Universidade Federal Rural do Semi-Árido
Pró-Reitoria de Pesquisa e Pós-Graduação
https://periodicos.ufersa.edu.br/index.php/caatinga
ISSN 1983-2125 (online)

http://dx.doi.org/10.1590/1983-21252024v3711792rc

Scientific Article

Water retention in sandy soils of different origins with the addition of biochar

Retenção de água em solos arenosos de diferentes materiais de origem com adição de biocarvão

Gilmar N. Torres[1]*, Ricardo S. S. Amorim[2], Luis A. Di L. Di Raimo[1], Ohana C. O. Faria[1], Eduardo G. Couto[3]

[1]Postgraduate Program in Tropical Agriculture, Universidade Federal de Mato Grosso, Cuiabá, MT, Brazil. [2]Department of Agricultural Engineering, Universidade Federal de Viçosa, Viçosa, MG, Brazil. [3]Department of Soil and Agricultural Engineering, Universidade Federal de Mato Grosso, Cuiabá, MT, Brazil.

ABSTRACT - This study evaluated biochar influence on water retention in sandy soils with different source materials. Samples from Horizon A of six profiles of Neossolos Quartzarênicos (Salto das Nuvens, Utiariti, Pantanal, Coberturas Detrito Lateríticas Ferruginosas, Botucatu e Bauru formations), collected in different regions of the state of Mato Grosso, Brazil, were used to determine the hydro-physical characteristics with the addition of biochar. The biochars assessed were produced from two sources of raw material (sugarcane filter cake and cotton husks) under pyrolysis at a temperature of 400 °C. Retention curves for soils with and without biochar, the field capacity, permanent wilting point, available water in the soil, total porosity, macroporosity, and microporosity were determined. The results evidenced that the application of biochar increases the microporosity (86.7% with cotton husks biochar and 67.9% with filter cake biochar) and reduces the microporosity of sandy soils (38.2% with cotton husks biochar and 36.0% with filter cake biochar); also, there was a higher increase in water availability with biochar from cotton husks (57.1%). There was an increase in soil microporosity and a reduction in macroporosity due to the influence of biochar addition in the sandy soils from the Salto das Nuvens, Utiariti, Pantanal e Coberturas Detrito Lateríticas ferruginosas, with no changes in the Botucatu and Bauru Formations. Biochar increases water retention in sandy soils; however, this does not occur for all geological formations studied.

Keywords: Neossolo Quartzarênico. Geological Formations. Fine Sand.

RESUMO - O objetivo deste trabalho foi avaliar a influência do biocarvão na retenção de água em solos arenosos de diferentes materiais de origem. Foram utilizadas amostras do Horizonte A de seis perfis de Neossolos Quartzarênicos (formações: Salto das Nuvens, Utiariti, Pantanal, Coberturas Detrito Lateríticas ferruginosas, Botucatu e Bauru), coletadas em diferentes regiões do estado de Mato Grosso, Brasil, para determinação das características físico-hídricas com adição de biocarvão. Os biocarvões testados foram produzidos a partir de duas fontes de matéria prima (torta do filtro de cana-de-açúcar e capulho do algodão) sob pirólise em temperatura de 400° C. Foram determinadas curvas de retenção para solos com e sem biocarvão, a capacidade de campo, o ponto de murcha permanente, água disponível no solo, porosidade total, macroporosidade e microporosidade. Os resultados mostram que a aplicação de biocarvão aumenta a microporosidade (86,7% com biocarvão de resíduos de algodão, 67,9% com biocarvão de torta de filtro) e reduz a macroporosidade dos solos arenosos (38,2% com biocarvão de resíduos de algodão, 36,0% com biocarvão de torta de filtro), e a disponibilidade de água aumenta ainda mais com o biocarvão de resíduos de algodão (57.1%). Houve um aumento na microporosidade do solo e redução na macroporosidade pela influência da adição do biocarvão nos solos arenosos das Formações Salto das Nuvens, Utiariti, Pantanal e Coberturas Detrito Lateríticas ferruginosas, sem mudanças nas Formações Botucatu e Bauru. O biocarvão aumenta a retenção de água nos solos arenosos, no entanto isso não ocorre para os solos arenosos de todas as formações geológicas estudadas.

Palavras-chave: Neossolo Quartzarênico. Formações Geológicas. Areia Fina.

Conflict of interest: The authors declare no conflict of interest related to the publication of this manuscript.

Received for publication in: March 21, 2023.
Accepted in: September 4, 2023.

***Corresponding author:**
<gilmaragro@gmail.com>

INTRODUCTION

Biochar is a porous, carbon-rich material produced by pyrolysis, i.e., heating organic matter of plant or animal origin to temperatures between 175°C and 950°C in an environment with little or no oxygen (LI et al., 2023; YANG et al., 2022), which has the potential to be used as a soil conditioner and corrective.

Indicated as a sustainability practice, the application of biochar to the soil brings several benefits, such as increased carbon sequestration in the soil and reduced greenhouse gas emissions, changes in chemical, physical and biological characteristics, increased water retention capacity, improved soil health, better crop growth, and yield (LEHMANN et al., 2021; MURTAZA et al., 2023; CARVALHO et al., 2020).

An important factor in water retention in the soil, considering the use of biochar, is the structure and porosity of the bioproduct, as the adsorption process takes place mainly in the micropores. Macropores and mesopores play important roles in the retention process as they act as conduits for water to reach the micropores. Carvalho et al. (2020) obtained results that biochar correction decreased soil bulk density and increased water retention capacity, micropore volume, and available water content, associating this greater soil water retention in corrected soil with the inherent characteristics of biochar (e.g., internal porosity) and potential improvements in soil structure. Other characteristics of biochar may be associated with greater water retention, such as specific surface area and CEC.

The surface area of biochar is generally greater than sand and comparable to clay. Mixing biochar with soil results in an increase in the total specific surface area of the soil (PITUELLO et al., 2018).

The total surface area of filter cake biochar is greater than that of cotton husks biochar, and the average particle size of filter cake biochar is smaller than that of cotton husks biochar. However, the cation exchange capacity (CEC) of biochar produced from cotton husks is approximately 12 times higher than the CEC of biochar from sugarcane filter cake, one of the most important properties for promoting changes in the soil's hydro-physical characteristics (SPERATTI et al., 2017). Cation exchange capacity and specific surface area are indirect measures of the capacity of soils to retain water, nutrients, and various contaminants, so adding materials with high CEC to the soil increases its water retention capacity and availability (EDEH; MAŠEK; BUSS, 2020).

Therefore, adding biochar to the soil can improve its structure, resulting in better nutrient cycling, reduced loss of cations through leaching, and greater water retention. These effects are particularly relevant in sandy soils due to the porosity of the biochar (LEHMANN; JOSEPH, 2015), however, in some cases, this effect is only observed in the long term due to the evolution of the interaction of the biochar with the soil matrix (MADARI et al., 2017).

Juriga et al. (2018) conducted a three-year study to investigate the impact of different biochar doses on soil organic matter and structure parameters. The researchers found that applying biochar improved the quantitative parameters of soil organic matter, including an increase in organic carbon content. Furthermore, when the 20 Mg ha^{-1} dose of biochar was applied, there was a significant increase in the content of water-stable macroaggregates compared to the control group. Consequently, this study showed a positive influence of biochar on soil structure and water retention. This study aimed to evaluate the influence of biochar on water retention in sandy soils of different origin.

MATERIAL AND METHODS

Soil collection and experimental design

To assess water retention and physical-hydric characteristics with the addition of biochar, samples of Horizon A were used from profiles of six Neossolos Quartzarênicos classified according to the Brazilian Soil Classification System (SANTOS et al., 2013) collected in different regions of Brazil within the state of Mato Grosso (Table 1) (Planalto dos Parecis, Planalto de Tapirapuã, Depressão Alto Rio Paraguai e a região do Planalto dos Guimarães). The geology and geomorphology information was obtained from the Diagnosis phase of the Ecological-Economic Zoning of the State of Mato Grosso (SEPLAN, 2001).

Table 1. Geographical coordinates (WGS84), geological formation (SEPLAN, 2001), and soil class of the profiles in which soil water retention was assessed.

Profile	Latitude	Longitude	Altitude (m)	Geological Formation	Soil (SiBCS)
P 03	15º22’34,5”S	55º37’02,5”W	480	Botucatu	RQo
P 04	15º15’59,4”S	55º34’14,5”W	401	Bauru	RQo
P 05	15º09’55,5”S	55º32’0,2”W	374	Bauru	RQo
P 06	15º14’24,2”S	55º32’48,1”W	426	Bauru	RQo
P 07	15º07’41,3”S	55º25’17,5”W	363	Bauru	RQo
P 08	15º07’53,3”S	55º22’39,1”W	392	Bauru	RQo
P 10	15º05’41,7”S	55º46’01,4”W	313	Bauru	LVd
P 13	15º04’46,1”S	55º54’28,4”W	344	Bauru	RQo
P 14	14°16'55.10"S	56°56'40.62"O	362	Salto das Nuvens	RQo
P 15	14°20'44.29"S	57°15'21.35"O	362	Salto das Nuvens	RQo
P 17	14°16'43.40"S	57°32'41.48"O	540	Utiariti	RQo
P 18	14°38'29.20"S	58°18'41.34"O	609	Utiariti	RQo
P 20	15° 6'32.85"S	58°32'42.45"O	510	Utiariti	RQo
P 21	13°35'47.32"S	59°50'29.48"O	584	Utiariti	RQo
P 23	13°46'36.73"S	59°42'44.74"O	591	Utiariti	RQo
P 24	14°11'45.44"S	59°27'18.67"O	637	Utiariti	RQo
P 25	14°42'49.55"S	59°02'14.32"O	598	Coberturas Detrito-Lateríticas Ferruginosas	RQo
P 29	15°24'38.03"S	57°27'54.78"O	187	Pantanal	RQo

The soil samples have a sandy texture, between the sandy and sandy loam classes (USDA, 1999), generally with high levels of fine and very fine sand and low levels of coarse sand and a soil bulk density of 1.38 and 1.66 $g.cm^{-3}$.

The biochars assessed were produced commercially (SPPT Ltda., Mogi Morim - SP) from two sources of raw material (sugarcane filter cake and cotton husks) under pyrolysis at a temperature of 400°C. The physical and chemical characteristics of the biochars are shown in Table 2. These were then ground and sieved through sieves with a mesh size of <2 mm. Cylinders 5 cm in diameter and 5 cm high were assembled with soil containing 1% dry mass of sugarcane filter cake biochar and 1% dry mass of cotton husks biochar. Field-collected samples of cylinders 5 cm in diameter and 5 cm high without added biochar were used as the control treatment. Three replicates were used for each treatment.

Table 2. Total surface area, average particle size, size at D10 (largest grain size at 10% of the distribution), size at D90 (largest grain size at 90% of the distribution), and cation-exchange capacity (CEC) of the biochars used.

	Total Surface Area (m^2 g^{-1})	Medium size (µm)	D10 (µm)	D90 (µm)	CEC pH7 ($cmol_c$ dm^{-3})
Cotton husks	0.2	888.2 ± 131.1	33.0 ± 7.3	2.790.5 ± 20	49.02
Filter cake	13.5	457.9 ± 7.3	42.4 ± 1.6	1.241.6 ± 61.7	3.88

Speratti et al. (2017).

Soil physical characteristics and water retention curve

Soil physical characteristics were determined, such as: soil bulk density (Db, dry soil mass by total sample volume), total porosity (TP, volume of saturated water by sample volume), macroporosity (Ma, volumetric water content in the soil retained at tensions <6 kPa), microporosity (Mi, volumetric water content in the soil retained at tensions >6 kPa), field capacity (FC, volume of water in the soil retained at tension equal to 10 kPa), and permanent wilting point (PWP, volume of water in the soil retained at tension 1500 kPa) (REINERT; REICHERT, 2006; KLEIN; REICHERT; REINERT,2006; KLEIN; LIBARDI, 2002).

To obtain the water retention curve (WRC) points, the following matrix tensions were used: a) by the tension table, at tensions of 0, 1, 6, and 10 kPa (REINERT; REICHERT, 2006); b) by the Richards pressure plate, at tensions of 33 and 100 kPa; and c) by the WP4 potentiometer (Dewpoint PotentiaMeter), at tensions of 500, 750, 1,000, 1,250, and 1,500 kPa (KLEIN; REICHERT; REINERT, 2006). With the volumetric moisture values (m^3 m^{-3}) obtained at each matric tension, the WRC was adjusted using the Van Genuchten (1980) model, according to Equation 1:

$$\theta = \theta r + \frac{(\theta s - \theta r)}{[1 + (\alpha \Psi)^n]^m} \qquad (1)$$

where: θ is the volumetric moisture (m^3 m^{-3}); θr is the residual moisture (m^3 m^{-3}); θs is the saturation moisture (m^3 m^{-3}); Ψ is the maximum potential (hPa); and α (hPa^{-1}), n and, m are the empirical parameters of the equation that determine the shape of the fitted curve.

The available water capacity (AWC) was calculated from the WRC, being the volumetric water content between the FC and the PWP. To verify possible changes in the WRC of the different soils, the area under the soil water retention curve (AUWRC) was calculated by integrating the areas under the retention curve between each matric tension determined, according to Equation 2.

$$AUWRC = \sum_{k=1}^{n} \frac{\theta_k + \theta_{k-1}}{2} \times \Psi j \qquad (2)$$

where: *AUWRC* is the area under the water retention curve (m^3 m^{-3} MPa^{-1}); θ is the volumetric soil moisture (m^3 m^{-3}); *k* is the moisture reading matric tension; *n* is the number of matric tensions determined on the retention curve; *j* is the value of the matric tensions (MPa) for each interval.

Particle size distribution

The particle size distribution of the soil was evaluated by laser diffraction with fractionated samples of particles <0.053 mm and from 0.053 to 2.0 mm (TORRES et al., 2023). The results of these particle size distribution curves were used to evaluate the grain size parameters according to the geometric method of graphical measurements of Folk and Ward (1957).

Statistical analysis

Tests were conducted for normal distribution, homogeneity of variance, and Kruskal-Wallis with multiple comparisons of the mean classification for all groups and confidence interval. The analyses were conducted using Statistica 6.0 software.

RESULTS AND DISCUSSION

Retention curve in biochar-soil mixtures

In general, the influence of biochar on water retention properties depends on factors such as the type of biomass used and the pyrolysis temperature used to produce it (OJEDA et al., 2015). Biochar from cotton waste produced at 400 ºC improved the soil water retention properties more efficiently than the sugarcane filter cake produced at 400 ºC (Figure 1).

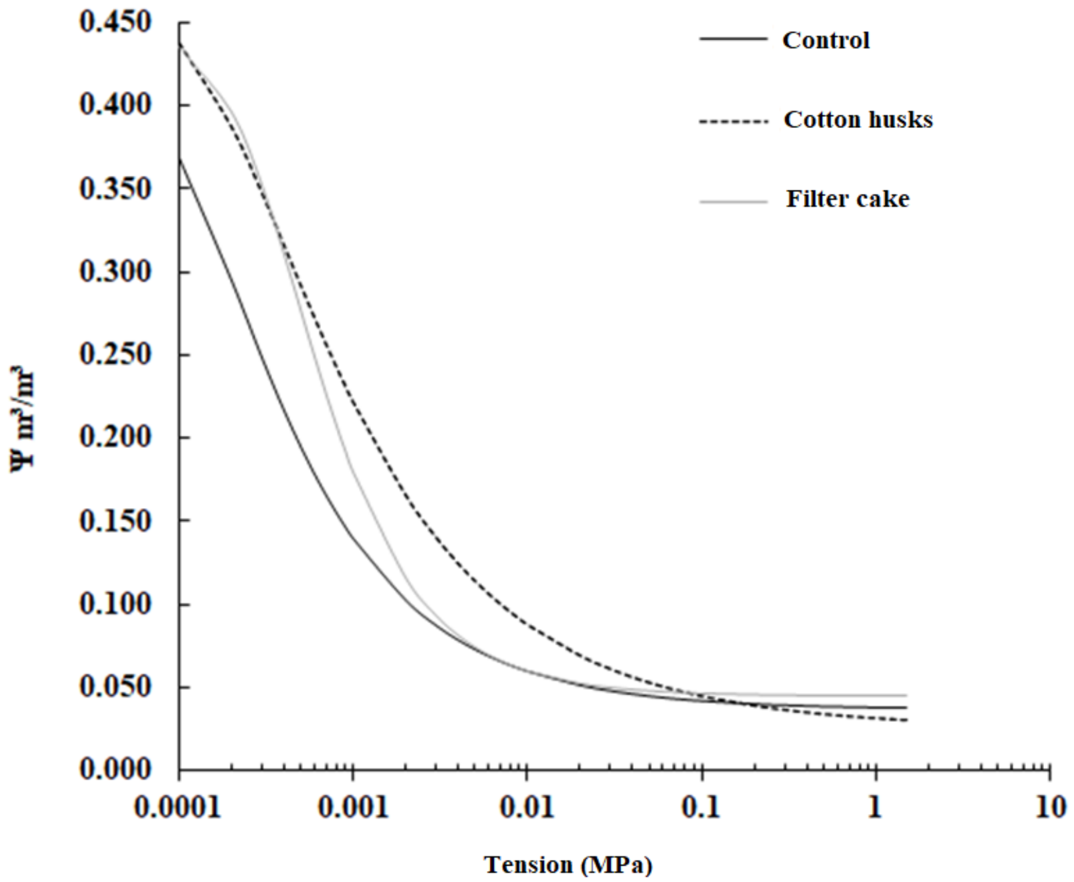

Figure 1. Soil water retention characteristic curve for soils without biochar (Control) and soils with biochar (cotton husks and filter cake).

An important factor in soil water retention is the structure and porosity of the biochar, as the retention process occurs mainly in the micropores. A second factor in the increase in soil microporosity may be due to the rearrangement of the particles, with the added biochar becoming another component in the structuring of the soil along with the sand, silt, clay, and organic components already present in it. Macropores and mesopores play important roles in the retention process as they act as conduits for water to reach the micropores, which retain the water in the soil (ZHANG; YOU, 2013).

When added to the soil, biochar has the potential to increase pores in the range between 30 and 0.3 nm in diameter (VERHEIJEN et al., 2010); however, pores related to water retention are in the range between 0.2 and 30 µm in diameter (HARDIE et al., 2014). In the soils with cotton biochar, there may have been a greater increase in porosity in this range, leading to an increase in AWC. However, when added to high levels (e.g. 5% w/w), the water retention in the soil caused by biochar can cause problems, as observed by Speratti et al. (2017) when cotton biochar increased AWC and nutrient availability, but the water probably lacked mobility, and thus this volume of water and solutes became unavailable for plant absorption (MASIELLO et al., 2015).

Effect of biochar on the physical characteristics of different sandy soils

The application of biochar has beneficial effects on some physical properties, especially on hydro-physical characteristics such as soil bulk density, porosity, retention capacity, and water availability in the soil, which can favor the development and yield of plants, natural ecosystems, and agroecosystems (XIAO et al., 2016; KARHU et al., 2011; ABEL et al., 2013). The surface area of biochar is generally greater than sand and comparable to clay. The soil-biochar mixture can then increase the total specific surface area of the soil (NOVAK et al., 2012).

Comparing the Db of soils with and without biochar, the Db remained the same after applying biochar. The treatments with added biochar were prepared under the same soil bulk density conditions as the soil without added biochar, using the average soil bulk density of the samples as a basis (Table 3).

The highest Db were obtained in the Coberturas Detrito Lateríticas Ferruginosas formation. This could be because the source material of these soils is rich in iron concretions, materials with a higher particle density, which usually results in soils with a higher Db (Figure 2).

Table 3. Soil bulk density (Db), total porosity (TP), macropores (Ma), and micropores (Mi) of soils from different geological formations without biochar (Control) and with biochar (cotton husks and filter cake).

Treatment	Db ($g.cm^{-3}$)	TP (%)	Ma (%)	Mi (%)
Control	1.495 a	44.65 b	28.66 a	15.99 b
Cotton husks biochar	1.497 a	47.55 a	17.69 b	29.86 a
Filter cake biochar	1.500 a	45.25 b	18.36 b	26.89 a

Multiple comparisons of mean scores for all groups, Kruskal-Wallis ($p<0.05$).

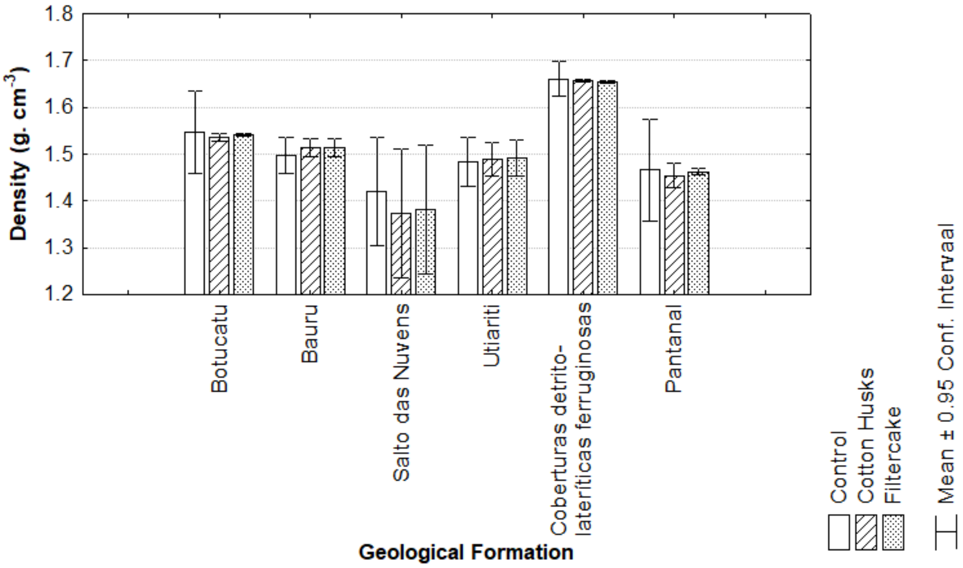

Figure 2. Soil bulk density from different geological formations without biochar (Control) and with biochar (cotton husks and filter cake).

The TP of the soil was altered by adding biochar, with a greater increase when cotton husks biochar was added, while sugarcane filter cake biochar did not increase the total porosity of the soil (Table 3). A visual analysis of Figure 3 shows more pores in the cotton husks biochar. Despite being different, the increase in soil TP with applying cotton husks biochar was only 6.5% compared to the soil without application. The increase in porosity was due to an increase in the number of micropores (Table 3). Total microporosity was higher with the application of biochar. This increase corresponded to 87% for cotton husks and 68% for sugarcane filter cake compared to soil without biochar application.

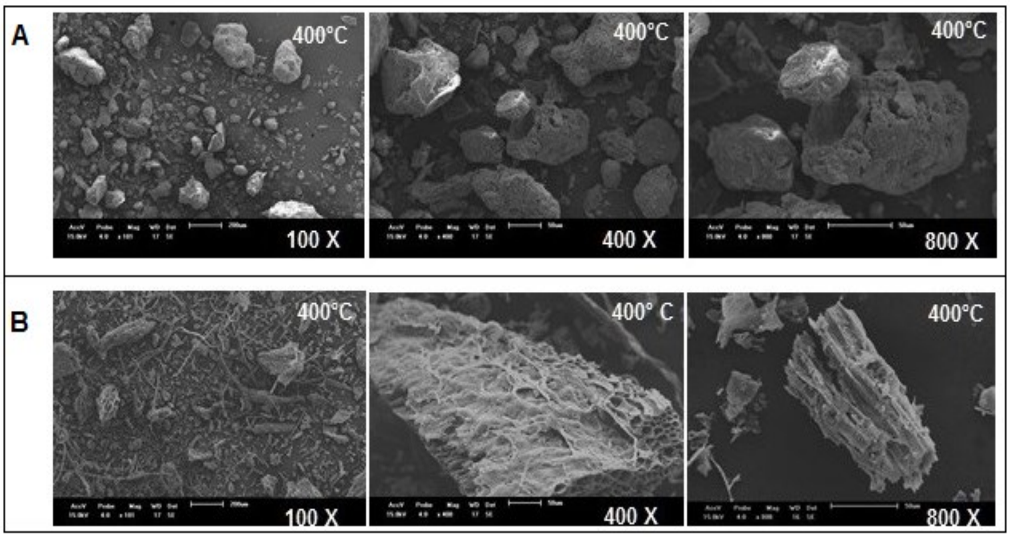

Figure 3. Scanning electron microscopy image of sugarcane filter cake biochar (A) and cotton husks biochar (B) produced at 400ºC (Shimadzu SSX-550 Superscan microscope).

Except for the soils from the Botucatu Formation (-11.2%), the average TP of the soils increased with the application of cotton husks biochar (1.2% to 19.5%). The sugarcane filter cake biochar also increased the total porosity (9.4% to 12.1%) of the soils in the Salto das Nuvens, Utiariti, and Coberturas Detrito Lateríticas Ferruginosas Formations (Figure 4), while the soils in the Bauru, Botucatu, and Pantanal Formations had a reduction of 5.3%, 14.1%, and 4.5% respectively.

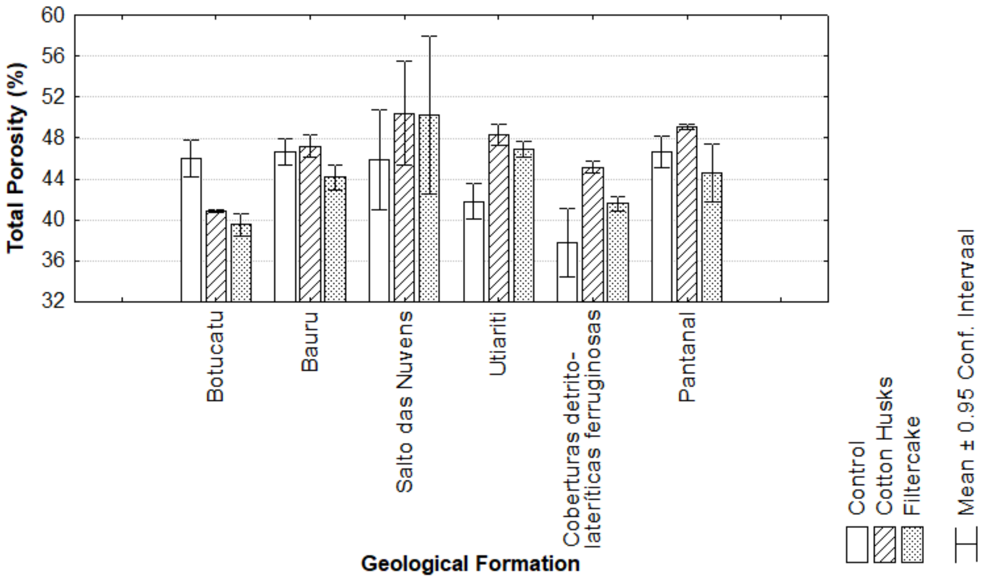

Figure 4. Total porosity of soils from different geological formations without biochar (Control) and with biochar (cotton husks and filter cake).

The soils from the Botucatu Formation have a coarser and spherical granulometry than the soils from the other formations. This may be one of the factors that influenced the greater reduction in TP with the application of filter cake biochar since filter cake biochar has a smaller average particle size than cotton biochar and can occupy the pore spaces of these soils. Yang, Liu, and Lu (2021) observed reduced total porosity using canola stem biochar, while rice straw biochar increased total porosity.

There was an increase in soil microporosity with the addition of cotton husks biochar for the soils of all the formations (Bauru - 32.5%; Botucatu - 15.4%; Ferruginous Detrital-Lateritic Cover - 179.0%; Pantanal - 197.7%, Salto das Nuvens - 78.0% and Utiariti - 155.9%). For filter cake, the significant increases in microporosity were in the sandy soils from the formations Salto das Nuvens (73.7%), Utiariti (147.1%), Pantanal (149.5%), Coberturas Detrito Lateríticas Ferruginosas (162.7%), Bauru (only 4.9%) and a reduction of microporosity in the soils from the Botucatu formation (-7.6) (Figure 5). Consequently, there was a reduction in the macroporosity of these soils (Figure 6), with the smallest changes occurring in the soils of the Botucatu and Bauru formations, with the addition of biochar from cotton husks and filter cake. Yang, Liu, and Lu (2021) observed increased soil microporosity when using rice straw biochar. In their study (JESUS DUARTE; HUBACH; GLASER, 2022), they attributed the increase in soil microporosity to the high amount of micropores in biochar (90% of the pore volume), 95% of which were composed of micro and mesopores.

In the soils with cotton husks biochar, FC, PWP, and AWC were higher than those with filter cake biochar, but the AWC of the soil without biochar was the same as that with biochar (Table 4). This was due to the increase in micropores, which correlate highly with FC.

In the soils studied, there was an increase in FC with the application of both biochars in the soils from the formations of Utiariti (75.4% and 56.4% for cotton husks biochar and sugarcane filter cake biochar, respectively) and the Cobertura Detrito-Laterítica Ferruginosa (51.2% and 25.4% for cotton husks biochar and sugar cane filter cake biochar respectively). For the Pantanal and Salto das Nuvens formation soils, both biochars promoted an increase in FC, 37.2% for cotton husks biochar and 21.5% for sugarcane filter cake biochar in the Pantanal formation soils, and 41.8% for cotton husks biochar and 21.9% for sugar cane filter cake biochar in the Salto das Nuvens formation soils. On the other hand, there was a reduction in FC when sugarcane filter cake biochar was applied to the formations of Bauru (-20.6%) and Botucatu (-35.8%) (Figure 7). In sandy soils, Wang et al. (2019) observed a greater increase in FC using walnut shell biochar from larger fractions (1 to 2 mm) compared to smaller biochar fractions (0.0-0.25; 0.25-0.5 and 0.5-1 mm).

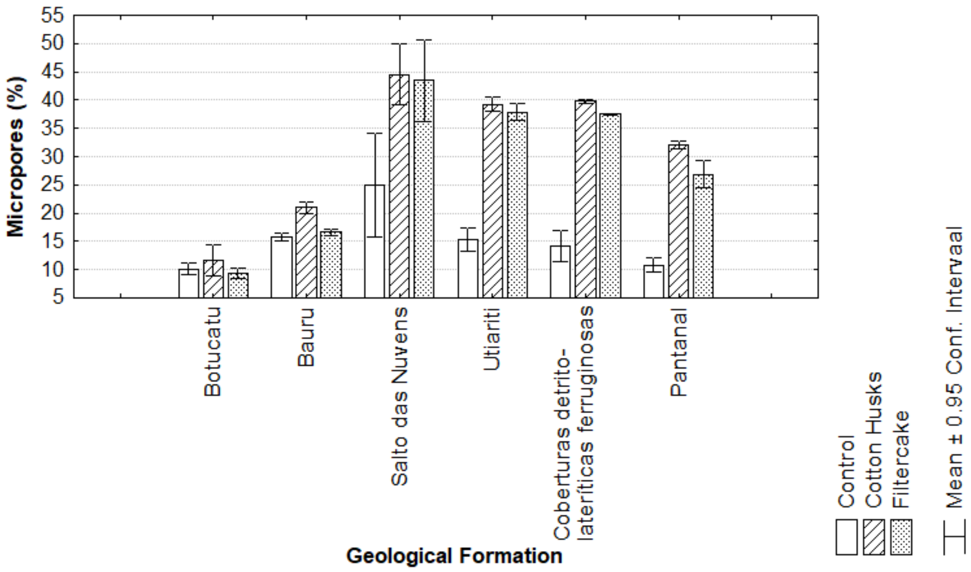

Figure 5. Microporosity of soils from different geological formations without biochar (Control) and with biochar (cotton husks and filter cake).

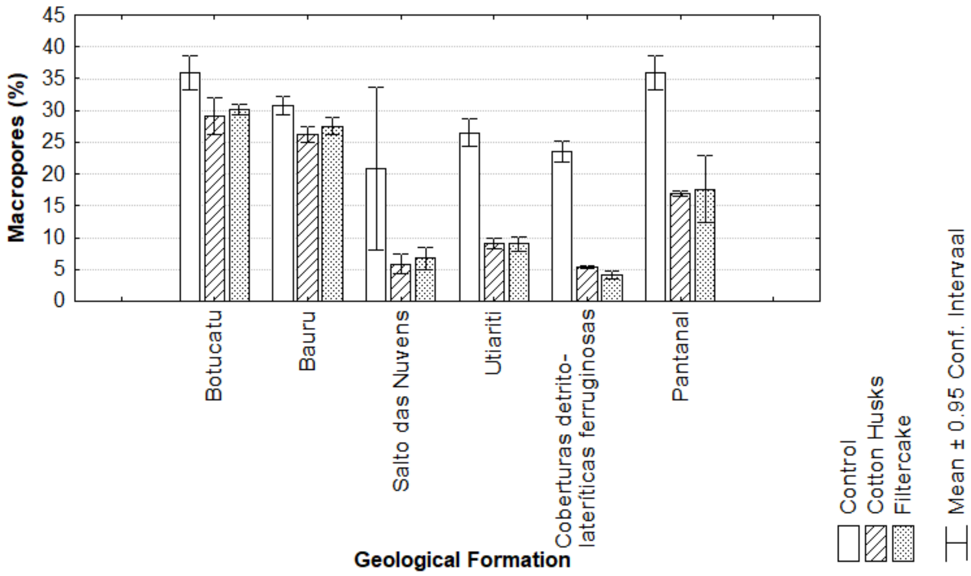

Figure 6. Macroporosity of soils from different geological formations without biochar (Control) and with biochar (cotton husks and filter cake).

Table 4. Field capacity (FC), permanent wilting point (PWP), available water capacity (AWC), and area under the soil water retention curve (AUWRC) of soils from different geological formations without biochar (Control) and with biochar (cotton husks and filter cake).

Treatment	FC (m^3 m^{-3})	PWP (m^3 m^{-3})	AWC (m^3 m^{-3})	AUWRC (m^3 m^{-3} MPa)
Control	0.058 b	0.0401 b	0.0182 ab	0.059 a
Cotton husks biochar	0.074 a	0.0455 a	0.0286 a	0.064 a
Filter cake biochar	0.057 b	0.0392 b	0.0179 b	0.057 a

Multiple mean score comparisons for all groups, Kruskal-Wallis (p≤0.05).

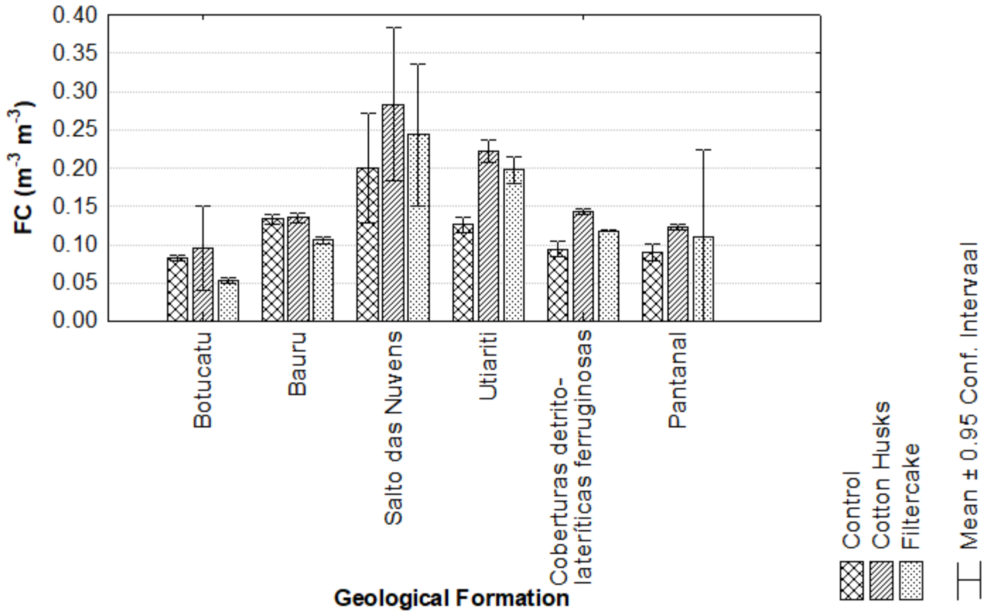

Figure 7. Field capacity of soils from different geological formations without biochar (Control) and with biochar (cotton husks and filter cake).

The most significant increase in the PWP of the soil (Figure 8) was in the soils from the Cobertura Detrito-Laterítica Ferruginosa formation, 156.5% for biochar from cotton husks, and 104.6% for biochar from sugarcane filter cake; for the soils from the other formations, the variations in PWP ranged from -12.4% (Bauru formation with biochar from sugarcane filter cake) to 39.4% (Botucatu formation with biochar from cotton husks). Abel et al. (2013); Silva Mendes et al. (2021) also observed increased water content in the PWP with biochar application.

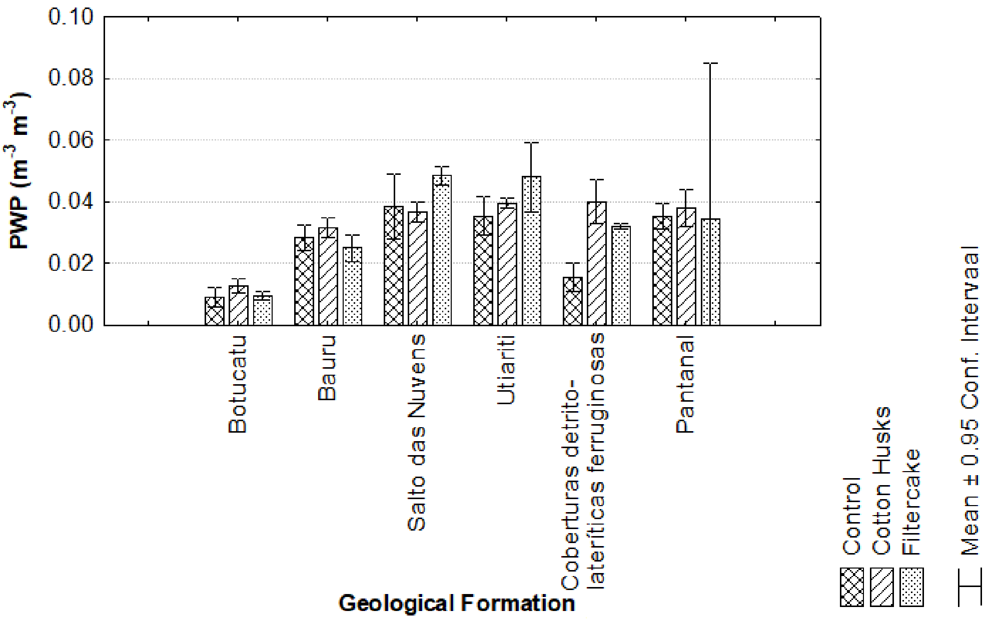

Figure 8. Permanent wilting point (PWP) of soils from different geological formations without biochar (Control) and with biochar (cotton husks and filter cake).

The addition of different biochars led to an increase in soil AWC in the Utiariti formation (100.03% and 64.7%) and a reduction for soils from the Bauru and Botucatu formations when sugarcane filter cake biochar was added (22.8% and 40.9% respectively) (Figure 9). In the soils of the Pantanal, Salto das Nuvens and Cobertura Detrito-Laterítica Ferruginosa formations, cotton husks biochar provided greater AWC in the soil (56.6%, 52.9% and 30.2%), while for the soils with biochar from sugar cane filter cake the increases were 36.9% (Pantanal formation), 20.9% (Salto das Nuvens formation), and 9.7% (Cobertura Detrito-Laterítica Ferruginosa formation). Hseu et al. (2014) observed increases in available water content in soils amended with biochar ranging from 18% to 89% due to the increase in micropores.

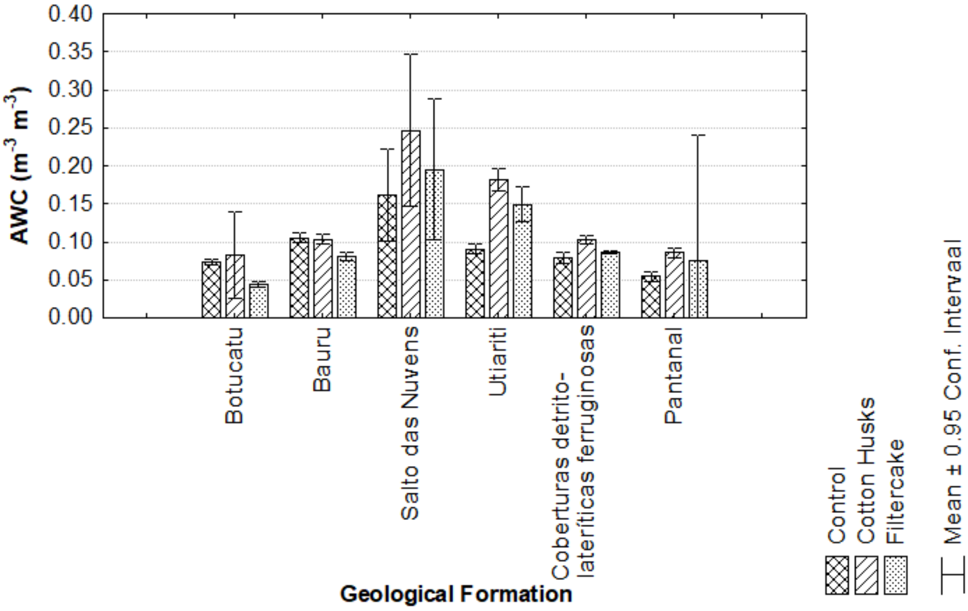

Figure 9. Available water capacity of soils from different geological formations without biochar (Control) and with biochar (cotton husks and filter cake).

CONCLUSION

Applying biochar increases the microporosity of sandy soils, and the highest available water capacity is observed with cotton husks biochar.

The increase in microporosity and decrease in macroporosity following adding biochar occurs in the soils from the Salto das Nuvens, Utiariti, Pantanal, and Cobertura Detrito-Laterítica Ferruginosa formations.

REFERENCES

ABEL, S. et al. Impact of biochar and hydrochar addition on water retention and water repellency of sandy soil. **Geoderma**, 202: 183-191, 2013.

CARVALHO, M. L. et al. "Biochar amendment enhances water retention in a tropical sandy soil". **Agriculture**, 10: 1-13, 2020.

EDEH, I. G.; MAŠEK, O.; BUSS, W. A meta-analysis on biochar's effects on soil water properties – New insights and future research challenges. **Science of the Total Environment**, 714: 01-15, 2020.

FOLK, R. L.; WARD, W. C. Brazos River bar: a study in the significance of grain size parameters. **Journal of Sedimentary Petrology**, 27: 3-26, 1957.

HARDIE, M. et al. Does biochar influence soil physical properties and soil water availability? **Plant Soil**, 376: 347-361. 2014.

HSEU, Z. Y. et al. Impacts of biochar on physical properties and erosion potential of a mudstone slopeland soil. **The Scientific World Journal**, 2014: 1-10, 2014.

JESUS DUARTE, S.; HUBACH, A.; GLASER, B. Soil water balance and wettability methods in soil treated with biochar and/or compost. **Carbon Research**, 1: 1-16, 2022.

JURIGA, M. et al. O efeito de diferentes doses de biochar e biochar em combinação com fertilizante N sobre os parâmetros de matéria orgânica do solo e estrutura do solo. **Journal of Ecological Engineering**, 19*:* 153-161, 2018.

KARHU, K. et al. Biochar addition to agricultural soil increased CH 4 uptake and water holding capacity–results from a short-term pilot field study. **Agriculture, Ecosystems & Environment**, 140: 309-313, 2011.

KLEIN, V. A.; LIBARDI, P. L. Condutividade hidráulica de um Latossolo Roxo, não saturado, sob diferentes sistemas de uso e manejo. **Ciência Rural**, 32: 945-953, 2002.

KLEIN, V. A.; REICHERT, J. M.; REINERT, D. J. Água disponível em um Latossolo Vermelho argiloso e murcha fisiológica de culturas. **Brasileira Engenharia Agrícola Ambiental**, 10: 646-650, 2006.

LEHMANN, J.; JOSEPH, S. **Biochar for environmental management: science, technology and implementation**. 2. ed. London, UK, Routledge, 2015, 920 p.

LEHMANN, J. et al. Biochar in climate change mitigation. **Nature Geoscience**, 14: 883-892, 2021.

LI, L. et al. Effects of pyrolysis temperature and feedstock type on biochar characteristics pertinent to soil carbon and soil health: A meta-analysis. **Soil Use and Management**, 39: 43-52, 2023.

MADARI, B. E. et al. Properties of a sandy clay loam Haplic Ferralsol and soybean grain yield in a five-year field trial as affected by biochar amendment. **Geoderma**, 305: 100-112, 2017.

MASIELLO, C. A., et al. **Biochar effects on soil hydrology**. In*:* LEHMANN, J.; JOSEPH, S. Biochar for environmental management: science, technology and implementation. 2. ed. London, UK, Routledge, 2015, 920 p.

MURTAZA, G. et al. Biochar-Soil-Plant interactions: A cross talk for sustainable agriculture under changing climate. **Frontiers in Environmental Science**, 11: 1-31, 2023.

NOVAK, J. M. et al. Biochars impact on soil moisture storage in an Ultisol and two Aridisols**. Soil Science**, 177: 310-320, 2012.

OJEDA, G. et al. Are soil–water functions affected by biochar application? **Geoderma**, 249: 1-11, 2015.

PITUELLO, C. et al. Effects of biochar on the dynamics of aggregate stability in clay and sandy loam soils. **European Journal of Soil Science**, 69: 827-842, 2018.

REINERT, D. J.; REICHERT, J. M. Coluna de areia para medir a retenção de água no solo: protótipos e teste. **Ciência Rural**, 36: 1931-1935, 2006.

SANTOS, H. et al. Sistema brasileiro de classificação de solos. 4. ed. Rio de Janeiro, RJ: Embrapa Solos, 2013, 353 p.

SEPLAN - Secretaria de Planejamento de Mato Grosso. **Diagnóstico Sócio-Econômico-ecológico do Estado de Mato Grosso**. Governo do Estado de Mato Grosso - Secretaria de Estado de Planejamento e Coordenação Geral, 2001. CD-ROM.

SILVA MENDES, J. et al. Chemical and physical changes of soil amended with biochar. **Water, Air, & Soil Pollution**, 232: 1-13, 2021.

SPERATTI, A. B. et al**.** Impact of different agricultural waste biochars on maize biomass and soil water content in a Brazilian Cerrado Arenosol. **Agronomy**, 07: 1-19, 2017.

TORRES, G. N. et al. "Metodologias para determinação do tamanho de partículas do solo. **Observatório de la Economía Latinoamericana**, 21: 19598-19622, 2023.

USDA - United States Department of Agriculture. **Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys**. 2. ed. Washington DC, USA: Agriculture Handbook, 1999, 869 p.

VAN GENUCHTEN, M. T. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. **Soil Science Society of America Journal**, 44: 892-898, 1980.

VERHEIJEN, F. G. A. et al. **Biochar application to soils - a critical scientific review of effects on soil properties, processes and functions.** EUR 24099 EN, Office for the Official Publications of the European Communities, Luxembourg. 24099: 2183-2207, 2010.

WANG, D. et al. Impact of biochar on water retention of two agricultural soils-A multi-scale analysis. **Geoderma**, 340: 185 -191, 2019.

XIAO, Q. et al. Sensitivity of soil water retention and availability to biochar addition in rainfed semi-arid farmland during a three-year field experiment. **Field Crops Research**, 196: 284-293, 2016.

YANG, C.; LIU, J.; LU, S. Pyrolysis temperature affects pore characteristics of rice straw and canola stalk biochars and biochar-amended soils. **Geoderma**, 397: 1-11, 2021.

YANG, Y. et al. Biochar stability and impact on soil organic carbon mineralization depend on biochar processing, aging and soil clay content. **Soil Biology and Biochemistry**, 169: 1-15, 2022.

ZHANG, J.; YOU, C. Water holding capacity and absorption properties of wood chars. **Energy Fuel**, 27: 2643-2648, 2013.