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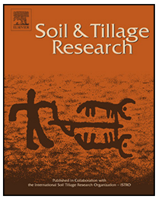

Gypsum effects on the spatial distribution of coffee roots and the pores system in oxidic Brazilian Latosol

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ABSTRACT

The aim of this study was to jointly evaluate the root system and soil pore distribution in depth and their relation to the development of the coffee crop. Three trenches were dug at random, longitudinal to the plant row, in a very clayey oxidic Latosol (Oxisol), subject to the following dose of gypsum: G0: absence of additional gypsum; G7: 7 Mg ha^{-1}; and G28: 28 Mg ha^{-1} of additional gypsum, both applied on the surface in the plant row. For the root system evaluation we used the crop profile method associated with 2D image analyzes, and subsequent elaboration of root variables maps. Soil pores system was quantified in 3D images, originated by X-ray CT scan, in undisturbed soil cores (0.06 m diameter and 0.14 m high) sampled at 0.20–0.34; 0.80–0.94; and 1.50–1.64 m depth. Roots and pores were classified by diameter. The statistical inferences were performed in R language. The increasing doses of gypsum favored the development of fine roots efficient in water absorption, and the highest gypsum dose promoted the better spatial distribution of the root system and was more homogeneous in the vertical direction of the soil profile, with highlighting to G28. The highest pore number and volume occurs in the 0.20–0.34 m structural layer, particularly pores with a diameter less than 2 mm. This management system that employs high gypsum doses contributed beneficially to a new structural organization in all depth studied, and most meaningful at 0.20–0.34 m depth, especially with the increase of pores and expertise of roots (smallest diameter: 1 mm) contributing to better exploitation of the soil conditions by the coffee plant. Image analyses are an tool with high predictive power to evaluated soil pores and roots system without destruction of the soil structure.

1. Introduction

With a record yield of 50.83 million bags of processed coffee in the 2012/2013 harvest, Brazil remains the leader in the ranking of coffee producers and exporters. The production in the Minas Gerais state represents more than half of all coffee produced in the country, and this is mainly due to the large area planted (>1.20 million hectares), particularly in the Cerrado region (CONAB, 2014), and mostly with Arabica (*Coffea Arabica*).

However, to increase productivity and remain competitive with the external market, the producers need to increasingly get better stringent in the management and conservation of soil and water, with the goal of improving the hydro-physical and soil chemistry quality, with a view toward agroecosystem sustainability (Araújo Junior et al., 2008).

Thus, detailed knowledge of the roots systems is of great value, being indicative of management adequacy. When associated with edaphic and biological factors there is an increase in the soil structural organization due to stabilization of aggregates formed (Salton et al., 2008), also improving the pore geometric and spatial distribution (Martin et al., 2012). In soil with adequate structure

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there is optimization of its exploitation by the plants, by allowing a better at-depth exploration by the roots with more efficient use of in stored nutrients and water (Partelli et al., 2006).

Management systems should therefore be adopted aiming to promote the improvement of the environment for the plant through practices that enhance the root distribution, principally in the vertical soil profile direction (van Raij, 2008; Cremon et al., 2009). With this purpose in particular, a management conservation system has been developed for coffee cultivation in the Alto São Francisco Valley, MG, Brazil.

This includes the preparation and fertilization of a deep furrow (0.60 m), associated with the cultivation of grasses (*Brachiaria* sp.) between rows in order to increase organic matter content and protection against soil erosion. The system also foresees the use of substantial gypsum doses aiming to precipitate the exchangeable aluminum, the formation of ionic pair ($AlSO_4^+$) and raise the exchangeable calcium content in depth (Serafim et al., 2011; Serafim et al., 2012) beyond improving the aggregates stability and their surface area (Cremon et al., 2009).

The factors that influence coffee root development and their affects on soil aggregates are complex. However, the study of the morphology and root distribution associated the soil structural organization is essential to evaluate performance of cultivated plants (Jesus et al., 2006), since there is still controversy regarding the distribution of the coffee root system (Franco and Inforzato, 1946; Rena and Guimarães, 2000). So, the aim of this study was to jointly evaluate the root system and soil pore distribution in depth and their relation with the development of the coffee crop in oxidic Brazilian Latosol.

2. Material and methods

2.1. Study area

The study was conducted on an experimental coffee plantation, located in the municipality of São Roque de Minas, physiographic region of the Alto São Francisco, MG, whose coordinates are 20°15′45″ S e 46°18′17″ W with 850 m altitude. The coffee crop was implanted in the first half of November 2008, conducted in accordance with the premisses of a soil management conservationist system that has been used in the region during 12 years and currently in other regions of the state. The climate is Cwa according to the Köppen classification, with annual precipitation of 1344 mm and having a well-defined dry season from May to September (Menegasse et al., 2002).

According to the premises of the management conservationist system of coffee (*Coffea arabica* L.) crop, the cultivar yellow Catucaí was implanted in narrow row with spacing of 2.50 × 0.65 m (between plants and between rows, respectively). Tillage was conducted using one plowing and two harrowings with application of correctives throughout the total area ($4\,Mg\,ha^{-1}$ dolomitic limestone+$1.92\,Mg\,ha^{-1}$ agricultural gypsum).

We used a subsoiler followed by a spade tool for the opening of the 60 cm deep and 50 cm wide furrow and mixed the soil at 40 cm depth, allowing the incorporation of basic fertilization (formula 08-44-00 [N–P–K]), enriched with 1.5% Zn and 0.5% B). This furrow was corrected at greater depth with dolomitic limestone $8\,Mg\,ha^{-1}$ ($2\,kg\,m^{-1}$) in all treatments. The coffee seedlings were planted between the second half of October and the first half of November 2008.

Additional agricultural gypsum was distributed on the soil surface and along the plant row about three months after planting, this material being covered with soil material mixed with inter-row plant material (mixture piled-up at the base of the coffee plant stem).

In conjunction with the installation of the coffee crop, *Brachiaria decumbens* (Syn Urochloa) was implanted as an inter-row cover crop, and periodically cut with a brush cutter, which minimizes competition with the main crop and allows the plant residue produced to be distributed along the row as well as between rows. A low slope of the terrain allowed most crop cultivation and harvesting operations to be mechanized, and some of them were carried out by means of animal traction equipment (Serafim et al., 2011; Carducci et al., 2013).

The parcels contain 10 rows with 36 plants each, totaling 360 plants per plot with an area of $585\,m^2$. The boundary corresponds to 3 plants at the beginning of the plot and two rows on the sides, totaling $360\,m^2$.

For this study the treatments included: G0 – absence of additional gypsum; G7 – $7\,Mg\,ha^{-1}$; and G28 – $28\,Mg\,ha^{-1}$ of additional gypsum, both applied on the surface in the plant row. The selection of these treatments was based on the hypothesis of possible structural alterations promoted by the application of gypsum and for this we evaluated the recommended dose found in the literature (G7), the reference dose for the system adopted itself (G28) and the treatment without additional gypsum (G0).

2.2. Roots system evaluation and 2D image acquisition

For the evaluation of the root system the trench-profile was used (Jorge and Silva, 2010). Three random trenches were dug lengthwise along the plant row, with dimensions of 0.70 m (width) × 1.50 m (lenght) × 1.50 m (depth). Based in the profile methods the vertical wall of the trench was scarified with the removal of a thin layer (0.03–0.05 m) to expose the roots and the procedure started at 0.10 m far from the stem of the plant under the canopy projection of the coffee plant. At the time of this study (September 2011) the coffee crop was young (≈3 years of implantation) and it was at the beginning of the reproductive-flowering period (Laviola et al., 2007).

In order to increase the color contrast (soil = red; roots = yellowish brown), after exposure of the roots in the vertical soil profile, the roots received a thin coat of white paint. Subsequently a grid made up of 0.05 m× 0.05 m square and the same trench dimension (0.70 m wide × 1.50 m depth) was placed in direct contact with the trench wall, over the roots.

Image acquisition was performed with a semiprofessional digital camera with a spatial resolution of seven megapixels. After image acquisition, we analyzed the roots variables and then quantified the surface area (mm^2), length (mm) and volume (mm^3), identified by the Safira software (Jorge and Silva, 2010).

For better data interpretation, root and soil pores were classified based on the collection depth of the samples used in X-ray CT scan.

2.3. Soil sampling, physical, chemical and mineralogical characterization

Following the acquisition of the coffee root system images, soil samples were sampled by hand, using plexiglass cylinders (0.065 m diameter and 0.14 m height) equipped with a specially

Table 1
Chemical and mineralogical characterisation of the B horizon of the Red Latosol (RL).

	Sulfuric acid digestion						
	SiO_2	Al_2O_3	Fe_2O_3	Ki[a]	Kr[b]	Kt[c]	Gb[d]
	$g\,kg^{-1}$					%	
Bw	104.9	391.7	169.0	0.46	0.36	22.55	58.53

[a] Ki: molecular ratio SiO_2: Al_2O_3.
[b] Kr: molecular ratio SiO_2: (Al_2O_3 + Fe_2O_3).
[c] Kt: kaolinite.
[d] Gb: gibbsite.