Revista Ibero-Americana de Ciências Ambientais
Ibero-American Journal of Environmental Sciences

Out 2022 - v.13 - n.10

RICA
ISSN: **2179-6858**

This article is also available online at:
www.sustenere.co

Biochar: sustainable alternatives for the physical recovery of degraded soils

This study evaluated the effects of different concentrations of Biochar applied to a Latossolo with sandy texture under pasture in the Cerrado Biome, Brazil, over six months. A randomized block design with three replications was set up, with the following treatments: T1 = 0.0; T2 = 1.0; T3 = 3.0; T4 = 5.0; T5 = 7.0 and T6 = 9.0 t ha-1 of Biochar applied in the experimental plots (5 x 5 m), with a Native Cerrado area as reference. After the evaluation period, soil samples with the preserved and non-preserved structures were collected at 0.2 m depth to quantify physical parameters, carbon stocks, and soil water storage. The results show that from the application of 3.0 t ha-1 (T3), significant improvements are obtained in flocculation, porosity, density, carbon stocks, and soil water storage, favoring the growth and development of cover crops. Therefore, the use of Biochar is shown to be a fast, cheap, and efficient alternative for the physical and hydric recovery of degraded soils in the Brazilian Cerrado.

Keywords: Soil ecosystem functions; Sustainability; Environmental degradation; Soil conditioners.

Biocarvão: alternativas sustentáveis para a recuperação física de solos degradados

Este trabalho avaliou em um prazo de seis meses os efeitos de diferentes concentrações de Biocarvão aplicadas em um Latossolo arenoso sob pastagem no Bioma Cerrado, Brasil. Um experimento em blocos casualizados com três repetições foi instalado, sendo os tratamentos: T1 = 0,0; T2 = 1,0; T3 = 3,0; T4 = 5,0; T5 = 7,0 e T6 = 9,0 t ha-1 de Biocarvão aplicadas nas parcelas experimentais (5 x 5 m), tendo como referência uma área de Cerrado Nativo. Após o período de avaliação, amostras de solo com estrutura preservada e não preservada foram coletadas à profundidade de 0,2 m para a quantificação de parâmetros físicos, dos estoques de carbono e do armazenamento de água no solo. Os resultados evidenciam que a partir da aplicação de 3,0 t ha-1 (T3), melhorias significativas são obtidas na floculação, na porosidade, na densidade, nos estoques de carbono e na lâmina de água armazenada no solo, favorecendo o crescimento e desenvolvimento das plantas de cobertura. Portanto, a utilização de Biocarvão configura-se uma alternativa rápida, barata e eficiente para recuperação físico-hídrica de solos degradados no Cerrado Brasileiro.

Palavras-chave: Funções do ecossistema do solo; Sustentabilidade; Degradação ambiental; Condicionadores de solo.

Topic: **Ciências do Solo**

Reviewed anonymously in the process of blind peer.

Received: **10/10/2022**
Approved: **20/10/2022**

Diony Alves Reis
Universidade Estadual do Tocantins, Brasil
http://lattes.cnpq.br/5707542223794836
dionyodin@gmail.com

Rayan Araújo Valério
Universidade Federal do Oeste da Bahia, Brasil
http://lattes.cnpq.br/7010730874024371
http://orcid.org/0000-0001-6862-8134
rayanaraujov@gmail.com

Tâmara Andressa Pires Cedro
Universidade Federal do Oeste da Bahia, Brasil
http://lattes.cnpq.br/9233640726506470
http://orcid.org/0000-0002-7225-9578
tamara_drica@hotmail.com

Valdeilson Souza Braga
Universidade Federal do Oeste da Bahia
http://lattes.cnpq.br/2198420901829162
http://orcid.org/0000-0002-9234-9204
vsbraga@gmail.com

DOI: 10.6008/CBPC2179-6858.2022.010.0001

Referencing this:

REIS, D. A.; VALÉRIO, R. A.; CEDRO, T. A. P.; BRAGA, V. S.. Biochar: sustainable alternatives for the physical recovery of degraded soils. **Revista Ibero Americana de Ciências Ambientais**, v.13, n.10, p.1-8, 2022. DOI: http://doi.org/10.6008/CBPC2179-6858.2022.010.0001

INTRODUCTION

It is estimated that 12 million hectares of soil are lost annually; also, 50% of the arable land of the planet is in a state of degradation ranging from moderate to severe, directly compromising 1.5 billion people due to the reduction in food production, which increases its average price, resulting in migration flows and social crises (FAO, 2020). In this sense, it becomes urgent to identify quick, cheap, and efficient solutions that recover the functions of the soil ecosystem, especially its ability to promote agricultural productivity.

In this context, biochar has aroused interest in the scientific community due to its positive effects on various soil chemical, physical and biological parameters. Biochar is a porous and carbonaceous material produced from the thermochemical decomposition (pyrolysis, hydrothermal carbonization, gasification, roasting, and microwave heating) of organic matter with limited or no oxygen. Organic solid wastes of urban or agricultural origin, from crops, algae, forestry, sewage sludge, and manure have been used for biochar production, generating an alkaline material with high cation exchange capacity (CEC), large specific surface area (100 - 460 m^2 g^{-1}), recalcitrance, and structural stability that improves various soil physical, chemical, and biological parameters (XIONG et al., 2019; FANG et al., 2018).

Therefore, this study aimed to evaluate over six months the effects of different concentrations of biochar (t ha^{-1}) on water-dispersible clay (WDC), degree of dispersion (DD), degree of flocculation (DF), total porosity (TP), macroporosity (MA), microporosity (MI), the total organic carbon (TOC), the bulk density (BD), the soil carbon stock corrected by equivalent mass (CS), and stored water (h) in a Latossolo with a sandy texture under pastures located in Cristópolis - Bahia, Brazil.

MATERIALS AND METHODS

The study was carried out in Cristópolis, western Bahia, Brazil. The climate of the region is Aw, according to the Köppen-Geiger classification, with a rainy summer from October to April and dry winter from May to September. The average temperature ranges from 20 to 32°C. The average precipitation varies from 700 to 1,800 mm per year (ALVARES et al., 2013). The soil is classified as Latossolo Vermelho Amarelo dystrophic (LVAd) (EMBRAPA, 2013) with a sandy texture (820 g kg^{-1} sand, 40 g kg^{-1} silt, and 140 g kg^{-1} clay) to a depth of 0.20 m.

In 2019, inserted in an area of ~50 hectares (ha) of brachiaria pasture (*Urochloa brizantha*) with more than 15 years of establishment, containing exposed and compacted soil, an area of ~700 m^2 (12°11' 39.80 "S, 44°31'42.39 "W), was randomly chosen and isolated for the implementation of an experiment arranged in a randomized block design with three replications. The treatments were: T1 = 0.0; T2 = 1.0; T3 = 3.0; T4 = 5.0; T5 = 7.0; T6 = 9.0 t ha^{-1} of biochar applied to 18 experimental plots (3 blocks x 6 plots) of 25 m^2 (5 x 5 m).

Before manual application of the treatments, the plots were homogenized by harrowing, and due to the scarcity of rainfall at the time, a drip irrigation system was installed to meet the evapotranspiration demand on germination and initial growth of Urochloa seeds used for planting in August 2019, and the irrigation system was removed in October 2019 at the beginning of the rainy season.

The biochar from burning eucalyptus (*Eucalyptus* sp.) in a boiler at a temperature of ~ 600°C, obtained by donation, was homogenized by sieving on 2 mm mesh sieves, followed by its chemical characterization (IBI, 2013) (Table 1).

Table 1: Chemical characterization of Biochar.

Description*	pH	EC	K	Na	C
	H_2O	mS cm^{-1}	---------------- g kg^{-1} ----------------		
Biochar	12.45	34.41	59.62	0.15	19.65
	10.18	30.17	63.25	0.11	14.95
	14.12	44.12	60.87	0.12	18.82
Average	12.25	36.23	61.25	0.13	17.81
Standard deviation	1.98	7.15	1.84	0.02	2.51
CV, %	16	20	3	15	14

*EC: Electrical Conductivity; K: Potassium; Na: Sodium, and C: Carbon; CV: Coefficient of variation.

Soil samples were collected six months after sowing (Feb 2022) in the soil layers of 0.00 - 0.05; 0.05 - 0.10, and 0.10 - 0.20 m. Samples with the unpreserved structure were collected using a cutting shovel, totaling 54 samples (1 sample x 3 layers x 3 blocks x 6 treatments). In contrast, samples with the preserved structure were collected in 4.8 cm diameter by 5.0 cm high volumetric rings, totaling 162 samples (3 samples x 3 layers x 3 blocks x 6 treatments). In addition, as a reference, three samples with unpreserved structures and nine samples with preserved structures were collected in the Native Cerrado (NC) area.

Soil samples with the unpreserved structure were used to determine soil particle size fractions, water-dispersible clay (WDC), degree of flocculation (DF), degree of dispersion (DD), total organic carbon (TOC), and soil carbon stocks (CS). The soil samples with the preserved structure were used to determine total porosity (TP), macroporosity (MA), microporosity (MI), bulk density (BD), and the water depth stored in the soil (h).

Soil particle size fractions were determined by the Pipette Method, using 1N NaOH as a dispersant, while water-dispersible clay (WDC, g kg^{-1}) was quantified without NaOH (TEIXEIRA et al., 2017).

The degree of flocculation (DF, %) was quantified using Equation 1:

$$\mathrm{DF} = \left(\frac{\mathrm{Arg_{dt}} - \mathrm{Arg_{da}}}{\mathrm{Arg_{dt}}}\right) * 100 \qquad \text{Eq. 1}$$

where DF – degree of flocculation, $\mathrm{Arg_{dt}}$, - fully dispersible clay, $\mathrm{Arg_{da}}$ - water-dispersible clay.

The degree of dispersion (DD, %) was quantified using Equation 2:

$$\mathrm{DD} = 100 - \mathrm{DF} \qquad \text{Eq. 2}$$

Total organic carbon (TOC) was determined by wet oxidation of organic matter with $K_2Cr_2O_7$ at 0.0667 mol L^{-1} in a sulfuric medium and titration with a standard solution of $Fe(NH_4)_2(SO_4)_2.6H_2O$ at 0.1 mol L^{-1} as described in Teixeira et al. (2017).

Carbon stocks (St_C, Mg ha^{-1}) were calculated using Equation 3:

$$\mathrm{St\_C} = \frac{(\mathrm{TOC\ x\ BD\ x\ e})}{10} \qquad \text{Eq. 3}$$

where TOC – total organic carbon content at the sampled depth (g kg^{-1}), BD – Bulk density (Mg m^{-3}), e – thickness of the considered layer (cm).

Subsequently, the St_C obtained were corrected by the equivalent mass, considering the correction of the method proposed by Fernandes and Fernandes (2013), using the Native Cerrado (NC) as a reference (Equation 4).

$$CS = \sum_{i=1}^{n-1} C_{ti} + \left[M_{tn} - \left(\sum_{i=1}^{n} M_{Ti} - \sum_{i=1}^{n} MS_i\right)\right] C_{tn} \qquad \text{Eq. 4}$$

where CS – St_C corrected by the soil mass of the reference area (Mg C ha^{-1}); $\sum_{i=1}^{n-1} C_{Ti}$ – sum of TOC (Mg ha^{-1}) from the surface layer to the c (n – 1) of the evaluated treatment; M_{tn} – soil mass of the last layer sampled in the treatment (Mg ha^{-1}); $\sum_{i=1}^{n} M_{Ti}$ – the sum of soil mass (Mg ha^{-1}) in the superficial layer (1) to the deepest layer (n) in the evaluated treatment; $\sum_{i=1}^{n} MS_I$ – sum of the total soil mass sampled in the reference area (Mg ha^{-1}); and C_{tn} – soil Carbon content in the last sampled layer (Mg C Mg^{-1}).

Soil samples with the preserved structure were saturated by capillarity for 48 hours to determine TP (m^3 m^{-3}), MA, and MI (m^3 m^{-3}) by the tension table method, which was subsequently dried in an oven at 105°C for ~24 h to quantify the BD (g cm^{-3}) (Teixeira et al., 2017), while the soil water storage (h, mm) was quantified by Equation 5, relating the volumetric water content (θ, m^3 m^{-3}) and its respective soil layer (Z, m):

$$h \cong \sum_{i}^{i} \theta_i \Delta Z_i \text{, mm} \qquad \text{Eq. 5}$$

Treatments were compared by the percentage difference of the value in the parameter under treatment, showing its increase (+) or decrease (-) relative to Native Cerrado (NC, Δref, %) and, excluding NC, the treatments were subjected to analysis of variance (ANOVA). Means were compared by Duncan's test ($p < 0.05$). In addition, regression models and Pearson correlation coefficient (r, $p < 0.05$) were used to verify the relationships between variables using SigmaPlot SPW11.0 software.

RESULTS AND DISCUSSION

High WDC and DD values (Δref+) and reduced DF values (Δref-) when compared to NC express soil degradation under pasture regarding structuring, aggregation, and susceptibility to soil loss by water or wind erosion. The application of higher biochar concentrations significantly reduced WDC and DD values. It increased the values of DF in the layers 0.00 – 0.05 and 0.05 – 0.10 m, evidencing the positive influence of biochar on the maintenance of mineral particles in the soil, improving its structuring and aggregation, mitigating soil losses, especially from the application of 3 t ha^{-1} (Table 2).

Clay dispersion results from surface electric charges generated by isomorphic substitution (permanent and negative) or radical dissociation (variable and pH-dependent, predominantly positive), favoring flocculation or dispersion, respectively, affecting soil structure and aggregation. Latossolos have variable charges and pH < 7.0 due to the positive charges resulting from the high concentration of H^+ or Al^{3+} ions, favoring a dispersed environment (WDC and DD), however, as the biochar is alkaline, rich in inorganic metal ions (Na and K), carbonates ($CaCO_3$ and $MgCO_3$) and negatively charged organic functional groups (-COOH, -COO, -O- and -OH), soil pH and attraction between particles increase, reducing WDC and increasing DF (REIS et al., 2019; KONG et al., 2015).

In the soil layers of 0.00 – 0.05 and 0.05 – 0.10 m, Tp and Mi values increased (Δref +) significantly due to biochar application, especially in T4: 5.0 t ha^{-1} (Table 3).

Table 2: Water-dispersible clay (WDC), degree of flocculation (DF), and degree of dispersion (DD) of a Latossolo under different concentrations of Biochar, cultivated with brachiaria and under Native Cerrado (NC) in western Bahia, Brazil.

Treatments	WDC	Δref	DF	Δref	DD	Δref
	$g\ kg^{-1}$	---------- % ----------				
	0.00 – 0.05 m					
T1: 0.0	6.02 ± 0.15 a	103	55.17 ± 1.02 d	-31	44.82 ± 1.02 a	125
T2: 1.0	5.73 ± 0.10 a	94	60.64 ± 1.23 c	-24	39.36 ± 1.83 b	97
T3: 3.0	5.27 ± 0.15 a	78	66.83 ± 2.03 bc	-17	33.17 ± 2.23 bc	66
T4: 5.0	4.50 ± 0.19 b	52	67.59 ± 1.94 b	-16	31.41 ± 2.14 c	57
T5: 7.0	4.17 ± 0.13 b	41	68.67 ± 1.83 b	-14	31.33 ± 2.18 c	57
T6: 9.0	3.82 ± 0.16 c	29	74.95 ± 1.40 a	-6	25.05 ± 1.36 d	26
NC	2.96	0	80.05	0	19.95	0
	0.05 – 0.10 m					
T1: 0.0	6.04 ± 0.30 a	64	52.76 ± 3.20 d	-35	47.24 ± 1.20 a	155
T2: 1.0	5.98 ± 0.28 a	63	57.33 ± 2.96 c	-30	42.67 ± 0.96 b	130
T3: 3.0	5.64 ± 0.32 a	53	61.51 ± 2.66 b	-24	38.49 ± 2.11 bc	107
T4: 5.0	5.27 ± 0.27 b	43	65.47 ± 2.12 b	-20	34.53 ± 2.12 c	86
T5: 7.0	5.03 ± 0.31 b	37	67.57 ± 3.90 b	-17	32.43 ± 2.91 c	75
T6: 9.0	3.93 ± 0.32 c	7	76.13 ± 2.15 a	-7	23.87 ± 2.15 d	29
NC	3.68	0	81.44	0	18.56	0
	0.10 – 0.20 m					
T1: 0.0	7.62 ± 0.27 a	91	50.02 ± 3.30 a	-33	49.98 ± 2.30 a	97
T2: 1.0	7.57 ± 0.29 a	89	51.97 ± 3.26 a	-30	48.03 ± 3.07 a	90
T3: 3.0	7.47 ± 0.22 a	87	52.49 ± 2.26 a	-30	47.50 ± 2.26 a	88
T4: 5.0	7.40 ± 0.18 a	85	52.75 ± 2.47 a	-29	47.25 ± 3.17 a	87
T5: 7.0	7.38 ± 0.15 a	85	53.39 ± 3.06 a	-29	46.61 ± 3.26 a	84
T6: 9.0	7.21 ± 0.12 a	80	53.40 ± 2.43 a	-28	46.60 ± 2.43 a	84
NC	4.00	0	74.68	0	25.32	0

*T1: 00; T2: 1.0; T3: 3.0; T4: 5.0; T5: 7.0, T6: 9.0 t ha^{-1} of Biochar; NC: Native Cerrado. Means followed by the same lowercase letter in the columns within each parameter and evaluated soil layer do not differ by Duncan's test at 5%.

Table 3: Total porosity (TP), macroporosity (MA), and microporosity (MI) of a Latossolo under different concentrations of Biochar, cultivated with brachiaria and under Native Cerrado (NC) in western Bahia, Brazil.

Treatments	TP	Δref	MA	Δref	MI	Δref
	$m^3\ m^{-3}$	%	$m^3\ m^{-3}$	%	$m^3\ m^{-3}$	%
	0.00 – 0.05 m					
T1: 0.0	0.36 ± 0.02 c	-8	0.03 ± 0.00 a	-84	0.33 ± 0.02 c	65
T2: 1.0	0.37 ± 0.03 c	-5	0.04 ± 0.00 a	-79	0.34 ± 0.01 c	70
T3: 3.0	0.38 ± 0.01 bc	-3	0.04 ± 0.00 a	-79	0.35 ± 0.03 b	75
T4: 5.0	0.39 ± 0.02 b	0	0.04 ± 0.00 a	-79	0.35 ± 0.02 b	75
T5: 7.0	0.42 ± 0.03 a	8	0.04 ± 0.00 a	-79	0.38 ± 0.02 a	90
T6: 9.0	0.43 ± 0.02 a	10	0.04 ± 0.00 a	-79	0.39 ± 0.01 a	95
NC	0.39	0	0.19	0	0.20	0
	0.05 – 0.10 m					
T1: 0.0	0.31 ± 0.03 c	-16	0.04 ± 0.00 a	-76	0.27 ± 0.02 c	35
T2: 1.0	0.35 ± 0.02 c	-5	0.04 ± 0.00 a	-76	0.31 ± 0.01 bc	55
T3: 3.0	0.36 ± 0.04 bc	-3	0.04 ± 0.01 a	-76	0.31 ± 0.03 bc	55
T4: 5.0	0.37 ± 0.02 b	0	0.04 ± 0.01 a	-76	0.33 ± 0.02 b	65
T5: 7.0	0.39 ± 0.01 b	5	0.04 ± 0.00 a	-76	0.35 ± 0.02 a	75
T6: 9.0	0.41 ± 0.02 a	11	0.04 ± 0.00 a	-76	0.36 ± 0.03 a	80
NC	0.37	0	0.17	0	0.20	0
	0.10 – 0.20 m					
T1: 0.0	0.31 ± 0.01 a	-16	0.03 ± 0.00 a	-82	0.29 ± 0.01 a	38
T2: 1.0	0.32 ± 0.02 a	-14	0.04 ± 0.00 a	-76	0.29 ± 0.02 a	38
T3: 3.0	0.32 ± 0.03 a	-14	0.04 ± 0.00 a	-76	0.29 ± 0.04 a	38
T4: 5.0	0.33 ± 0.01 a	-11	0.04 ± 0.00 a	-76	0.29 ± 0.03 a	38
T5: 7.0	0.33 ± 0.02 a	-11	0.04 ± 0.00 a	-76	0.30 ± 0.01 a	43
T6: 9.0	0.34 ± 0.03 a	-8	0.04 ± 0.00 a	-76	0.30 ± 0.02 a	43
NC	0.37	0	0.17	0	0.21	0

*T1: 00; T2: 1.0; T3: 3.0; T4: 5.0; T5: 7.0, T6: 9.0 t ha^{-1} of Biochar; NC: Native Cerrado. Means followed by the same lowercase letter in the columns within each parameter and evaluated soil layer do not differ by Duncan's test at 5%.

Soil pores vary according to texture, structure, and organic matter content and as a function of soil aggregates. Reichert et al. (2016) suggest that the TP of sandy soils ranges between 0.32 and 0.47 m^3 m^{-3}, corroborating the results of this study, with inadequate soil management being the main responsible for reducing TP and MA and increasing BD to levels similar to compacted soils (ISLABÃO et al., 2016).

TOC values from T5: 7.0 t ha^{-1} were higher (Δref +) than NC in the 0.05 – 0.10 m layer, while BD values were higher than NC in the three evaluated layers (Table 4). The increase in TOC resulting from the applied biochar decreased the BD, despite having an average carbon content (17.81 g kg^{-1}, Table 1) below the reference range suggested by Chan and Xu (2009) from 172 to 905 g kg^{-1}.

Table 4: Total organic Carbon (TOC) and bulk density (BD) of a Latossolo under different concentrations of Biochar, cultivated with brachiaria and under Native Cerrado (NC) in western Bahia, Brazil.

Treatments	TOC	Δref	BD	Δref
	g kg^{-1}	%	g cm^{-3}	%
	0.00 – 0.05 m			
T1: 0.0	4.74 ± 0.14 d	-77	1.64 ± 0.02 a	17
T2: 1.0	7.84 ± 0.21 c	-62	1.62 ± 0.01 a	16
T3: 3.0	10.62 ± 0.13 b	-49	1.57 ± 0.02 ab	12
T4: 5.0	11.48 ± 0.16 ab	-44	1.55 ± 0.01 b	11
T5: 7.0	12.04 ± 0.23 a	-42	1.54 ± 0.02 c	10
T6: 9.0	13.26 ± 0.25 a	-36	1.51 ± 0.01 c	8
NC	20.68	0	1.40	0
	0.05 – 0.10 m			
T1: 0.0	5.83 ± 0.21 d	-39	1.74 ± 0.01 a	18
T2: 1.0	7.70 ± 0.34 c	-19	1.72 ± 0.03 a	17
T3: 3.0	8.71 ± 0.22 bc	-9	1.69 ± 0.02 ab	15
T4: 5.0	9.45 ± 0.25 b	-1	1.66 ± 0.01 b	13
T5: 7.0	12.49 ± 0.25 a	31	1.65 ± 0.03 b	12
T6: 9.0	13.50 ± 0.27 a	41	1.64 ± 0.02 b	12
NC	9.55	0	1.47	0
	0.10 – 0.20 m			
T1: 0.0	4.74 ± 0.22 b	-50	1.77 ± 0.04 a	25
T2: 1.0	4.96 ± 0.25 b	-47	1.76 ± 0.04 a	24
T3: 3.0	6.94 ± 0.25 ab	-26	1.76 ± 0.02 a	24
T4: 5.0	6.95 ± 0.31 a	-26	1.74 ± 0.03 a	23
T5: 7.0	7.37 ± 0.29 a	-22	1.73 ± 0.03 a	22
T6: 9.0	7.39 ± 0.35 a	-22	1.73 ± 0.02 a	22
NC	9.43	0	1.42	0

*T1: 00; T2: 1.0; T3: 3.0; T4: 5.0; T5: 7.0; T6: 9.0 t ha^{-1} of Biochar; NC: Native Cerrado. Means followed by the same lowercase letter in the columns within each parameter and evaluated soil layer do not differ by Duncan's test at 5%.

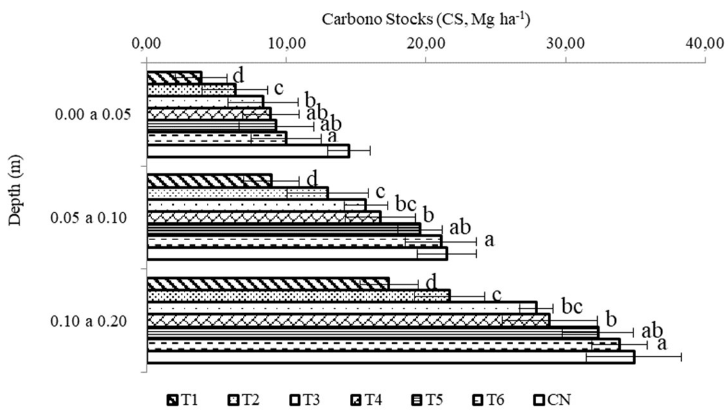

Figure 1: Equivalent mass corrected carbon stocks (CS) of a Latossolo under different concentrations of Biochar, cultivated with brachiaria and under Native Cerrado (NC) in western Bahia, Brazil.

The negative charges of biochar increased DF, protecting the Carbon inside the microaggregates, reducing its consumption by microorganisms or its losses to the atmosphere in the form of CO_2, and increasing the carbon stocks in the soil (Figure 1) (PLAZA et al., 2016; PRAYOGO et al., 2014).

Due to the electrochemical nature, size, shape, uniformity concerning soil pores, and the interaction that Biochar presents with soil texture, the water content stored in sandy soils is higher when compared to clayey soils (Peake et al., 2014; Liu et al., 2013). Thus, the natural porosity and specific surface area of the biochar are responsible for increasing water retention directly through capillarity and indirectly through soil aggregation (Figure 2).

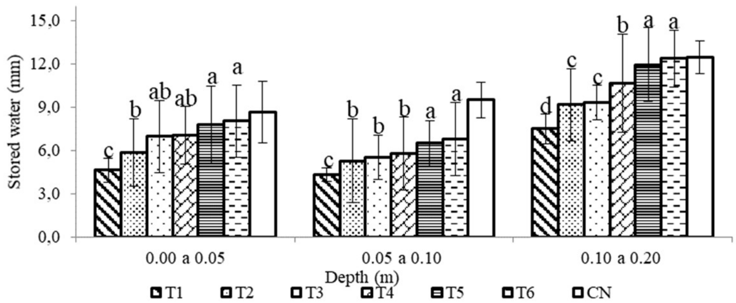

Figure 2: Stored water (h, mm) of a Latosol under different concentrations of Biochar, cultivated with brachiaria and under Native Cerrado (NC) in western Bahia, Brazil.

The Pearson correlation results (Table 5) show that higher WDC values reduce DF (r = -0.96; p < 0.01), Tp (r = -0.85; p < 0.01), Mi (r = -0.58; p < 0.01), and TOC (r = -0.81; p < 0.01). Also, biochar reduced WDC, increasing flocculation and carbon content (correlation between DF and TOC: r = 0.82; p < 0.01). MI and CS are positively related to h, expressing better structural conditions due to biochar. On the other hand, Jeffery et al. (2013) and Obia et al. (2016) emphasize the need for further studies on the effects of biochar and especially on the duration of its impact since they would be dependent on the soil textural class, the source material of the biochar, the amount, the application rate, and the aging time of the biochar in the soil.

Table 5: Correlations between parameters of a Latossolo under different concentrations of Biochar, cultivated with brachiaria in western Bahia, Brazil.

	DF	DD	TP	MA	MI	TOC	BD	CS	h
WDC	-0.96**	0.96**	-0.85**	0.04ns	-0.58**	-0.81**	0.90**	0.33ns	-0.16ns
FD		-1.00**	0.82**	-0.11ns	0.66**	0.82**	-0.90**	-0.13ns	0.26ns
DD			-0.82**	0.11ns	-0.65**	-0.82**	0.90**	0.13ns	-0.26ns
TP				0.44*	0.18ns	0.76**	-0.73**	-0.37ns	0.11ns
MA					-0.80**	0.01ns	0.22ns	-0.45*	-0.35ns
MI						0.49*	-0.75**	0.25ns	0.50*
TOC							-0.73**	-0.15ns	0.19ns
BD								0.19ns	-0.43ns
CS									0.60**

n = 54; *WDC: Water-dispersible clay (g kg^{-1}); FD: Flocculation degree (%); DD: Degree of dispersion (%); TP: Total Porosity (m^3 m^{-3}); MA: Macroporosity (m^3 m^{-3}); MI: Microporosity (m^3 m^{-3}); TOC: Total organic carbon (g kg^{-1}); BD: Bulk density (g cm^{-3}); CS (Mg ha^{-1}); h: Stored water (h, mm); ns: Not significant; *: Significant at 5% level; **: Significant at the 1% level.

CONCLUSIONS

The application of increasing concentrations of Biochar reduces water dispersive clay (WDC), soil degree dispersion (DD), and bulk density (Bd) while increasing the degree of flocculation (DF), total porosity (Tp), Microporosity (Mi), carbon stocks (Cs) and water storage in soil (h).

Biochar concentrations ≥ 3 t ha^{-1} are sufficient to positively alter the structural quality of Latossolo with sandy texture in the Brazilian Cerrado biome.

REFERENCES

ALVARES, C. A.; STAPE, J. L.; SENTELHAS, P. C.; GONÇALVES, J. L. M.; SPAROVEK, G.. Köppen's climate classification map for Brazil. **Meteorologische Zeitschrift**, v.22, p.711-728, 2013. **DOI**: http://doi.org/10.1127/0941-2948/2013/0507

CHAN, K. Y.; XU, Z.. Biochar: Nutrient Properties and Their Enhancement. In: LEHMANN, J.; JOSEPH, S.. **Biochar for environmental management:** Science and Technology. Earthscan, 2009.

EMBRAPA. Empresa Brasileira de Pesquisa Agropecuária. **Sistema brasileiro de classificação de solos**. 3 ed. Brasília: EMBRAPA, 2013.

FERNANDES, F. A.; FERNANDES, A. H. B. M.. **Atualização dos métodos de cálculo dos estoques de carbono do solo sob diferentes condições de manejo**. Comunicado técnico 95. Embrapa Pantanal, 2013.

FANG, J.; ZHAN, L.; OK, Y. S.; GAO, B.. Minireview of potential applications of hydrochar derived from hydrothermal carbonization of biomass. **Journal of Industrial and Engineering Chemistry**, v.57, p.15-21, 2018. **DOI**: http://doi.org/10.1016/j.jiec.2017.08.026

FAO. Food and Agriculture Organizations of the United Nations. **The State of Food and Agriculture**. Overcoming water challenges in agriculture. Rome: FAO, 2020.

IBI. International Biochar Initiative. **Standardized product definition and product testing guidelines for biochar that is used in soil**. IBI, 2013.

ISLABÃO, G. O.; LIMA, C. L. R. DE; VAHL, L. C.; TIMM, L. C.; TEIXEIRA, J. B. D. S.. Hydro-physical properties of a typic Hapludult under the effect of fice. **Revista Brasileira de Ciência do Solo**, v.40, n.1, p.1-13, 2016. **DOI**: http://doi.org/10.1590/18069657rbcs20150161

JEFFERY, S.; BEZEMER, T. M.; CORNELISSEN, G.; KUYPER, T. W.; LEHMANN, J.; MOMMER, L.; SOHI, S. P.; VAN DE VOORDE, T. F. J.; WARDLE, D. A.; VAN GROENIGEN, J. W.. The way forward in biochar research: targeting trade-offs between the potential wins. **GCB Bioenergy**, 2013. **DOI**: http://doi.org/10.1111/gcbb.12132

KONG, S.; YAO, X.; ZHANG, J.; YAO, X.; ZENG, H.. Review of characteristics of biochar and research progress of its application. **Ecology and Environmental Sciences**, v.24, p.716-723, 2015.

LIU, Z.; DUGAN, B.; MASIELLO, C. A.; GONNERMANN, H.. Impacts of biochar concentration and particle size on hydraulic conductivity of soil-biochar mixtures. **Geological Society of America Abstracts with Programs**, v.45, n.7, p.104, 2013. **DOI**: http://doi.org/10.1016/j.jhydrol.2015.12.007

OBIA, A.; MULDER, J.; MARTINSEN, V.; CORNELISSEN, G.; BØRRESEN, T.. In situ effects of biochar on aggregation, water retention and porosity in light-textured tropical soils. **Soil & Tillage Research,** v.155, p.35-44, 2016. **DOI**: http://doi.org/10.1016/j.still.2015.08.002

PEAKE, L. R.; REID, B. J.; TANG, X.. Quantifying the influence of biochar on the physical and hydrological properties of dissimilar soils. **Geoderma**, v.235-236, n.1, p.182-190, 2014. **DOI**: http://doi.org/10.1016/j.geoderma.2014.07.002

PLAZA, C.; GIANETTA, B.; FERNÁNDEZ, J. M.; SÁ, E. G. L.; POLO, A.; GASCÓ, G.; MÉNDEZ, A.; ZACCONE, C.. Response of different soil organic matter pools to biochar and organic fertilizers. **Agriculture, Ecosystems & Environment**, v.225, p.150- 159, 2016. **DOI**: http://doi.org/10.1016/j.agee.2016.04.014

PRAYOGO, C.; JONES, J. E.; BAEYENS, J.; BENDING, G. D.. Impact of biochar on mineralization of C and N from soil and willow litter and its relationship with microbial community biomass and structure. **Biology and Fertility of Soils,** v.50, p.695-702, 2014. **DOI**: http://doi.org/10.1007/s00374-013-0884-5

REICHERT, J. M.; RODRIGUES, M.F.; BERVALD, C. M. P.; KATO, O. R.. Manejo de pousio livre de fogo por corte mecanizado de biomassa para agricultura sustentável na Amazônia Oriental: Efeitos na compactação do solo, porosidade e retenção e disponibilidade de água. **Degradação e Desenvolvimento da Terra**, v.27, n.5, p.1403-1412, 2016.

REIS, D. A.; PORTELLA, R. B.; FAGUNDES, M. O.; JÚNIOR, F. R. F.; SANTOS, J. R. S.; BOGIANI, J. C.; PERINA, F. J.. Grau de dispersão, biomassa microbiana e Carbono orgânico de um Latossolo cultivado com soja sob plantio convencional e direto no cerrado (savana) do oeste da Bahia, Brasil. **Revista Ibero-Americana de Ciências Ambientais**, v.10, n.1, p.363-375, 2019. **DOI**: http://doi.org/10.6008/CBPC2179-6858.2019.001.0030

TEIXEIRA, P. C.; DONAGEMMA, G. K.; FONTANA, A.; TEIXEIRA, W. G.. **Manual de métodos de análise de solo**. 3 ed. Brasília: EMBRAPA, 2017.

XIONG, X.; YU, I. K. M.; TSANG, D. C. W.; BOLAN, N. S.; SIK OK, Y.; IGALAVITHANA, A. D.; KIRKHAM, M. B.; KIM, K. H.; VIKRANT, K.. Value-added chemicals from food supply chain wastes: state-of-the-art review and future prospects. **Chemical Engineering Journal,** v.375, n.121983, 2019. **DOI**: http://doi.org/10.1016/j.cej.2019.121983