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Sugarcane filter cake application to coffee crop and soil physical attributes

Aplicação de torta de filtro de cana-de-açúcar na cultura do café e relações de atributos físicos do solo

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SUMMARY: Filter cakes are solid organic byproducts of the sugarcane industry that are generally used as fertilizers for crops such as coffee. Filter cake application has improved soil chemical, physical and microbiological attributes, especially for weathered soils. This study aimed to evaluate the influence of filter cake applications on the soil attributes cultivated with coffee in a Cerrado region. The study was conducted in a commercial coffee crop area (coffee cultivar Topázio MG 1190) in a Dystrophic Oxisol. The experimental design used was randomized blocks, in a factorial scheme of 4 x 4, with four doses of filter cake applied in the planting furrow (0, 4, 8, 12 L m^{-1}) and four soil depths (0-0.1, 0.1-0.2, 0.2-0.3, 0.3-0.4 m). Soil density, soil mechanical resistance to root penetration, moisture, porosity (micro, macro, and total) and aggregate stability were evaluated. In general, the application of sugarcane filter cake over a long period has little effect on the soil's physical attributes, regardless of the filter cake rate used in the coffee crop. Only the soil porosity is affected by 12 L m^{-1} of filter cake, increasing the micro and macroporosity of the soil and promoting adequate conditions for the growth of coffee root, which can generate large soil water retention, benefiting coffee crops in the long-term.

Keywords: Aggregation stability. *Coffea arabica* L. Organic fertilization. Soil moisture. Soil density.

RESUMO: Tortas de filtro são subprodutos orgânicos sólidos da indústria canavieira que geralmente são utilizados como fertilizantes em culturas como o café. A aplicação da torta de filtro melhora os atributos químicos, físicos e microbiológicos do solo, especialmente em solos intemperizados. O objetivo deste estudo foi avaliar a influência das aplicações de torta de filtro nos atributos de solo cultivado com café em uma região do Cerrado. O estudo foi realizado em cafezal (cultivar Topázio MG 1190) cultivado em um Oxisol Distrófico. O delineamento experimental utilizado foi de blocos randomizados em esquema fatorial 4 x 4, sendo quatro doses de torta de filtro aplicados no sulco de plantio (0, 4, 8, 12 L m^{-1}) e quatro profundidades no solo (0-0,1, 0,1-0,2, 0,2-0,3, 0,3-0,4 m), com três repetições. Foram avaliadas a densidade do solo, a resistência mecânica do solo à penetração radicular, umidade, porosidade (micro, macro e total) e estabilidade de agregada. A dose de 8 L m^{-1} de torta de filtro apresentou diferenças entre as profundidades do solo para resistência à penetração na linha de plantio, densidade do solo e umidade. A densidade dos macroporos foi sempre superior a 40%, indicando que as raízes do café não encontraram impedimentos físicos para crescer. A maior quantidade de agregados de solo foi retida na peneira de 0,25 mm, demonstrando alto nível de desestruturação do solo na área do cafezal.

Palavras-chave: Coffea arabica L. Fertilização orgânica. Umidade do solo. Densidade do solo. Estabilidade da agregação.

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INTRODUCTION

Brazil is the largest coffee producer and exporter, and the second-largest consumer of the product in the world (ICO, 2020). The Brazilian coffee production (Arabica *plus* Conilon coffee) in 2019 was 49.3 million bags (60 kg), and the 2020 coffee production is estimated to reach up to 62 million bags, in a coffee area estimated at 2.16 million hectares, and an average yield between 27.2 and 32.9 bags per hectare (CONAB, 2020). Minas Gerais state produces approximately 32.1 million bags, which is more than 50% of the entire Brazilian coffee production. Almost

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all coffee production areas are in the Cerrado biome (Savannah like biome) (CONAB, 2020) where Oxisols are the prevailing soils (REATTO; MARTINS, 2005; HUNKE *et al.*, 2015). This class of soils exhibits a considerable variation of their morphological, chemical and physical attributes, with a texture varying from 15 to 80% clay content (KER, 1997; SANTOS *et al*., 2018).

Some soil physical attributes have been used as indicators of soil quality changes. The soil density, soil mechanical resistance to root penetration, macro and microporosity, total porosity, water retention capacity and soil aggregate stability are primary attributes used to study soil quality (PEZARICO *et al*., 2013). These indicators are directly influenced by the amount of soil organic matter, which can be changed through the continuous deposition of plant residues on the soil surface.

This continuous supply of organic matter can be achieved via the fertilization with organic sources and by the constant renewal of the plant roots in the soil profile and generating positive changes in the soil structural quality (GUARESCHI *et al*., 2012; SILVA *et al*., 2020). According to Burak *et al*. (2016), the soil physical attributes are crucial to coffee development because such attributes define the proportion of solids and spaces in the soil and directly affect the supply of nutrients and plant growth.

In natural conditions, the stability of the soil structure is highly and directly related to the concentration of organic matter, the soil texture and microbiota, since these factors directly interfere with the formation and flocculation of the soil aggregates (TORRES *et al*., 2019). However, soil cultivation changes the quantity, size, shape, and orientation of the soil empty spaces, altering the relationship between macro and micropores (LIMA *et al*., 2013). The presence of an optimal network of pores in the soil, with a wide range of diameters, is an essential factor in soil fertility, since it affects the relations between the water content available to the plants, absorption of nutrients, root penetration, soil aeration and temperature (LOSS *et al*., 2009).

Coffee is produced mainly in Oxisols in the Cerrado biome (Savanah biome). Such soils present low levels of organic matter, requiring a continuous supply of organic material for soil fertility maintenance, improved physical attributes and water retention capacity (MACHADO *et al*., 2008). Fidalski and Chaves (2010) evaluated the responses of coffee cultivated in a Dystrophic Oxisol after the application of organic residues. The authors observed that the majority of the residues tested caused positive changes to the soil fertility and that the filter cake increased the soil Ca content contributing to the coffee plant development and production.

Filter cakes are a solid organic byproduct of the sugarcane industry, obtained in rotating filters after extraction of residual sucrose from the dregs, which has been used as fertilizers for several cultures. According to Santos *et al*. (2010), the organic components present in filter cake bring benefits when applied in agriculture, because the minerals present are less subject to leaching, as a consequence of the increase of the soil cation exchange capacity and the soil organic carbon. Filter cake application to the soil also provides phosphorus, calcium and nitrogen, reduces the levels of exchangeable aluminum, rises of the water retention, and improves the physical and microbiological soil conditions (NOLLA *et al*., 2017).

The studies that deal with the benefits of the application of filter cake in soil physical attributes from areas cultivated with coffee are still very scarce and need to be better assessed. In this context, this study aimed to evaluate the influence of the annual application of sugarcane filter cake on soil physical attributes of an Oxisol cultivated with coffee in the Cerrado biome.

2 MATERIAL AND METHODS

2.1 EXPERIMENTAL AREA

This study was conducted in an experimental area of the Federal Institute of Triângulo Mineiro (Campus Uberaba), located in Uberaba, Minas Gerais state, at 19º39'19" S and 47º57'27" W, with an average altitude of 795 m. The coffee crop area was established in 2012, and the experiment was conducted until 2016.

2.2 CLIMATE OF THE REGION

The climate of the region, according to Köppen, is classified as Aw, i.e., tropical hot, with hot, rainy summers and cold, dry winter (Beck et al., 2018), with average annual precipitation and temperature of 1600 mm and 22.6 °C, respectively (INMET, 2018).

2.3 SOIL TYPE

The soil in the area was classified as a dystrophic Red Oxisol (Santos et al., 2018), medium texture. The soil superficial layer (0-0.2 m) presented: 210, 710, 80 g kg^{-1} of clay, sand and silt, respectively; pH (H_2O): 6.3; P (Mehlich-1): 19 mg dm^{-3}; K^+: 2.9 mmol$_c$ dm^{-3}; Ca^{2+}: 22 mmol$_c$ dm^{-3}; Mg^{2+}: 10 mmol$_c$ dm^{-3}, H+Al: 20 mmol$_c$ dm^{-3}; organic matter (OM): 16 g dm^{-3} and 64% of bases saturation. The analyzes were carried out at the Institute of Agricultural Sciences (ICIAG) of the Federal University of Uberlândia (UFU) following the methodologies proposed by Teixeira *et al*. (2017).

2.4 EXPERIMENTAL DESIGN AND CONDUCTION

The experimental design was randomized blocks, in factorial 4 x 4, with four doses of filter cake applied in the planting furrow (0, 4, 8, 12 L m^{-1}) and four soil depths (0-0.1, 0.1-0.2, 0.2-0.3, 0.3-0.4 m), with three repetitions.

The soil in the experimental area was conventionally cultivated with deep plowing and two harrowing activities, followed by the furrow opening and subsequent planting of coffee seedlings (Topázio MG 1190 coffee cultivar) in 2012. The planting spacing was 3 x 0.7 m, and the coffee seedlings had 6 to 7 pairs of leaves (approximately 60 days old).

The first application of sugarcane filter cake was performed in the furrows before planting. Then it was applied annually, always in December (2013, 2014, 2015), at the same dose and consistently below the coffee canopy projection on the soil surface. Each experimental plot was composed of eight plants, being considered useful only the six central plants. In December 2016, before filter cake fertilization, the soil samples were collected for soil physical attributes evaluation.

The coffee plants were watered using a drip irrigation system for all treatments. The drippers were separated from each other by 0.7 m, being an emitter per plant, with an irrigation line for each block. The irrigation control was performed based on the data obtained from the experimental station placed in IFTM: temperature, relative humidity, wind speed, and solar radiation were used to estimate the crop evapotranspiration by the method of Penman-Monteith, as adapted by Smith (1991).

At planting and subsequently, the mineral fertilization was used for coffee nutrition based on soil analysis and in accordance with the recommendation of the Committee of Soil Fertility in the State of Minas Gerais (1999). The macronutrient fertilization for the present study consisted of 450 kg ha^{-1} of N, 100 kg ha^{-1} of P_2O_5 and 400 kg ha^{-1} K_2O, as urea, superphosphate and potassium chloride, respectively.

2.5 SOIL ATTRIBUTES EVALUATED

2.5.1 Soil penetration resistance

The soil resistance to penetration of roots (SRP) was determined in the planting line and between planting lines (interrow) in the coffee crop in 12 points per treatment with the aid of an impact penetrometer (Planalsucar/IAA) with 30° angle conical tip (STOLF *et al.*, 2014). In each plot were performed three determinations of SRP at depths of 0-0.1; 0.1-0.2; 0.2-0.3 and 0.3-0.4 m. The field data were obtained in numbers of impacts (dm^{-1}), having been processed in kgf cm^{-2} by means of the equation: SRP (kgf cm^{-2}) = 5.6 + 6.98 N (SENE *et al*., 1985), then these values were multiplied by 0.098 and processed in units MPa (ARSHAD *et al*., 1996).

2.5.2 Soil density, macroporosity, microporosity and total porosity

The soil density (SD) was determined in samples with undisturbed soil structure by the volumetric ring method. The samples were collected in rings of 48 mm in diameter by 53 mm height with the aid of the Uhland treaty, at soil depths of 0-0.1, 0.1-0.2, 0.2-0.3, and 0.3-0.4 m (BLAKE; HARTGE, 1986). These samples were saturated, weighed, and dried in an oven at 105 °C for 24 h. In the same samples, the soil macroporosity (Ma), microporosity (Mi), total porosity (TP), and proportion of macropores (Ma/TP), were determined according to Teixeira *et al*. (2017).

2.5.3 Soil water content

Soil samples were taken to assess water content on the same day and soil depths, being taken two samples per plot and homogenized for obtaining the weight of the soil moist and dry. These samples were packed in aluminum containers, weighed, and placed for drying in an oven with forced circulation at 105 °C for 24 hours to estimate the volumetric soil water (TEIXEIRA *et al*., 2017).

2.5.4 Soil aggregation

The soil aggregate stability was evaluated in three deformed soil samples that were collected in each plot with the aid of a hoe. The soil depths of 0-0.1; 0.1-0.2; 0.2-0.3 and 0.3-0.4 m were collected as described by Kemper and Chepil (1965). The soil samples were manually braked, sifted, and the aggregates which passed in the 9.52 mm sieve and retained in the 4.76 mm were used to determine soil aggregates stability. The aggregates retained were weighed in duplicates of 50 g of soil air dried, which were moistened by capillarity for 10 minutes. These samples were transferred to a set of sieves (2, 1, 0.5, 0.25, 0.13 mm), which were subjected to vertical oscillation for 15 minutes in water.

The soil contents of each sieve were transferred to metal containers previously weighed and subjected to dry for 24 hours in an oven at 105 °C. With that the aggregates were separated into the following classes of diameter (C): C1 (9.52-4.76 mm), C2 (4.76-2 mm), C3 (2-1 mm), C4 (1-0.5 mm), C5 (0.5-0.25 mm) and C6 (< 0.25 mm).

2.5.5 Soil aggregation index

The weighted average diameter (WAD) was calculated using the soil aggregate mass (Equation 1), which is higher for the large aggregates retained; therefore, the presence of large soil aggregates, or large WAD, may reflect the soil resistance to erosion.

WAD = Σ (xi.wi) (Equation 1), where *xi* is the mean diameter of classes (mm) and *wi* is the proportion of each class in relation to the total (WENDLING *et al*., 2005).

The geometric mean diameter (GMD) represents an estimate of the size of the class of aggregates of more abundant occurrence and can be estimated by Equation 2.

DMG = exp{Σ[(ln[xi]*[pi])] / [pi]} (Equation 2), where *ln [xi]* is the natural logarithm of average diameter of classes and *pi* is the weight (g) retained in each sieve (DEMARCHI *et al*., 2011).

2.6 STATISTICAL ANALYSIS

All data about filter cake doses and soil depth were submitted to ANOVA (F test, $p<0.05$) after the attendance of the assumption of residues normality (Kolmogorov-Smirnov test) and homogeneity of variances (Levene test), both at $p>0,01$. The filter cake doses were compared by polynomial regressions ($p<0.05$), and the averages of the soil depths were compared by the Tukey test ($p<0.05$). All analyses were performed using the software SPSS® 17.0 and SISVAR®.

3 RESULTS AND DISCUSSION

3.1 THE SOIL PHYSICAL ATTRIBUTES

The ANOVA results for the studied variables according to the present design and scheme of followed are presented in Table 1. Only soil microporosity, macroporosity and the Ma/TP proportion differed among the filter cake doses; however, only the soil resistance to penetration between planting lines and the soil moisture content differed among soil depths. No interaction between the factors (filter cake doses and soil depths) were detected ($p > 0.05$) for all variables evaluated.

Table 1. ANOVA (*F* test) of the variables studied with filter cake doses (FCD) at different soil depths (SD)

Source of Variation	df	SRP_L	SRP_{BL}	SD	MC	Ma	Mi	TP	Ma/TP	GMD	WAD
FCD	3	1.889	2.649	2.671	1.458	3.073*	6.160**	1.560	3.423*	0.248	0.164
SD	3	0.593	13.838**	1.317	6.864**	0.300	2.257	0.643	0.355	0.798	0.603
FCD*SD	9	1.077	0.436	0.816	0.354	0.911	1.388	0.901	0.972	0.384	0.350
CV (%)		22.06	14.53	5.63	6.07	23.24	5,10	7.87	17.75	34.70	38.31
GA		1.641	2.177	1.511	0.170	18.35	26.26	44.61	0.402	0.642	1.272

SRP_L: soil resistance to penetration in line (kgf cm^{-2}); SRP_{BL}: soil resistance to penetration between lines (kgf cm^{-2}); SD: soil density (kg dm^{-3}); MC: moisture content (dm^3 dm^{-3}); Ma: soil macropores (%); Mi: soil microporosity (%); TP: soil total porosity (%); Ma/TP: soil macroporosity proportion (%); GMD: geometric mean diameter (mm); WAD: weighted average diameter (mm); CV (%): coefficient of variation; GA: general average.

*, **: significant at 5 and 1% of probability, respectively.

The SRP has no agreement in the literature about what is the critical limit for plant development; however, 2 MPa is an accepted value for many studies (BEUTLER *et al*., 2004; SILVA *et al*., 2008; 2020; TORRES *et al*., 2012). According to Grant and Lanfond (1993), SRP increases with compression, which is restrictive to root growth when RSP ranges from 1.5 to 3.0 Mpa; for Arshad *et al*. (1996) these values range from 2.0 to 4.0 Mpa.

Arshad *et al*. (1996) separated SRP for all soil textures in levels of resistance to plant root development: a) extremely low: SRP < 0.01 MPa; b) very low: $0.01 \leq$ SRP < 0.1 MPa; c) low: $0.1 \leq$ SRP < 1.0 MPa; d) moderated: $1.0 \leq$ SRP < 2.0 MPa; e) high: $2.0 \leq$ SRP < 4.0 MPa; f) very high: $4.0 \leq$ SRP < 8.0 MPa; and, g) extremely high: SRP > 8.0 Mpa. The majority of the observed values in planting line areas are classified as moderate, while in the interrow areas the SRP was classified as high, or harder for root development (Table 2).

Table 2. Soil resistance to penetration (SRP), soil density (SD) and moisture content (MC) in the coffee planting line and between lines in areas with the application of 0, 4, 8 and 12 L m^{-1} of filter cake

(Continua)

Soil depth (m)	Planting line			Interrow		
	SRP (MPa)	SD (kg dm^{-3})	MC (cm^3 cm^{-3})	SRP (Mpa)	SD (kg dm^{-3})	MC (cm^3 cm^{-3})
			0 L m^{-1}			
0-0.1	1.40^{ns}	1.51^{ns}	0.16^{ns}	2.32^{ns}	1.51^{ns}	0.16^{ns}
0.1-0.2	1.56	1.57	0.16	2.32	1.57	0.16
0.2-0.3	1.66	1.55	0.17	2.17	1.55	0.17
0.3-0.4	1.56	1.46	0.18	1.63	1.46	0.18

(Conclusão)

Soil depth (m)	Planting line			Interrow		
	SRP (MPa)	SD (kg dm^{-3})	MC (cm^3 cm^{-3})	SRP (Mpa)	SD (kg dm^{-3})	MC (cm^3 cm^{-3})
			4 L m^{-1}			
0-0.1	1.48^{ns}	1.55^{ns}	0.17^{ns}	2.09 b[1]	1.55^{ns}	0.17^{ns}
0.1-0.2	1.40	1.55	0.17	2.55 a	1.55	0.17
0.2-0.3	1.33	1.52	0.18	2.17 b	1.52	0.18
0.3-0.4	1.63	1.50	0.19	1.71 c	1.50	0.19
			8 L m^{-1}			
0-0.1	1.63 b	1.47 b	0.16 b	1.94 b	1.47 b	0.16 b
0.1-0.2	1.94 a	1.64 a	0.16 b	2.55 a	1.64 a	0.16 b
0.2-0.3	1.79 b	1.56 b	0.16 b	2.25 a	1.56 b	0.16 b
0.3-0.4	1.63 b	1.50 b	0.18 a	1.56 b	1.50 b	0.18 a
			12 L m^{-1}			
0-0.1	1.40^{ns}	1.46^{ns}	0.16^{ns}	2.40 b	1.46^{ns}	0.16^{ns}
0.1-0.2	2.02	1.45	0.16	2.78 a	1.45	0.16
0.2-0.3	2.02	1.42	0.17	2.40 b	1.42	0.17
0.3-0.4	1.63	1.48	0.18	2.02 c	1.48	0.18
CV (%)	22.06	5.63	6.07	14.53	5.63	6.07

^{ns} = non-significant (Tukey test, $p<0.05$). [1] = Averages followed by the same letter are similar according to the Tukey test ($p<0.05$). CV: coefficient of variation.

The high values of SRP found in the interrow areas between 0.1 and 0.2 m soil layer indicate the existence of a denser layer. This soil compaction is probably derived from the machinery traffic and from the harvest that is done by people walking in the area, which negatively impacts the root system development due to the soil compression caused.

The SD critical value to the root system development is also not well established in the literature. According to Reinert *et al.* (2008), the value of 1.55 kg dm^{-3} is considered as critical to characterize a soil as compacted if it presents between 200 and 550 g kg^{-1} of clay. Silva and Rosolem (2001) noted that the critical SD is mainly dependent on textural class and that the critical limit for crop development is about 1.6 kg dm^{-3}; however, Araújo *et al.* (2004) pointed that the critical value is around 1.65 kg dm^{-3} for sand soils and 1.45 kg dm^{-3} for clay soils.

The soil of the experimental area is an Oxisol, which has 210 g kg^{-1} of clay, and no differences for SD ($p<0.05$) were observed between the treatments (doses) 0, 4 and 12 L m^{-1}. However, differences were observed in the dose 8 L m^{-1}, where the soil depth of 0.1-0.2 m reached a SD of 1.64 kg dm^{-3} and a SRP of 2.55 MPa, which are an indication of soil compaction.

In a general view, the soil's physical attributes are directly related to productivity and crop development. The soil compaction raises SD and SRP, decreases the total porosity, pore size and breaks the space continuity in soil (LIMA *et al.*, 2013; TORRES *et al.*, 2019). Richart *et al.* (2005) complemented that the soil texture also influences the soil compaction process, once the mineralogical composition and quantity of the clay fraction in soil transfer the pressure received to deeper layers, accentuating the problem of soil compaction.

The soil moisture content also differed ($p<0.05$) according to the soil depth evaluated. The highest soil moisture observed value at 0.3 to 0.4 m for all treatments, and was around 18%, while in the more superficial layers presented soil moisture content around 16%.

To Pimentel Gomes and Garcia (2002), the variability of an attribute can be classified according to the magnitude of its coefficient of variation (CV). The CV can be low when it is less than 10%, moderate when between 10 and 20%, and very high when above 30%. The values for SRP and SD in the interrow were located between low and moderate CV ratings, which indicate that the variables can be considered homogeneous, increasing the credibility of the results presented.

Through the Pearson correlation analysis, a negative linear correlation ($p<0.01$) between soil density and moisture content in the planting line and interrow and between MC and SRP in the interrow, indicate an inverse relationship between these variables (Table 3).

According to Beutler *et al*. (2001), the reduction of the water content in the soil increases soil resistance to penetration, as was observed in this study, where the moisture ranged from 0.16 to 0.19 cm^3 cm^{-3} (Table 2). However, even in conditions of low soil moisture, the correlations between SRP, DS and UV do not change (BEUTLER *et al*., 2004; SILVA *et al*., 2008; TORRES *et al*. 2012; 2019). Arshad et al. (1996) emphasized that the ideal soil moisture to evaluate compaction is when soil is at field capacity.

The positive correlation between SD and SRP and the low negative correlations between DS and MC, and SD and SRP, reveal that the soil water content influenced the occurrence of large SRP and SD in the soil depths evaluated. This effect was especially large for the filter cake dose of 8 L m^{-1} at the soil depth between 0.1 and 0.2 m. This result can be justified by the dry period occurred in June 2016, when the undisturbed soil samples were collected for evaluations of the soil attributes.

Table 3. Pearson correlations between the values of soil resistance to penetration (SRP), soil density (SD) and moisture content (MC) assessed in areas with the application of 0, 4, 8 and 12 L m^{-1} of filter cake in the coffee crop

Variable	Pearson correlation '*r*'
Planting line	
SD x MC	- 0.22*
MC x SRP	- 0.20*
SD x SRP	0.25*
Interrow	
SD x MC	- 0.22*
MC x SRP	- 0.70*
SD x SRP	0.20*

* significant at 5%.

In studies with other crops, Araújo *et al*. (2004) found similar results and highlighted that the SRP has increased to the extent that the MC decreased. However, Martins *et al.* (2012) observed that the SRP remained constant even with the reduction of MC and explained that this is due to the high content of organic matter and the low performance of the forces of cohesion between the soil particles.

These correlations between the SD and the other soil attributes evaluated proved its importance as an indicator of soil quality because it is a component that is highly sensitive to changes caused by crop management (RAMOS *et al*. 2010; TORRES *et al*. 2015). The correlations of MC with all the other soil attributes prove their importance to the crop management since MC directly influences SRP and SD, and affects the development of the plant root system and crop production. Soils with higher SD and SRP have reduced permeability and infiltration of water, destruction of soil aggregates and jeopardize soil physical quality (PEZARICO *et al.* 2013).

The different doses of filter cake tested affected positively and significantly ($p<0.05$), soil macroporosity (Ma) that ranged between 18.4 and 21.4%, being greater in treatment 12 L m^{-1}, when compared to lower doses that were similar among each other (Figure 1). The soil depths evaluated did not differ for soil macroporosity ($p<0.05$). Soil microporosity (Mi) and macroporosity/total porosity (Ma/TP) relationship presented small changes ranging from 25 and 27.2%, and from about 44 e 46.1%, respectively. The regression curves adjusted for filter cake doses and soil porosity variables are presented in Figure 1.

According to Lake *et al.* (2012), conservation systems of soil management that incorporate organic matter present, after 3 to 4 years, high values of SD and Mi in the superficial layer and low values of Ma and TP, when compared with soils that received no input of organic compounds. The authors explained that this occurs due to the natural soil rearrangement over the years of organic inputs and the pressure caused by the transit of machinery and heavy implements.

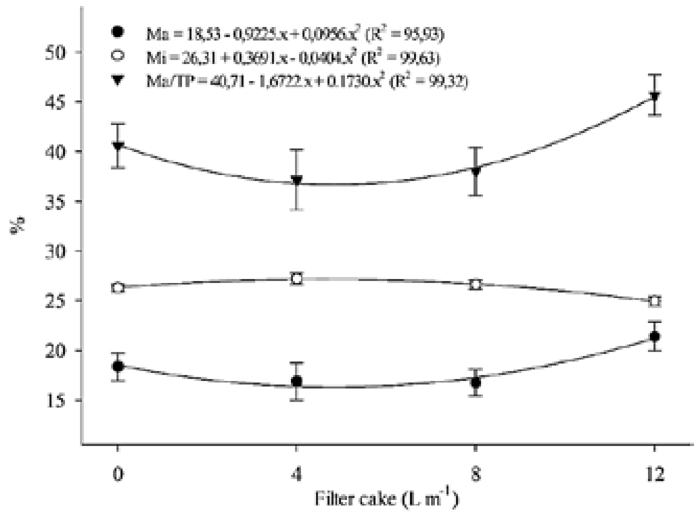

Figure 1. Macroporosity (Ma), microporosity (Mi) and macropore relation of the soil in coffee crop treated with sugarcane filter cake.

The critical limit for Ma considered to hinder the growth of roots is 10% for annual crops, and the ideal soil is the one that contains 1/3 Ma (34%) and 2/3 Mi (67%) (KIEHL, 1979). Taylor and Stewart (1972) highlight the density of soil macropores (Ma/TP) is an indication of favorable conditions to plant roots development, which must be greater than 33%.

In this study this relationship Ma/TP for all depths and filter cake doses were above 40%, indicating that there is enough space for the free growth of the coffee roots, even with the indication of soil compaction in the interrow for the doses of 4, 8 and 12 L m^{-1}. It should be noted that the distribution of pores in the soil depths evaluated, for all filter cake doses applied, was above the critical limit; however, below the ideal level, indicating that soil restructuration after the soil mobilization has not happened. As soil depth increases, there is an improvement in the distribution of pores by size, but not reaching the ideal condition (34% Ma and 67% Mi).

The study of different crops in areas where there is regular input of organic matter on the soil surface showed that the changes in soil physical attributes mainly occur in the superficial layer with the increase of SD and Mi, and decrease of Ma and TP (GUARESCHI *et al.*, 2012).

The soil aggregates retained in the 0.25 mm sieve (Table 4) demonstrated that the destructuring of the soil as a result of plowing, harrowing and furrow opening, persisted even after three years in a soil with low clay (210 g kg^{-1}) and organic matter (16 g dm^{-3}) content.

Table 4. Distribution of classes of soil aggregates in the coffee crop area treated with sugarcane filter cake

Soil depth (m)	Soil aggregate class					
	2	1	0.5	0.25	0.16	< 0.16
	……………………………….. % ………………………………..					
			0 L m^{-1}			
0-0.1	9.40 cB[1]	11.74 aA	18.25 aA	37.53 aA	17.32 aA	5.65 aA
0.1-0.2	16.30 bA	13.27 aA	17.36 aA	27.11 cB	18.61 aA	7.27 aA
0.2-0.3	23.62 aA	14.60 aA	19.19 aA	24.21 cB	12.20 bA	6.08 aA
0.3-0.4	16.60 bA	15.51 aA	17.25 aB	32.19 bB	12.10 bA	6.55 aA
			4 L m^{-1}			
0-0.1	14.05 aB	12.21 aA	18.86 bA	35.69 aA	14.32 aA	4.78 aA
0.1-0.2	14.58 aA	14.17 aA	19.37 bA	34.15 aA	10.26 aB	7.38 aA
0.2-0.3	16.11 aB	14.38 aA	20.69 bA	30.81 aA	12.25 aA	5.66 aA
0.3-0.4	13.96 aA	14.03 aA	25.13 aA	30.78 aB	12.30 aA	5.93 aA
			8 L m^{-1}			
0-0.1	21.39 aA	12.37 aA	16.49 bA	31.73 aA	11.17 aB	6.78 aA
0.1-0.2	16.48 aA	12.76 aA	19.80 aA	33.09 aA	13.06 aB	4.70 aA
0.2-0.3	13.71 aB	12.63 aA	21.95 aA	34.12 aA	12.88 aA	5.40 aA
0.3-0.4	13.38 aA	10.36 aB	20.70 aB	36.78 aA	12.75 aA	5.93 aA
			12 L m^{-1}			
0-0.1	10.39 aB	13.66 aA	17.82 bA	35.80 aA	16.57 aA	5.68 aA
0.1-0.2	14.66 aA	12.54 aA	18.41 bA	35.51 aA	12.88 bB	5.90 aA
0.2-0.3	15.06 aB	12.60 aA	20.29 aA	34.61 aA	1.117 bA	6.17 aA
0.3-0.4	11.58 aA	10.57 aB	22.99 aA	36.59 aA	13.37 bA	4.81 aA
CV (%)	13.48	18.38	11.44	9.41	16.34	13.01

[1] = Averages followed by the same letters (lowercase in the line and uppercase in the columns) do not differ variable for the same filter cake dose, according to Tukey test ($p<0.05$). CV: coefficient of variation.

The highest soil aggregates mass was recovered from the 2 mm sieve at the dose of 8 L m^{-1}, at the filter cake added, which favors the renewal of the coffee roots and the decomposition of plant residues that remain on the soil surface. The filter cake applied also favors the development of soil microorganisms that release aggregating substances that improve soil stability (COUTINHO *et al*. 2010).

Most of the coffee roots are located in the superficial soil layer. Since the presence of plant roots favors the stability of the soil aggregates, so there is an increased formation of new soil aggregates that will be frequently observed at this superficial soil layer. Plant roots and their exudates are responsible for making the connection between the soil mineral particles and aggregates, improving its stabilization (LOSS *et al*., 2009).

Gomar *et al*. (2002), assessing the influence of root biomass in soil physical attributes, concluded that the roots influenced the interaction between soil physical particles, the inflow of cementing agents (root exudates) and the activation of the microbial biomass. There are still beneficial effects of organic matter to the stabilization and formation of larger soil aggregates.

Regard to the weighted average diameter (WAD) and geometric (GMD) no significant differences ($p>0.05$) were observed among the factor (filter cake dose) levels or soil depths (Table 5). This situation of no differences among factor levels can be justified by the soil disruption caused during tillage operations and coffee planting process - about three years before evaluations.

Table 5. Geometric mean diameter (GMD) and weighted average diameter (WAD) and in coffee crop area treated with sugarcane filter cake

Soil depth (m)	0 L m^{-1}	4 L m^{-1}	8 L m^{-1}	12 L m^{-1}
	.... %			
		GMD		
0 - 0.1	0.43 ns	0.86 ns	0.67 ns	0.59 ns
0.1 - 0.2	0.44	0.65	0.66	0.56
0.2 - 0.3	0.72	0.61	0.57	0.66
0.3 - 0.4	0.53	0.58	0.53	0.66
Média	0.54	0.67	0.60	0.62
CV (%)	........................26.80........................			
		WAD		
0 - 0.1	1.10	1.42	1.01	1.19
0.1 - 0.2	0.77	1.31	1.04	1.14
0.2 - 0.3	1.06	1.19	0.75	1.32
0.3 - 0.4	0.80	1.14	0.86	1.24
Media	0.93	1.26	0.91	1.22 a
CV (%)	........................22.95........................			

CV: coefficient of variation.

The stability of soil aggregates, the WAD and GMD are directly influenced by the presence of organic matter in soil; however, as the area is a new coffee crop, the organic matter inflow from roots is still small. High values of WAD and GMD were observed in the most superficial soil layer due to the presence of the abundant root system of Poaceae species, which provided greater aggregation of particles and supply of carbon into the soil (COUTINHO *et al*. 2010).

Pereira *et al*. (2010), studying five management systems under the rotational cultivation of corn and soybean, observed that higher values of WAD and GMD highlight the contribution of management to the stabilization of soil aggregates. Similar results were observed by Demarchi *et al*. (2011), that reported great WAD and GMD values in pasture areas with other grasses such as *Urochloa brizantha*. The authors explained that these values were a consequence of great soil aggregation promoted by the plant roots cultivated in the area.

4 CONCLUSIONS

In general, the application of sugarcane filter cake over a long period has little effect on the soil physical attributes cultivated with coffee, regardless of the rate used. Only the porosity of the soil is affected by the application of filter cake rates, in which the 12 L m^{-1} rate increases the micro and macroporosity of the soil. This increase in micro and macroporosity promotes adequate conditions for the growth of coffee, which can generate great root growth and soil water retention, benefiting the crop in the long-term.

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