ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
Brazilian Journal of Agricultural and Environmental Engineering
v.26, n.10, p.743-746, 2022
Campina Grande, PB – http://www.agriambi.com.br – http://www.scielo.br/rbeaa

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v26n10p743-746

# How does organic carbon operate in the pore distribution of fine-textured soils?[1]

## Como o carbono orgânico opera na distribuição de poros dos solos de textura fina?

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*HIGHLIGHTS:*

*Soil organic carbon creates organic pores.*
*Sugarcane presents higher soil carbon stock than coffee.*
*Organic pores promote microporosity in fine-textured soils.*

**ABSTRACT:** Soil quality is important for providing adequate conduction for the production of food, fiber, and energy without significant alterations in the environment. Fragile soil indexes have been presented as soil quality indicators (i.e., soil porosity and carbon stocks) due to the easy modification by soil management and crop cultivation systems. The objective of this study was to determine and discuss how carbon operates in the distribution of macro- and micropores in fine-textured soils in tropical conditions using sugarcane and coffee production. The experiments were conducted in the region of Triângulo Mineiro, Minas Gerais, Brazil, using sugarcane cultivation (*Saccharum officinarum*) and coffee (*Coffea* sp.) in the conditions of the Brazilian Cerrado. It was verified that the distribution of micropores in fine-textured soils was higher than macropores due to the natural increment of clay in the soil. Organic carbon produced organic pores that positively impacted microporosity.

**Key words:** soil quality, macroporosity, microporosity, crop residues

**RESUMO:** A qualidade do solo é importante para proporcionar uma condição adequada à produção de alimentos, fibras e energia sem alterações significativas no ambiente. Índices de fragilidade do solo têm sido apresentados como indicadores de qualidade do solo (exemplo, porosidade do solo e estoques de carbono), devido à fácil modificação pelo manejo do solo e sistemas de cultivo. Um estudo foi realizado para explicar como o carbono atua na distribuição de macro e microporos. Verificou-se que em solos de textura fina a distribuição de microporos foi maior que macroporos devido ao aumento natural de argila no solo. O carbono orgânico criou poros orgânicos que impactaram positivamente a microporosidade.

**Palavras-chave:** qualidade do solo, macroporosidade, microporosidade, distribuição de poros

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• Ref. 261800 – Received 07 Mar, 2022
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• Accepted 24 Jun, 2022 • Published 30 Jun, 2022
Editors: Ítalo Herbet Lucena Cavalcante & Walter Esfrain Pereira

## INTRODUCTION

Soil attributes have been presented as soil quality indexes (i.e., soil porosity and soil organic carbon) because they can be easily modified by soil management and crop cultivation (Almeida et al., 2019).

Soil porosity is among the most important components in agro-ecosystems and is vital to the reserve of water and air for plants (Lucas et al., 2019). Soil porosity is classified as a gap between solid mineral particles (clay, silt, and sandy) and organic matter (Mota et al., 2018).

The porosity can be classified according to size and function with distribution in micropores and macropores (Lima et al., 2022). The fluxes of oxygen and carbon dioxide, and available water are related to the distribution of pores in the soil, where the macropores present a close association with the fluxes of gases and higher water drainage, while micropores are associated with water retention (Almeida et al., 2018).

Soil organic carbon has a direct correlation with soil porosity due to the creation of fissures and biopores in the soil with the accumulation of residues that promotes biological activity and carbon stocks (Almeida et al., 2016).

A concept exists whereby organic matter creates only macropores in soil, however, that influence depends upon texture-soil. Kirchmann & Gerzabek (1999) demonstrated that organic matter was associated with an increase of macro- and micropores in fine textured soil and the increase of microporosity was comparable to macroporosity.

Thus, the objective of this study was to determine how carbon operates with the distribution of macro- and micropores in fine-textured soils in tropical conditions with sugarcane and coffee production.

## MATERIAL AND METHODS

The study was developed to characterize the distribution of macro- and micropores, and organic carbon in agricultural tropical soils using the cultivation of sugarcane (*Saccharum officinarum*) and coffee (*Coffea arabica*) in the conditions of the Brazilian Cerrado from January to August, 2019.

The experiments were conducted in the region of Uberlândia, Triângulo Mineiro, Minas Gerais, Brazil (19° 12’ 11” S and 48° 11’ 30” W), with an average altitude of 830 m and the climate was classified as tropical rainy with dry winters (Aw) (Novais, 2021).

At all sites during the establishment, the soil was prepared using the conventional system of: (i) plowing, (ii) disking, (iii) harrowing, and (iv) furrowing. Applications of lime and gypsum were applied before planting, aiming to achieve 70% of base saturation at a soil depth of 0.25 m. Fertilization was performed in the furrow providing adequate availability of nutrients to the plants. The experimental areas presented fine-textured soils with average content of clay exceeding 60%, and comprising sand, silt and clay contents of 145, 170 and 685 g kg$^{-1}$ (coffee) and 290; 105 and 605 g kg$^{-1}$ (sugarcane), respectively, in the layer soil of 0-0.2 m.

The coffee cv. Mundo Novo, was spaced 4 × 0.7 m between planting lines and coffee plants, irrigated (localized dripping system; flow rate 0.5 L h$^{-1}$) with mechanical management, and considered a stabilized coffee area (10 years after planting). The coffee harvest was mechanized, and straws, leaves and other crop residues were left over the soil.

The sugarcane area was cultivated with a CTC variety, developed by Centro de Tecnologia Canavieira - CTC, at a population density of 60,000 ha$^{-1}$ with the accumulation of crop residues on the surface and soil collecting in the second harvest after the implantation. There was no irrigation, and sugarcane was on the second harvest (second ratoon), three years after planting.

The dataset presents an average of 60 samples which were collected in the layers 0.0-0.2 m (15 samples in the soil surface) and 0.2-0.4 m (15 samples in the soil subsurface) for each crop (total of 30 samples for coffee in both layers and 30 samples for sugarcane in both layers). Both sites presented a soil classified as an Oxisol with a respective value of pH (in $H_2O$) and concentrations of phosphorus (HCl, 0.05 mol L$^{-1}$ + $H_2SO_4$, 0.0125 mol L$^{-1}$), calcium, magnesium, potassium, and aluminum (KCl, 1 mol L$^{-1}$) of 5.2; 13.0 mg dm$^{-3}$; 1.5 cmol$_c$ dm$^{-3}$; 0.7 cmol$_c$ dm$^{-3}$; 0.5 mg dm$^{-3}$; 0.2 cmol$_c$ dm$^{-3}$ (coffee), and 6.2; 3.2 mg dm$^{-3}$; 1.4 cmol$_c$ dm$^{-3}$; 0.7 cmol$_c$ dm$^{-3}$; 52.0 mg dm$^{-3}$; 0.04 cmol$_c$ dm$^{-3}$ (sugarcane).

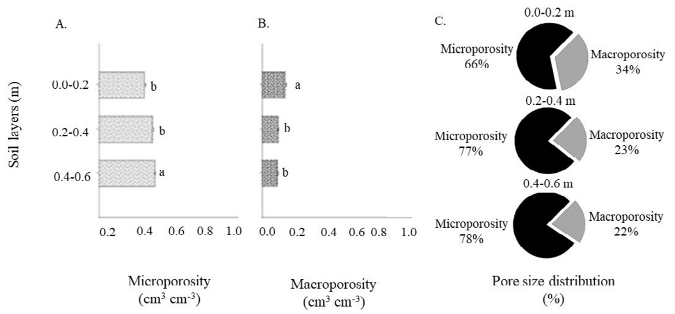
The dataset was composed of information of macro- and micropores and organic carbon in soil layers, 0.0-0.20, 0.20-0.40, and 0.40-0.60 m, respectively. The soil collection was performed in the entire area of planting (planting line, canopy projection, between planting lines) in the sugarcane and coffee cultivations.

Disturbed soil samples were collected to determine the organic carbon using the oxidation with the potassium dichromate method (Yeomans & Bremner, 1988). While, undisturbed soil samples were collected in a volumetric ring to determine macro- and microporosity. The microporosity was determined by the content of water in the soil at the potential of -0,006 MPa. While, macroporosity was obtained by the difference between the total porosity and microporosity (EMBRAPA, 2017). Soil density was determined based on difference between the mass of dry soil and the volume of the sample, and was calculated with the mass of soil dried in an oven at 105 ºC for 24 hours.

The dataset was evaluated using the assumptions of data normality and homogeneity of variance in the Shapiro-Wilk test (Sigmaplot Inc.) and the Bartlett test (SPSS Inc.), respectively. The data from soil layers were submitted to analysis of variance. When the F-test was significant ($p \leq 0.05$), the means of organic carbon, and macro- and micropores were evaluated by the least significant difference (LSD) test ($p \leq 0.05$). The concentrations of organic carbon with macro and micropores were correlated by Pearson correlation ($p \leq 0.01$).

## RESULTS AND DISCUSSION

On the soil surface (0-0.2 m), higher macroporosity occurred with a decrease in the subsequent layers corresponding to a general average from 0.15 ± 0.06 to 0.10 ± 0.02 cm$^3$ cm$^{-3}$, representing a 44% decrease. Simultaneously, an average increase of 19% occurred in microporosity in the subsurface (0.2-0.6 m) (Figure 1A and B).



*Bars followed by different letters indicate significant differences at $p < 0.05$ according to the F-test.
Horizontal bars represent the mean of layer (n = 60)

**Figure 1.** Microporosity (A), macroporosity (B) and pore size distribution (C) in function of soil layer

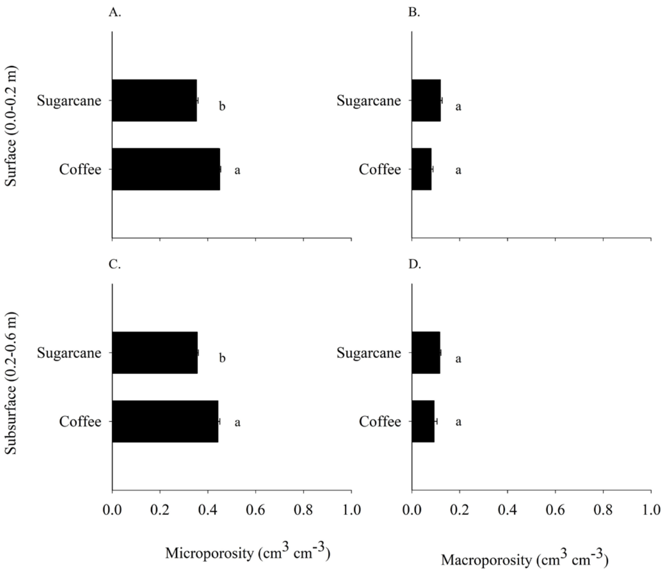
Both macro and micropores are important in soil life; macropores play a role in hydraulic functions with freely draining and easy movement of water and air, while micropores act in water retention to aid the development of plants and animals (Fu et al., 2019). The adequate balance of macro- and micropores is key to soil quality without significant alterations in the soil processes in the pedosphere.

The distributions of micropores were higher than macropores due to the natural increment of particles of clay in soil compared with the content of silt and sandy. In addition to the increase in clay, they were organized in the soil, occupying larger spaces between the particles, favoring the formation of micropores.

The high content of clay promoted the formation of micropores with a general average of 0.33 ± 0.08 $cm^3 cm^{-3}$, which represented more than 67% of total pores in soils. Macroporosity recorded a general average of 0.13 ± 0.05 $cm^3 cm^{-3}$, representing less than 34% of total pores in soils (Figure 1C).

The greater distribution of micropores compared with macropores was expected because this dataset was comprised of fine-textured soils with micropore predominance. Further, the dataset represented agricultural soils that were mechanically amended which influences microporosity by placing pressure on the soil and mechanical compaction. Cavalcanti et al. (2020) showed that sugarcane management practices lead to alterations in soil porosity with an increase of microporosity and reduction of macroporosity. The modification of soil structure can alter the functions and services provided by soils as macroporosity is associated with water drainage and oxygenation (Canisares et al., 2019).

On the surface and subsurface, coffee was characterized by higher microporosity (Figure 2A and C). However, there was no difference between coffee and sugarcane in terms of macroporosoity (Figure 2B and D). Souza et al. (2017) also identified higher soil microporosity in organic conilon coffee (Coffea canephora) areas which was associated with the mechanical management and stabilization of coffee planted over 10 years.

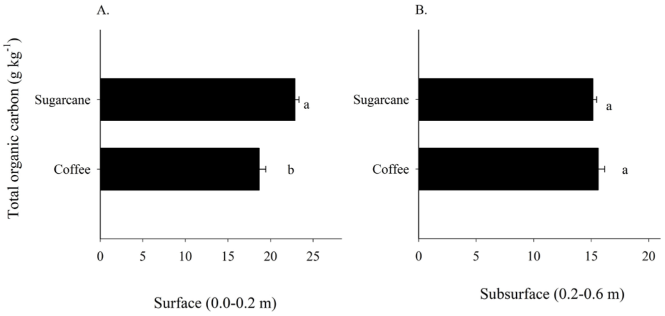


*Bars followed by different letters indicate significant differences at $p \leq 0.05$ according to the F-test. Horizontal Horizontal bars represent the mean of layer (n = 60)

**Figure 2.** Macro and micropores of soils with sugarcane and coffee in the surface (A and B) and subsurface (C and D)

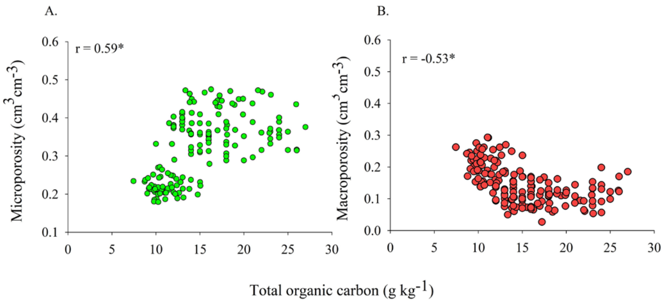
On the soil surface, the higher carbon content was associated with sugarcane while there was no difference between sugarcane and coffee in the subsurface soil (Figure 3A and B). Commonly, the highest contents of total organic carbon in the soil are found on the soil surface with a consecutive decrease in the subsequent soil layers (Almeida et al., 2019). Carbon on the soil surface was explained by the accumulation of organic residues (animal and vegetal) with consequent decomposition and stabilization of carbon in the soil (Mikhael et al., 2019). Sugarcane recorded a higher carbon content due to the accumulation of crop residues on the surface with an average of 10-15 Mg $ha^{-1}$ of crop residue (stubble, pointers, and green leaves) after each harvest (Almeida et al., 2016). Morais et al. (2020) showed that sugarcane residues prevented organic matter depletion and consequently caused soil health degradation in an Oxisol and an Ultisol in Southeastern Brazil.

Organic carbon created organic pores that directly impacted the increase of microporosity (r: 0.59; $p \leq 0.01$), with an average ranging from 0.17 to 0.47 cm $cm^{-3}$ (Figure 4A). While, organic matter reduced the macroporosity in soil (r: -0.53; $p \leq 0.001$), from 0.02 to 0.29 cm $cm^{-3}$ (Figure 4B). In both conditions, the organic matter presented stocks ranging from 7.4 to 27.0 g $kg^{-1}$ (Figure 4). A long-term experiment conducted by Kirchmann & Gerzabek (1999) demonstrated that an increase in organic carbon in fine-textured soil increased the micropores (1-30 µm), with a non-uniform distribution of pores. Further, micropores are protective habitats for microorganisms where biological activities are higher in soil (Bach et al., 2018).



*Bars followed by different letters indicate significant differences at $p \leq 0.05$ according to the F-test. Horizontal bars represent the mean of layer (n = 60)

**Figure 3.** Total organic carbon in soils with sugarcane and coffee in the surface (A) and subsurface (B)



* Significant at $p \leq 0.01$ by t test (n=60)

**Figure 4.** Correlation of total organic carbon with micropores (A) and macropores (B) in soil cultivated with sugarcane and coffee

## Conclusions

1. In fine-textured soils, the percentages of micropores are higher than macropores due to the natural increment of clay particles in the soil.

2. The highest concentrations of organic carbon are found in the soil surface with consecutive declines in subsequent soil layers. Sugarcane presents higher organic matter stock than coffee due to the accumulation of residues on the soil surface.

3. The organic carbon produced organic pores which positively correlates with microporosity.

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