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Scientific Article

Short-term effects of filter cake and biochar on the physical-hydric properties of an oxisol

Efeitos de curto prazo da torta de filtro e biocarvão nas propriedades físico-hídricas de um Latossolo

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ABSTRACT – The residues and by-products from sugarcane processing can modify the primary soil structure and promote sustainable cultivation. Understanding the residue-soil interaction in water availability in tropical soils is essential for various economically important crops. Thus, this study aimed to evaluate the effects of filter cake and biochar application on the physical-hydraulic parameters of Oxisol in the short term. A field experiment was conducted on a commercial farm using six strip-plot treatments with four replications: Control; Bc100 (10 Mg ha^{-1} of biochar); Bc50 (5 Mg ha^{-1} of biochar); Fc100 (40 Mg ha^{-1} of filter cake); Fc50 (20 Mg ha^{-1} of filter cake); and Fc100+Bc100. After one year, soil samples (0-0.1 m layer) were collected and analyzed for bulk density, total porosity, macroporosity, microporosity, and the area under the soil water retention curve (AUWRC). Filter cake and biochar application did not influence soil density in the short term. However, applying 40 Mg ha^{-1} of filter cake increased total porosity and soil water retention. Additionally, combining 40 Mg ha^{-1} of filter cake with 10 Mg ha^{-1} of biochar further enhanced water retention, whereas biochar alone showed no significant effect. The results indicate that filter cake, either alone or in combination with biochar, improves the physical-hydraulic properties of medium-textured soil after one year of application.

Keywords: Coarse-textured soil. Slow pyrolysis. Soil water retention. Sugarcane residue.

RESUMO – Os resíduos e coprodutos do processamento da cana-de-açúcar podem modificar a estrutura primária do solo e favorecer o cultivo sustentável. Em solos tropicais, compreender a interação resíduo-solo na disponibilidade de água é essencial para diversos cultivos de interesse econômico. Assim, objetivou-se avaliar os efeitos da aplicação de torta de filtro e biocarvão sobre os parâmetros físicos-hídricos de um Latossolo em curto prazo. Um experimento de campo foi realizado em uma fazenda comercial, utilizando seis tratamentos, em faixas, com quatro repetições: Controle; Bc100 (10 Mg ha^{-1} de biocarvão); Bc50 (5 Mg ha^{-1} de biocarvão); Fc100 (40 Mg ha^{-1} de torta de filtro); Fc50 (20 Mg ha^{-1} de torta de filtro) e Fc100+Bc100. Após um ano, amostras de solo (0-0,1 m) foram coletadas e analisadas quanto à densidade aparente, porosidade total, macroporosidade, microporosidade e área sob a curva de retenção de água no solo (AUWRC). A aplicação de torta de filtro e biocarvão não influencia a densidade do solo em curto prazo. No entanto, a aplicação de 40 Mg ha^{-1} de torta de filtro aumenta a porosidade total e retenção de água no solo. Além disso, a mistura de 40 Mg ha^{-1} de torta de filtro + 10 Mg ha^{-1} de biocarvão promove o aumento da retenção de água no solo, ao contrário da aplicação isolada de biocarvão, que não apresenta efeito significativo. Os resultados indicam que a torta de filtro, isolada ou combinada com biocarvão, melhora as características físico-hídricas de um solo de textura média após um ano de aplicação.

Palavras-chave: Solo de textura grosseira. Pirólise lenta. Retenção de água no solo. Resíduo de cana-de-açúcar.

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INTRODUCTION

In 2024, sugarcane production in Brazil reached approximately 678 million tons, highlighting its relevance to the agro-industrial sector (CONAB, 2024). In addition to agronomic and socio-economic benefits, this high production generates large volumes of agro-industrial waste, which can be reused in the soil as organo-mineral fertilizers and conditioners to improve water retention (KINPARA, 2020).

Among these wastes, filter cake stands out for its composition rich in organic matter and nutrients. However, its effects on soil physical-hydraulic properties are still less studied than other aspects, although interest in this area has grown recently (DUARTE et al., 2020; TORRES et al., 2021). For every ton of sugarcane processed, it is estimated that 30 to 40 kg of filter cake is generated (BONASSA et al., 2015), making it widely available and with great potential for agricultural use. A promising alternative to adding value to this waste is its conversion into biochar, a material resulting from the pyrolysis process, characterized by high concentrations of carbon and a porous structure, which can contribute to improving soil properties (GHAZOUANI et al., 2023; YANG et al., 2022).

Compared to raw filter cake, there are more reports in the literature on the effects of biochar on soil physical-hydraulic properties (SPERATTI et al., 2017; TORRES et al., 2024). Biochar stands out for its greater stability and resistance to microbial degradation (KRULL et al., 2009), while filter cake, due to its high organic matter content (ALMEIDA JÚNIOR et al., 2011), can be rapidly decomposed, especially in tropical agroecosystems, where conditions favor intense soil microbial activity (PRIMAVESI, 2016). In this context, Oxisols, widely predominant in the Cerrado and essential for cultivating major economically important crops, have particular physical characteristics that can be enhanced by adding these residues. In particular, those with sandier textures exhibit high drainage, increased permeability, and low water retention capacity, making them more susceptible to erosion when not properly managed (REATTO et al., 2008).

Given the need for proper disposal of filter cake, it is essential to investigate its effects on soil in its raw form and as biochar, especially in coarser-textured soils, where increasing water retention is a constant challenge. Additionally, the evolution of these effects may differ over time, making it crucial to understand this dynamic to inform strategies that improve water retention and soil structural quality.

Thus, this study aimed to evaluate the effects of filter cake and biochar application on improving the physical-hydraulic parameters of a Red Oxisol with medium texture one year after application.

MATERIAL AND METHODS

Location and experimental characteristics

The experiment was carried out in Jaciara–MT, Brazil, to evaluate the effects of organic residues on the soil. The experimental area was located at 16º03'56.5" S, 55º05'35.7" W, under a tropical climate with dry winter (Aw), according to the classification of Köppen and Geiger (1928) (APARECIDO et al., 2020). In the last ten (10) years, the area has been used for the cultivation of soybeans (*Glycine max* (L) Merrill) and corn (*Zea mays* L.) in a crop succession system with fallow on a dystrophic Red-Yellow Oxisol of medium texture (75% sand, 23% clay and 2% silt).

For the tests, six (06) treatments were implemented in strips, with four replications each: Control; 10 Mg ha^{-1} of biochar; 100% of the dose (Bc100); 5 Mg ha^{-1} of biochar; 50% of the dose (Bc50); 40 Mg ha^{-1} of filter cake; 100% of the dose (Fc100); 20 Mg ha^{-1} of filter cake; 50% of the dose (Fc50), and Fc100+Bc100. All treatments received NPK mineral fertilizer at a rate of 0.35 Mg ha^{-1} using the 04-30-20 formulation. The fertilizer was applied to the soil in February 2018. Figure 1 presents the location of the farm in Mato Grosso State and the cultivated area used in the experiment.

Biochar was produced by the company SPPT Pesquisas Tecnológicas (Mogi Mirim, SP, Brazil) through slow pyrolysis at 600 °C temperature, using sugar cane filter cake purchased from Porto Safe sugarcane mill located in the same region as the experiment.

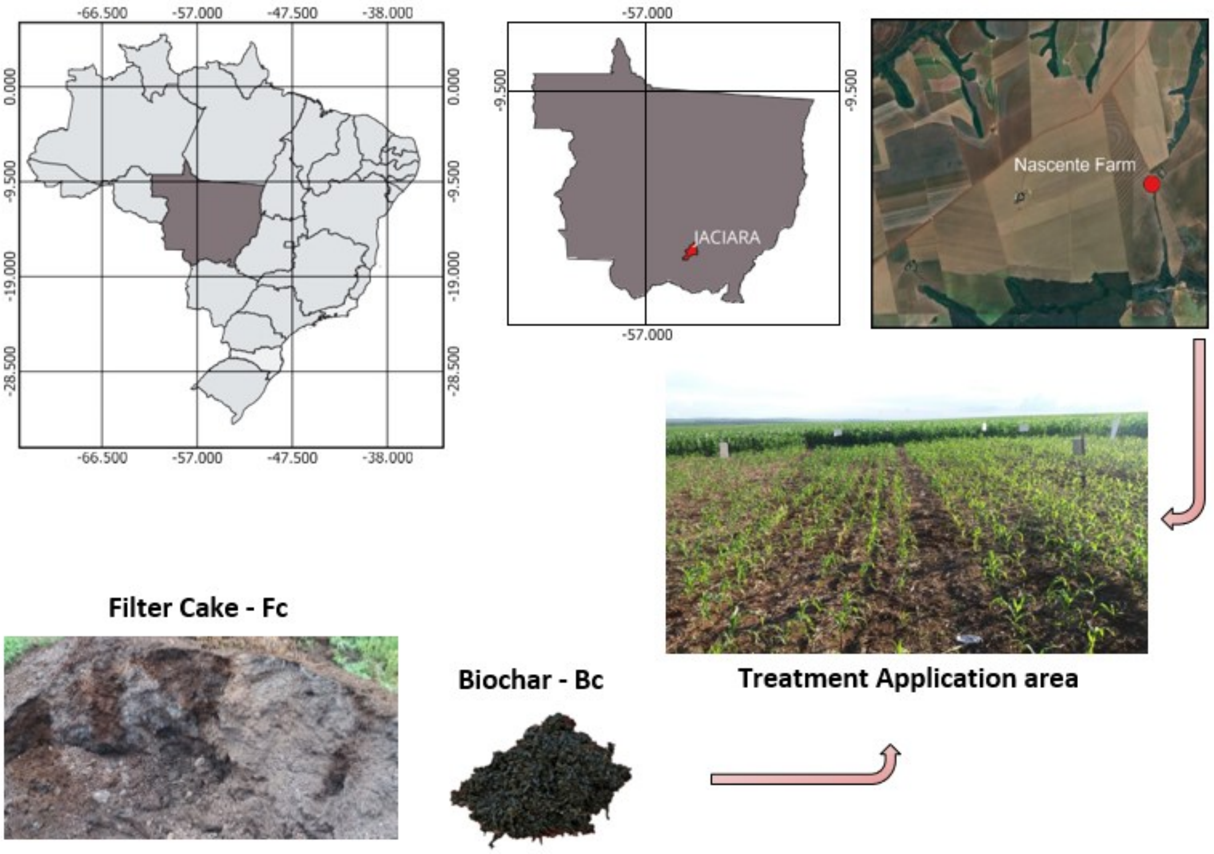

Figure 1. Location and experimental area treated with biochar and filter cake, Jaciara, MT, Brazil.

Physical-hydric properties of the soil analyzed

Undisturbed soil samples were collected from the 0–0.05 m and 0.05–0.10 m soil layers in each experimental plot one year after the treatments were applied. In these samples, soil bulk density (BD, in kg m^{-3}), total porosity (TP, in m^3 m^{-3}), macroporosity (Ma, in m^3 m^{-3}), and microporosity (Mi, in m^3 m^{-3}) were determined using the volumetric ring method. Soil moisture at matric potentials of -10, -40, -60, -100, -330, -600, and -1,000 hPa were measured using a Sand Tension Table and Richards Chamber, according to Teixeira et al. (2017).

The psychrometric method was used to determine soil moisture at a matric potential of –15,000 hPa. This method estimates specific points on the soil water retention curve based on pre-defined readings obtained with the WP4C Dewpoint Potential Meter. For this, disturbed samples were collected in the same locations and depths as the undisturbed samples. Five reading intervals between 0 and -25,000 hPa were defined and used to estimate soil moisture at the matric potential of -15,000 hPa using the linear regression method.

With the pairs of volumetric humidity values and their respective matric potentials, the parameters were adjusted to the Van Genuchten model (VAN GENUCHTEN, 1980) using the SWRC software (DOURADO-NETO et al., 2000), according to Equation 1:

$$\theta = \theta_r + \frac{(\theta_s - \theta_r)}{[1 + (\alpha|\Psi|)^n]^m} \quad (1)$$

Where: θ is the volumetric humidity (m^3 m^{-3}); θ_r is the residual moisture (m^3 m^{-3}); θ_s is the saturation humidity (m^3 m^{-3}); Ψ is the matric potential (hPa); and α, n, and m are the empirical parameters of the equation that govern the shape of the fitted curve.

The area under the soil water retention curve (AUWRC) was obtained for each treatment, according to Equation 2:

$$AUWRC = \sum_{i=1}^{n} [\theta_i(\Psi_{mi+1} - \Psi_{mi}) + 0.5(\theta_{i+1} - \theta_i)(\Psi_{mi+1} - \Psi_{mi})] \quad (2)$$

Where: AUWRC is the area under the soil water retention curve (m^3 m^{-3} hPa^{-1}); θ_i is the initial humidity (m^3 m^{-3}), and Ψ_{mi} is the initial matric potential (hPa).

Statistical analysis

To analyze the effects of residue application on the soil, treatments with residue application were contrasted with the treatment without application (control) using Student's t-test ($P \leq 0.05$) for independent samples. The trend effect was discussed when $0.05 < P \leq 0.10$. The analyses considered the average between the depths from 0.00 to 0.05 m and 0.05 to 0.10 m.

The soil water retention curves were adjusted based on minimizing deviations and the coefficients of determination (R^2) for the selection of significant model parameters. The AUWRC was calculated by numerically integrating, using the trapezoid method, the adjusted parameters of the soil water retention curve as a function of the matric potential.

All statistical analyses were performed using RStudio software, version 2023.

RESULTS AND DISCUSSION

Short-term effect of treatments on soil porosity and density

After one year of application, filter cake and biochar did not significantly alter soil bulk density (BD) ($P > 0.14$), with an average of 1.4135 kg m^{-3}. However, compared to the control treatment, the Bc50 and Bc100 treatments slightly reduced BD.

Despite the relatively short period, a decreasing trend in BD was observed in the biochar treatments, whereas filter cake, both alone and in combination with biochar, tended to increase this parameter. On the other hand, the evaluation of total porosity (TP) showed that the 100% filter cake dose significantly increased TP, followed by the Fc50 and Bc50 treatments ($P \leq 0.05$) (Figure 2).

Duarte et al. (2020) and Torres et al. (2021) observed a similar effect on TP after 18 and 36 months of application, corroborating our findings. It is believed that the porous structure of the filter cake and the contribution of organic matter contributed to the improvements observed in our study, especially in the expansion of voids in the soil after 12 months of application.

Within the soil's porous structure (TP), larger pores (Ma) are responsible for aeration and drainage, while smaller pores (Mi) retain water. The balance between these pores is essential to ensure suitable conditions for plant growth (YUDINA et al., 2022; RIBEIRO et al., 2007). In this study, an increase of 9.06% and 14.57% in Ma was observed in the Bc50 ($P \leq 0.01$) and Fc100+Bc100 ($P \leq 0.01$) treatments, respectively. Conversely, a reduction of 25.19% and 32.59% in Mi was recorded in the Fc100+Bc100 ($P \leq 0.01$) and Fc100 ($P \leq 0.01$) treatments, respectively, compared to the control (Ctrl) (Figure 3).

The observed results may be related to the structural characteristics of the materials applied to the soil. The increase in Ma in the Bc50 and Fc100+Bc100 treatments can be attributed to incorporating organic material, which promotes aggregate formation and, consequently, the development of larger pores. This effect may be enhanced by the decomposition of organic matter, which fosters soil structure reorganization and greater aggregate stability, resulting in improved pore connectivity (YU et al., 2023).

On the other hand, the reduction in Mi in the Fc100+Bc100 and Fc100 treatments may be associated with pore redistribution in the soil. The introduction of organic materials can reduce compaction and favor the formation of larger pores at the expense of smaller ones, particularly in initially denser soils (RICHART et al., 2005). This effect suggests that adding filter cake and biochar can modify pore space distribution, improving aeration and water infiltration, which are essential factors for water dynamics and root development.

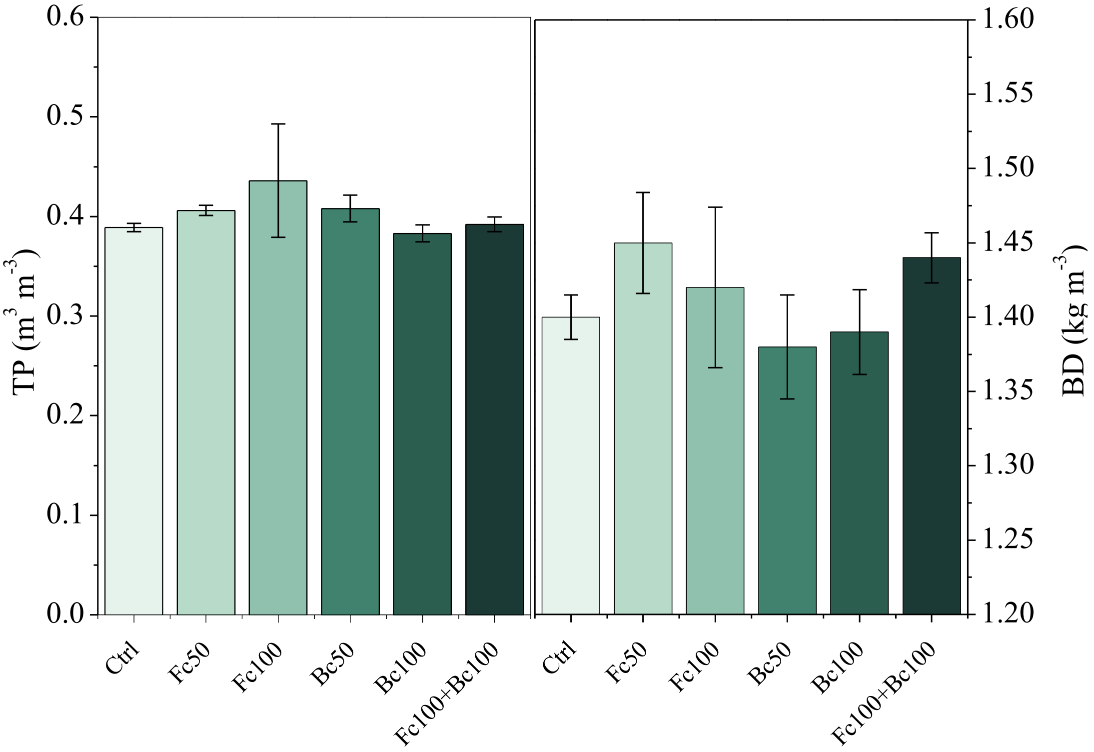

Figure 2. Short-term effects on the bulk density (BD) and total porosity (TP) of an Oxisol following filter cake and biochar application. Error bars represent the standard error of the mean.

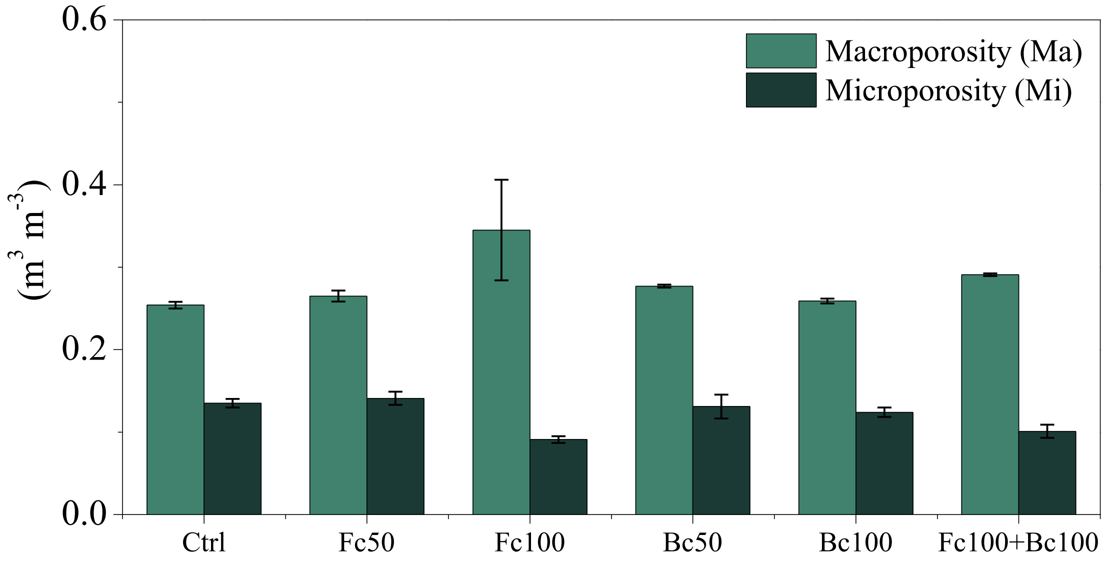

Figure 3. Short-term effects on the macroporosity (Ma) and microporosity (Mi) of an Oxisol following filter cake and biochar application. Error bars represent the standard error of the mean.

Short-term effect of treatments on the soil water retention curve

The soil water retention curves exhibited good fits ($R^2 > 0.60$) for all treatments, enhancing the accuracy of comparisons between treatments, as shown in Table 1 for the parameters saturation moisture (θs), residual moisture (θr), and the empirical parameters of the equation (α, m, and n).

Filter cake application resulted in an increasing trend in AUWRC, with an 18.2% increase at 50% of the recommended dose ($P = 0.08$) and approximately 84.6% at the full dose ($P = 0.07$) compared to the control. However, biochar application did not significantly affect AUWRC ($P \geq 0.12$), with an average value of 3,162.32 m^3 m^{-3} hPa^{-1} (Figure 4).

Table 1. Parameters of the soil water retention equation fitted for the different treatments with sugarcane filter cake and biochar.

Treatment	Adjusted parameters – Van Genuchten (1980)					R^2
	θ_S	θr	α	m	n	
Ctrl	0.4718	0.1635	9.9×10^{-8}	386.21	0.5977	0.69
Fc50	0.4598	0.1828	1.3×10^{-5}	10.330	0.4089	0.92
Fc100	0.5465	0.264	9.3×10^{-7}	12.853	0.3678	0.74
Bc50	0.4561	0.1820	3.1×10^{-6}	12.727	0.3658	0.93
Bc100	0.4782	0.1798	8.7×10^{-7}	12.799	0.2825	0.88
Fc100+Bc100	0.4639	0.2264	6.7×10^{-7}	12.882	0.3112	0.84

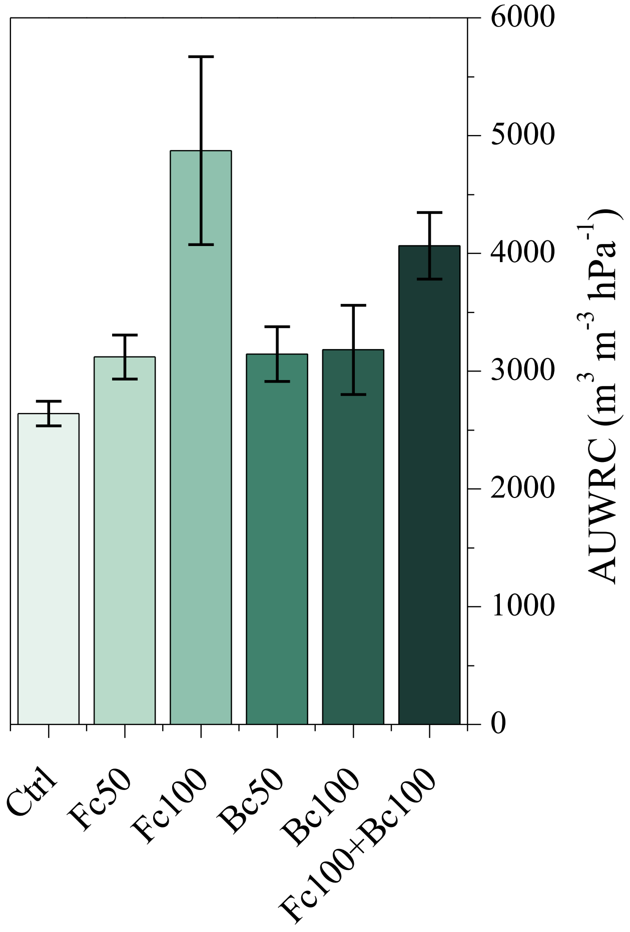

Figure 4. Short-term effects on the area under the soil water retention curve (AUWRC) of an Oxisol following filter cake and biochar application. Error bars represent the standard error of the mean.

Filter cake application resulted in an increasing trend in AUWRC, with an 18.2% increase at 50% of the recommended dose (P = 0.08) and approximately 84.6% at the full dose (P = 0.07) compared to the control. However, biochar application did not significantly affect AUWRC ($P \geq 0.12$), with an average value of 3,162.32 m^3 m^{-3} hPa^{-1} (Figure 4).

The filter cake and biochar characteristics contributed to improving soil water retention (Figure 5). However, the substantial increase observed in the Fc100 treatment highlights the impact of filter cake, especially when combined with biochar, resulting in a significant 53.94% increase (P<0.01) in AUWRC compared to the control area. Although there was a 19.86% reduction between the Fc100 and Fc100+Bc100 treatments, the combined application remains a viable alternative, considering not only the positive effects of biochar on soil water retention but also its long-term benefits (DUARTE et al., 2020).

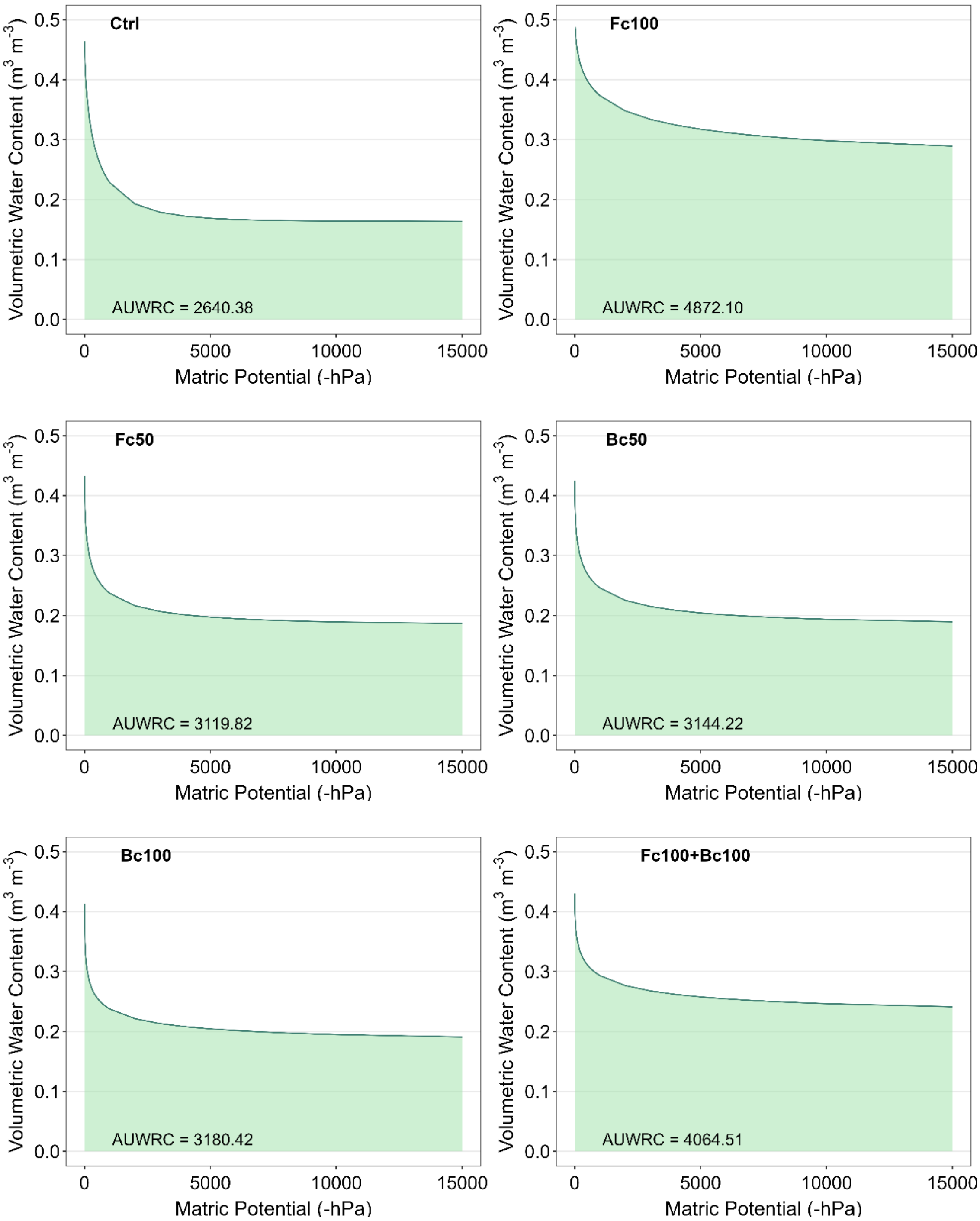

Figure 5. Soil water retention curves and area under the soil water retention curve (AUWRC, in $m^3 m^{-3} hPa^{-1}$) for treatments with filter cake and biochar application.

The Fc50, Bc50, and Bc100 treatments showed slight variation among themselves (< 2.0%), indicating that the recommended dose of biochar did not have a superior effect compared to the reduced dose (50%) and that both biochar treatments maintained the soil water retention characteristics observed in the Fc50 treatment. On the other hand, the Fc100 treatment had a more pronounced impact, standing out from the others.

These results indicate that even in coarser-textured soils (75% sand), the application of filter cake improves short-term water retention, which is particularly relevant for the state of Mato Grosso, considering the need for sugarcane residue allocation and the diversity of soils in the region. It is believed that the satisfactory performance of filter cake may be related to its high organic matter content, which promotes the formation of stable aggregates and improves soil structure, especially in treatments with the recommended dose, which is four times higher than the recommended dose of biochar.

Oxisols, which account for approximately 48% of the soil class in the Cerrado and 9% in the state of Mato Grosso (REATTO et al., 2008), have high permeability and drainage, but their water retention can be enhanced with the application of filter cake, contributing to more efficient management.

Although biochar also improves soil water retention properties (GONDIM et al., 2018; SPERATTI et al., 2017), its benefits tend to become more evident in the long term. Additionally, its production requires specific methods that may be unfeasible or unavailable in certain regions. On the other hand, filter cake emerges as a viable alternative for improving soil physical quality, especially in annual crops that require more immediate effects.

Some studies indicate that the efficiency of biochar in the soil is influenced by the application time and dose, with more pronounced effects from the second year onward and at doses exceeding 20 Mg ha^{-1} (DUARTE et al., 2020; CHEN et al., 2018). Since our objective was to evaluate the short-term effects on the soil, the results for biochar were promising, even with the maximum application of 10 Mg ha^{-1} in a coarser-textured soil.

These findings are particularly relevant in the context of climate change, where improving water use efficiency and enhancing soil resilience are critical to sustaining agricultural productivity. Adopting practices that increase soil water retention in the short term can help mitigate the impacts of drought and promote the sustainability of agricultural areas. In this sense, the results of this study not only confirm the effectiveness and potential of filter cake and biochar in coarser-textured soils in the short term but also pave the way for future research on how combinations of raw and processed organic residues can maximize the benefits for soil health and food production.

CONCLUSIONS

The application of filter cake and biochar does not alter soil density in the short term;

The application of 40 Mg ha^{-1} of filter cake increases total porosity and soil water retention;

The combination of 40 Mg ha^{-1} of filter cake with 10 Mg ha^{-1} of biochar enhances water retention, while the isolated application of biochar shows no significant effect;

The results indicate that filter cake, at the recommended dose of 40 Mg ha^{-1}, whether applied alone or combined with biochar, improves the physical-hydraulic properties of medium-textured soil after one year of application.

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