μm, the managements that cause soil disturbance practically presented the same behavior in relation to water retention (MHW: ~52% of water retained, RTILL: ~53%, PREH: ~50%) (Figure 2b). This behavior is an indication that for the smallest pores, the effect of the changes in soil structure caused by these managements was similar in relation to FRT (Figure 2f).

The C_θ results showed distinct changes in the soil structure induced by the weed control methods for the lower layer studied (Figure 2d). A decrease in the frequency of pores was observed among managements in the following sequence: PREH>MHW>RTILL. The largest decrease in the frequency of pores found for RTILL is an indication of the damage caused to the soil structure by this weed control method (Lal & Shukla, 2004). The narrowest C_θ distribution was also found for this management. In addition, the C_θ peak presented a shift toward small h values among the managements in relation to FRT (-0.20 kPa).

An analysis of pore size distribution based on the Greenland classification was also carried out (Greenland, 1977). For the upper layer (0–0.05 m) studied, 57.1% of the FRT pores comprised transmission pores and fissures (Figure 3a), which are responsible for water transmission and redistribution throughout the soil profile (Hillel, 1998; Libardi, 2005; Lal & Shukla, 2004). Regarding these pore classes, FRT was followed by CHECK>POSH>MOW (managements without soil disturbance) and RTILL>PREH>MHW (managements with soil disturbance). The smallest proportion of transmission pores and fissures was found for MHW (32.1%). On the other hand, 67.9% of MHW pores belonged to residual (48.0%) and storage (19.9%) pores (Figure 3a). In the case of FRT, 42.9% of the pores were included in these two classes (33.2%: <0.25 μm and 9.7%: 0.5–0.25 μm).

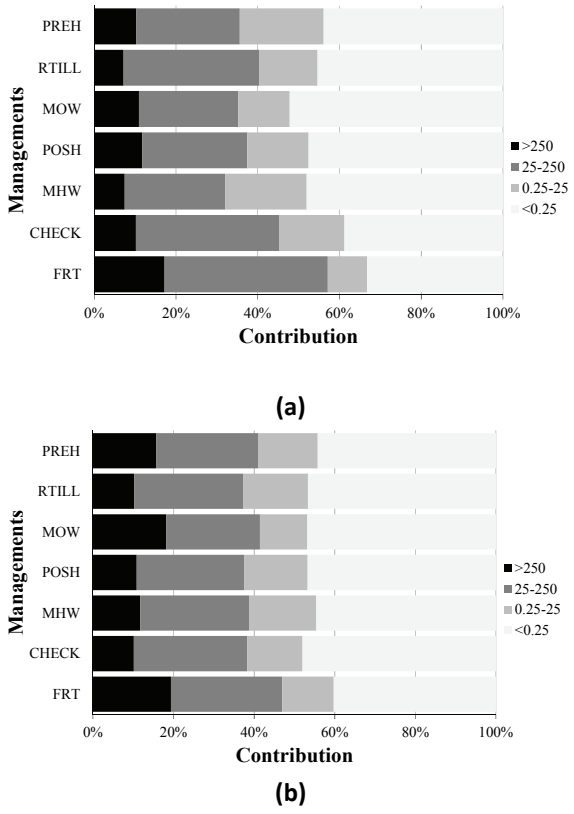

Figure 3. Pore size distribution according to the Greenland (1977) classification system for the different soil layers studied: 0–0.05 m (a) and 0.10–0.15 m (b). FRT=forest; CHECK=weed check; POSH=post-emergence herbicide; MOW=mechanical mower; MHW=hand-hoe weeding; RTILL=rotary tiller; PREH=pre-emergence herbicide.

Similarly, for the lower layer (0.10–0.15 m), FRT presented the largest contribution (47.0%) of transmission pores and fissures followed by MOW>CHECK>POSH (managements without soil disturbance) and PREH>MHW>RTILL (managements with soil disturbance) (Figure 3b). The smallest proportion of transmission pores and fissures was found for RTILL (37.3%). The largest proportion of residual pores was found for CHECK (48.0%) and that of storage pores for MHW (16.7%). In the case of FRT, 53.0% of the pores were included in these two classes (40.3%: <0.25 μm and 12.7%: 0.5–0.25 μm).

Conclusion

The application of different weed control methods produced changes in soil structure in relation to the native forest as observed by measurements of water retention, volumetric water capacity, pore size distribution and air-filled porosity. The upper layer (0–0.05 m) was more sensitive to changes than the lower layer (0.10–0.15 m).

In the interrow area (between coffee rows), the mechanical mower weed control method resulted in a lower layer soil structure that was very similar to the native forest. For the upper layer, the weed check and post-emergence herbicide methods exhibited the best agreements. The rotary tiller resulted in the selection of a weed plant (*Cyperus rotundus* – "tiririca") that is undesirable for coffee plantation management.

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