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Soil physico-hydrical properties changes induced by weed control methods in coffee plantation

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ABSTRACT

Weed management between coffee inter rows plays a key role in minimizing soil degradation processes. Soil structure and, consequently, its pore size distribution (PSD), water retention (SWRC) and availability can be greatly affected by the weed control methods. In this study, the effect of six different weed control methods on pore size distribution of a Haplustox was analyzed. Two soil depths (0–3 and 10–13 cm) were investigated. Weed control methods in the inter row area were: no weed control; post-emergence herbicide (Glyphosate); mechanical mower; hand-hoe weeding; rotary tiller; pre-emergence herbicide (Oxyfluorfen). An adjacent area of native forest close to the field experiment was used as a reference. The application of different weed control methods produced alterations in the soil structure in relation to the native forest as observed by measurements of SWRC and PSD. The upper soil surface layer (0–3 cm) was more sensitive to changes than the lower surface layer (10–13 cm). In the inter row area (between coffee rows), the weed control methods hand hoe weeding, mechanical mower (both mechanical methods) and pre-emergence herbicide decreased the volume of pores responsible for water drainage, with equivalent pore radius > 25 μm, in the layer 0–3 cm in relation to the 10–13 cm layer.

1. Introduction

Brazil is the largest coffee producer, being responsible for over 30% of the international production followed by countries such as: Vietnam, Colombia, Mexico, Indonesia, Cote d'Ivoire, India, Guatemala, Ethiopia and Uganda (Ponte, 2002).

Although the coffee cropping system differs from one producer to another (Donald, 2004), weed competition represents a great economic problem in coffee plantations (Ronchi et al., 2007). Coffee yield and quality can be dramatically affected by weed and, therefore, its control is an important operation requiring substantial investment (Ronchi and Silva, 2004).

Weed management methods in the area between coffee-shrub rows could also play a key role in minimizing soil physical degradation potential such as compaction and hydric erosion, organic matter loss and weed diversity (Alcântara and Ferreira, 2000a; Alcântara et al., 2009; Araujo-Junior et al., 2011a, 2011b; Cogo et al., 2013; Martins et al., 2015). Araujo-Junior et al. (2011a) and Martins et al. (2015) have shown that soil cover provided by weeds diversity protects soil surface against hydric erosion (direct raindrop impact and surface sealing), compaction and it provokes increases in organic matter content and organic carbon stocks. Due to this, the analysis of the effect of weed management methods on the soil structure is crucial.

Araujo-Junior et al. (2012, 2013) working in the same experimental area of this study demonstrated that weed control methods have great influence on soil physical properties, mainly in the surface layer (0–10 cm). The greatest alterations in the soil bulk density, total porosity, macroporosity and microporosity was found for the mechanical mowing, disk harrowing and pre-emergence weed managements. In other two papers published in 2011, the same authors described changes induced in the soil water retention and the load bearing capacity due to the weed managements (Araujo-Junior et al., 2011a, 2011b). The parameters of the mathematical adjustment of the water retention curves were used to describe the differences observed in the

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soil structure among weed control managements.

The pore size distribution (PSD) is an interesting tool to investigate changes in the soil structure. The PSD can be obtained directly through image analysis or indirectly by employing methods based on; soil water retention, nitrogen adsorption, mercury porosimetry, etc (Hajnos et al., 2006; Pires et al., 2009, 2017; Deng et al., 2015; Passoni et al., 2015).

The PSD provides useful information about the physical quality of the soil pore system (SPS). Many soil processes related to gas diffusion, root penetration, water movement, retention and availability, CO_2 flux and retention are directly affected by the SPS, for instance (Lal and Shukla, 2004; Pires et al., 2008). Thus, investigating the SPS focusing on the PSD can be a feasible way to evaluate changes in the soil structure due to natural and anthropogenic factors.

According to Kutílek (2004) the SPS is composed of three main pore categories: submicroscopic pores; micropores (divided into matrix or textural and structural pores) or capillary pores; and macropores or non-capillary pores. Textural pores are basically related to the distribution of soil particles in relation to size and they are more stable. On the other hand, structural pores are associated with the shape, orientation and position of soil aggregates. These pores are mainly affected by natural processes or anthropogenic activities.

The PSD derived from the soil water retention curve (SWRC) can be based on spline models utilized for the mathematical adjustment of the SWRC (Kutílek, 2004; Kutílek et al., 2006; Pires et al., 2008; Ogunwole et al., 2015). The SWRC derivative curve can sometimes present two or even three peaks when adjusted by these models, which indicate the existence of soil structure (Lipec et al., 2006). The PSD gives valuable information about the textural and structural pores, which directly affect plant productivity and the environment (Lipiec et al., 2007; Cássaro et al., 2011).

The objective of the work reported here was to show the effects of cultural, mechanical and chemical methods of weed control in coffee crop. The main hypothesis is that the maintenance of cover crops in the inter rows is the best way to improve the soil quality, in relation to the mechanical and chemical weed control methods. Six weed control methods and two soil depths were investigated and PSDs were indirectly determined by using SWRCs fitted using cubic spline functions.

2. Material and methods

2.1. Site description

Soil samples were extracted in the Experimental Farm of the Minas Gerais Corporation for Agriculture and Livestock Research, located in São Sebastião do Paraíso County, Minas Gerais, Brazil (20°55′00” S, 47°07′10” W, ≈ 885 m a.s.l.). The experimental area was submitted to mechanical, chemical and cultural methods for weed control (Alcântara and Ferreira, 2000b; Araujo-Junior et al., 2011a, 2011b). According to the Köppen classification, the region has a tropical highland climate (Cwa). The average annual temperature is 20.8 °C and the average annual rainfall is 1470 mm (Alcântara and Ferreira, 2000b).

The soil derived from basalt was classified as Ferralsol with a ferralic horizon, according to the world reference base for soil resources (FAO, 2006), Rhodic Hapludox, according to the USDA Soil Taxonomy (Soil Survey Staff, 2013) and “Latossolo Vermelho Distroférrico típico” (Dystroferric Red Latosol), according to the Brazilian Soil Classification System (Santos et al., 2013). The experimental field has a slope of 8%. Textural and mineralogical attributes of the 0–30 cm depth, before the experiment installation, are presented in Table 1.

At the beginning of the experiment in 1977, the field was planted with coffee shrubs (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 decline of the plant yield, the coffee shrubs were replaced with a new-coffee cultivar (Paraíso).

The previous crop was removed from the area with the aid of a subsoiler and, later on, the furrows were open in the same place of the previous planting line (row area). These operations were carried out preserving the inter row area over the years.

Table 1
Soil textural and mineralogical attributes (n = 3) in the 0–30 cm depth, before the experiment installation.

Soil use	Sand[†]	Silt	Clay	SiO_2[††]	Al_2O_3	Fe_2O_3	Ki[‡]	Kr[‡‡]
	g kg^{-1}							
Natural forest (FRT)	600	200	200	78	250	260	0.53	0.32
Coffee crop	560	230	210	70	250	270	0.47	0.28

[†] Sand, Silt and Clay: determined by pipet method.
[††] SiO_2, Al_2O_3 and Fe_2O_3: Total oxides contents extracted by sulfuric acid attack.
[‡] Ki: molecular relation $SiO_2/Al_2O_3 \times 1.7$.
[‡‡] Kr: molecular relation $1.7 \times SiO_2/[Al_2O_3 + (Fe_2O_3 \times 0.6375)]$. Adapted from Araujo-Junior et al. (2011a, 2011b).

2.2. Experimental design

In 1977, the weed control methods were laid out in a randomized complete block design with three replicates. Each plot measured 36 × 12 m. The treatments were the six weed control methods and a native forest (FRT). 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 for the 30 years 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., 2011a, 2011b).

The weed control methods chosen were: (i) No-weed control between coffee rows and below the coffee canopy, weed check (CHECK), in which a high diversity and density of weed plants was found at the time of sampling; (ii) Post-emergence herbicide (POSH), in which 8 applications of glyphosate + N-(fosfonometil) glicina were used with the aid of a knapsack sprayer, at a rate 2.0 L ha^{-1} of commercial product and 0.72 kg active ingredient ha^{-1}; (iii) Mechanical mower (MOW), in which a mechanical mower Kamaq® (model 132 KD) with 132 cm cutting width and 340 kg static mass was used to mow the weed plants; (iv) Mechanical hand hoeing weeding (MHW), in which the plants were managed with the aid of a hoe after reaching 45 cm height, totaling 8 times; (v) Rotary tiller (RTILL), in which the weeds were incorporated at 10 cm using equipment with a five-flanged axes (two sides with three knives and threes edges with six knives); (vi) Pre-emergence herbicide (PREH), in which 6 applications of oxyfluorfen (2-cloro-a,a,a-trifluoro-*p*-tolyl-3-ethoxy-4-nitrophenyl ether), on the soil surface without vegetation, were carried out with the aid of a knapsack sprayer, at a rate of 2.0 L ha^{-1} commercial product and 0.48 kg active ingredient ha^{-1}.

2.3. Soil sampling

In December 2007, undisturbed soil samples were collected from 12th until 23rd December, in the inter row area (between coffee rows), 2 m from the stems of the coffee shrubs. The samples were collected at depths: 0–3 and 10–13 cm, totaling 36 soil samples (6 weed control methods × 2 depths × 3 replicates). Simultaneously, undisturbed soil samples were collected at equivalent depth from a native forest adjacent to the coffee plantation. The soil samples were collected using a cylindrical Uhland sampler with aluminum volumetric rings (height of 2.54 cm and a diameter of 6.35 cm).

2.4. Soil water retention curve and water availability parameters

The undisturbed soil samples were saturated by the capillary rise method and submitted to the following pressure heads (h): −20; −40;