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Alterations in soil salinity with the use of different biochar doses

Alterações na salinidade do solo com o uso de diferentes doses de biocarvão

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ABSTRACT

Biochar produced from a poultry litter has a pH around 10 and a high concentration of basic cations. The objective of this work was to evaluate the effect of this biochar in the salinity of a Yellow Red Latosol. The experiment was conducted in a completely randomized design with four replicates using columns of 20 cm height filled with soil, presenting in the first 5 cm of the column, doses corresponding to 0; 10; 15; 20; 25 and 30 t ha^{-1} of biochar mixed to the soil, totalizing 24 experimental units. For 30 days, 44 mL of deionized water was applied daily to each column. After this period, soil samples were collected at two depths (0-10; 10-20cm) and analyzed chemically concerning: ECse, pH, potassium, sodium, calcium and magnesium in each experimental plot. From the results SAR and ESP indicators were calculated. The biochar rates increased ECse, pH, Na and K, as well as SAR and ESP, being more pronounced in the first depth (0-10 cm) for most of the analyzed parameters. The soil was classified as non-saline, however, the increase in all the analyzed parameters points to a careful use of the biochar studied.

Keywords: Oxisol, Chicken bed, Soil chemical properties.

RESUMO

Biocarvão produzido com cama de galinha apresenta um pH de cerca de 10 e uma elevada concentração de cátions básicos. O objetivo deste trabalho consistiu em avaliar o efeito da aplicação do biocarvão na salinidade de um Latossolo Vermelho Amarelo. O ensaio experimental foi conduzido em delineamento inteiramente casualizado com quatro repetições utilizando colunas de 20 cm de altura preenchidas com solo, apresentando nos primeiros 5 cm da coluna, doses correspondentes a 0; 10; 15; 20; 25 e 30 t ha^{-1} de biocarvão misturadas ao solo, totalizando 24 unidades experimentais. Durante 30 dias, aplicou-se diariamente 44 mL de água desionizada em cada coluna. Após este período, foram retiradas amostras de solo, em cada coluna, em duas profundidades (0-10; 10-20cm) que foram analisadas quimicamente no que respeita a: CEse, pH, potássio, sódio, cálcio e magnésio. A partir dos resultados foram calculados os indicadores RAS e PST. As doses de biocarvão promoveram aumento da CEes, pH, Na e K, bem como da RAS e PST, sendo mais acentuado na primeira profundidade de avaliação para a maioria dos parâmetros analisados. O solo foi classificado como não salino, no entanto, o aumento verificado em todos os parâmetros analisados aponta para uma utilização cuidadosa do biocarvão em estudo.

Palavras-chave: Oxissol, Cama de galinha, propriedades químicas do solo.

INTRODUCTION

From an agricultural point of view, sodic soils are those that present exchangeable sodium in excess, presenting a exchangeable sodium percentage (ESP) of more than 15%, an electrical conductivity (ECse) below 4 dS m^{-1} and a pH above 8.5. The adverse effects of soil sodicity are very serious and can lead to physical and chemical degradation of soil properties, which can cause the loss of one or more soil functions with consequent reduction of crop production (Singh and Singh, 2013). While soil sodization is the process by which the Na^+ ion gains preponderance in the soil exchange complex, soil salinization is a process that leads to increase the concentration of the soil solution in soluble salts (Na^+, Ca^{2+}, Mg^{2+}, K^+) to levels detrimental to plants. Soil salinization could be due to natural causes, like the weathering of rocks, involving physical, chemical and biological processes, through the action of factors such as climate, relief, living organisms and time, or by human interventions such as inappropriate irrigation practices, use of salt-rich irrigation water and/or poor drainage control (Dias, 2004). Excess salts severely limit agricultural production mainly in the arid and semi-arid regions, where about 25% of the irrigated area is salinized (FAO, 2006).

The recovery of saline/sodic soils generally involves two processes: the leaching of soluble salts (saline soils) and the replacement of exchangeable Na^+ by exchangeable Ca^{2+} (sodic soils). A surplus of irrigation water and correctives such as gypsum, sulfuric acid, elemental sulfur and organic matter could be used. When used correctly, they improve the chemical and physical properties of the soil, facilitating the removal of excess salts and even replacing the exchangeable sodium (Araújo *et al*., 2017).

Recently, several researches were using biochar as a conditioner in salt affected soils (Wu *et al*., 2014; Elshaikh *et al*., 2017; Sappor *et al*., 2017). Biochar is a carbon residue resulting from the pyrolysis of plant or animal biomass (Lehmann *et al*., 2006; Verheijen *et al*., 2010; Kookana *et al*., 2011). Pyrolysis is a thermal treatment of decomposition of biomass in an environment with high temperatures (> 400°C) and low concentration of oxygen, resulting in gas (mainly hydrogen, methane and carbon monoxide), bio-oil (alcohols, oils, tars and acids) and biochar (mainly C, O, H, N and ash) (Laird *et al*., 2009; Novak *et al*., 2010).

The type of feedstock used in the pyrolysis process significantly influences the properties of the biochar (Silva *et al*., 2017). In Brazil, a type of available residue is the poultry litter which has been used in the manufacture of biochar. However, their effects on the environment require specific studies but, unfortunately, the knowledge about the impact of this material on soil properties is still scarce.

The objective of this study was to evaluate the effect of a biochar, produced from a poultry litter, in the salinity/sodicity of a Yellow Red Latosol.

MATERIALS AND METHODS

The experiment was carried out in Irrigation and Salinity Laboratory of the Agricultural Engineering Department, UFCG, from May 2017 to July 2017 using soil columns described below. The experimental design was completely randomized, in subdivided plots, with 4 replications. The plots corresponded to the six biochar doses (0; 7.85; 11.77; 15.7; 19.62 and 23.55 g/0.00785m^2, according to 0, 10, 15, 20, 25 and 30 t ha^{-1}) and the subplots were the soil depths (0-10 and 10-20 cm).

The biochar used in this study was produced from poultry litter (PL), a solid waste resulting from chicken rearing, under slow pyrolysis, at a temperature of 400 ^{o}C, by SPPT Technological Research Ltda. The following attributes were found according to the methodology Brasil (2014): pH = 9.45, P_2O_5 = 7.78%, K_2O = 4.90%, Ca = 6.83%, Mg = 1.34%, Na = 0.73%, S = 0.74%, Fe = 0.46%, Mn = 0.09%, Cu = 0.04%, Zn = 0.08%, B = 0.01%, organic matter = 39.77%.

Soil sample used was collected from the top layer (0-0.20 m) of a Red Yellow Latosol, located in the municipality Areia, State of Paraiba, Brazil. This sample was, then, air-dried for 3 days, sieved with 2 mm screen and characterized according to the methodology EMBRAPA (2011). It presents the following physical and chemical attributes: clay = 305.5 g kg^{-1}, silt = 262.0 g kg^{-1}, sand = 432.5 g kg^{-1}, pH (H_2O) = 5.30, Ca = 0.93 cmol$_c$ kg^{-1}, Mg = 0.55 cmol$_c$ kg^{-1}, Na = 0.02 cmol$_c$ kg^{-1}, K = 0.04 cmol$_c$ kg^{-1}, H = 1.83 cmol$_c$ kg^{-1}, Al = 1.8 cmol$_c$ kg^{-1}, P = 3.3 mg kg^{-1}, organic matter = 13.6 g kg^{-1}.

Soil column was prepared using PVC pipe with diameter of 10 cm and length of 22 cm. In general it is in the first 20 cm of the soil that the chemical reactions between the soil and any corrective occur, and also where we can find the presence of a greater density of roots. Soil sample was put into the column and compacted by knocking the base of the column until the soil height achieved 20 cm; the biochars treatments were incorporated into the top 5 cm of the soil in the columns in order to simulate the disposition of this material on the surface as usually organic matter is applied to the soil. The remaining 2 cm of the upper part were not filled with soil in order to facilitate the addition of water during the percolations. A mesh was attached to the bottom of the columns to prevent soil from falling out and, to facilitate the drainage of the leachates which were collected in containers placed below the columns. The columns were placed in trays containing water to reach the field capacity through the capillary ascension. After 24h, a volume of 44.0 mL of deionized water was applied on each column, daily (during 30 days), simulating a monthly rainfall of 168.15 mm (average for the city of Campina Grande in April).

After that period (30 days), each column was sectioned in two parts, 10 cm each (0-10 cm, denominated "top" and 10-20 cm, denominated "base"), dried at room temperature, sieved in a 2 mm mesh. Then, soil samples were analyzed for soil salinity, measuring in the saturation extract the electrical conductivity (ECse) and the soluble cations: sodium, potassium (by flame photometer), calcium and magnesium (by titration).

The indicator used to determine sodicity was the percentage of exchangeable sodium (ESP) based on the ratio between exchangeable sodium, extracted from the soil with Mehlich 1 method and quantified in the extract according to flame photometry, and cation exchange capacity (CEC). The exchangeable sodium percentage was determined from equation 1.

$$\mathrm{ESP} = \frac{\overline{Na^+}}{CEC} \times 100 \qquad (1)$$

Where: ESP is the exchangeable sodium percentage, %;

$\overline{Na+}$ is the exchangeable sodium content, $\mathrm{cmol_c\ dm^{-3}}$;

CEC is the cation exchange capacity, $\mathrm{cmol_c\ dm^{-3}}$.

It was also determined the sodium adsorption ratio (SAR), defined by the relationship between soluble Na^+ concentration (mmol L^{-1}) and soluble Ca^{2+} + Mg^{2+} concentration (mmol L^{-1}), according to equation 2.

$$\mathrm{SAR} = \frac{Na^+}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}} \qquad (2)$$

The data of the soil were submitted to analysis of variance (ANOVA) applying the SISVAR software (Ferreira, 2011). With the significance of the doses the average of the parameters evaluated in the soil (plots) were submitted to regression analysis. These parameters were also analyzed in the soil according to the two depths (subplots) comparing their means to each other within the same dose by the "t" test.

RESULTS AND DISCUSSION

Soil electrical conductivity

The mean electric conductivity of the saturation extract (ECse) was adjusted to the linear positive model (Table 1), with an approximate increase of 0.042 dS m^{-1} per unit increase (t ha^{-1}) of applied biochar (Figure 1).

Also with respect to Figure 1, with the application of the highest dose (30 t ha^{-1}) the ECse was estimated at 1.55 dS m^{-1}, corresponding to an increase of 439.9% when compared to ECse of the absolute control.

Similar results were observed by Rombolà *et al.* (2015), who evaluated changes in the chemical characteristics of soils with the application of biochar and found that their use promoted an increase in soil salinity.

Although the salinity response differs considerably among plant species, seed germination and plant growth in saline conditions may be impaired, especially in the seedling phase (Mengel and Kirkby, 1987).

In general, salinity effects are practically insignificant in soil extracts with readings less than or equal to 2 dS m^{-1} (Hoekstra *et al.*, 2002). Although this critical level was not exceeded with

Table 1 - Summary of the analyses of variance of chemical parameters in the two soil layers (0-10 cm; 10-20 cm) as a function of the six biochar doses

Source of variation	DF	Mean Square									
		pH	EC	Ca	Mg	HCO_3	Na	K	Cl	ESP	SAR
DOSES (D)	5	1.67**	1.70**	1.85**	2.53**	0.83**	0.08**	17.39**	12.33**	20.23**	0.026**
Linear	1	7.52**	8.18**	4.11**	6.12**	2.85**	0.38**	83.73**	49.85**	92.14**	0.12**
Quadratic	1	0.76**	0.01^{ns}	2.59**	5.72**	0.85**	0.005^{ns}	0.15^{ns}	1.39^{ns}	7.54**	0.002^{ns}
Deviation	3	0.03*	0.10^{ns}	0.86**	0.27^{ns}	0.15**	0.011*	1.03^{ns}	3.47*	0.49**	0.002^{ns}
residue 1	15	0.008	0.06	0.091	0.192	0.014	0.003	0.45	0.661	0.07	0.001
Depth (De)	1	25.9**	0.01^{ns}	0.22^{ns}	7.25**	1.67**	0.013*	1.76^{ns}	1.17^{ns}	64.08**	0.023**
D * De	5	1.17**	0.07^{ns}	6.90**	5.70**	0.08*	0.006^{ns}	1.61*	1.59*	1.57**	0.002^{ns}
D/De1											
Linear	1	12.2**	-	18.01**	1.09^{ns}	1.84**	-	34.2**	16.7**	65.15**	-
Quadratic	1	1.66**	-	17.09**	24.94**	0.27**	-	0.72^{ns}	4.71**	8.06**	-
Deviation	3	0.05**	-	0.21^{ns}	1.14*	0.11**	-	2.52*	3.54**	1.22**	-
D/De2											
Linear	1	0.14**	-	1.89*	6.02**	1.06**	-	50.35**	34.83**	30.28**	-
Quadratic	1	0.003^{ns}	-	3.44**	2.59**	0.60**	-	1.97^{ns}	0.25^{ns}	1.09**	-
Deviation	3	0.0^{01}ns	-	0.91*	1.03*	0.15**	-	0.08^{ns}	0.85^{ns}	0.25^{ns}	-
residue 2	21	0.005	0.047	0.290	0.312	0.023	0.002	0.514	0.44	0.13	0.0011
CV 1 (%) =		1.40	25.47	16.65	22.09	8.53	19.68	27.95	18.33	5.57	19.86
CV 2 (%) =		1.15	22.02	29.75	28.11	10.65	18.51	29.78	15.03	7.33	16.49
General Average		6.65	0.99	1.81	1.98	1.43	0.28	2.41	4.43	4.95	0.21

Significant at 5% (*) and 1% (**) of probability by F test, ns= not significant, DF = Degree of freedom, CV% = Coefficient of variation.

the application of biochar, the increase of EC from 0.287 dS m^{-1} (control) to 1.55 dS m^{-1} (30 t ha^{-1}) is worrying given the short period in which the test was conducted.

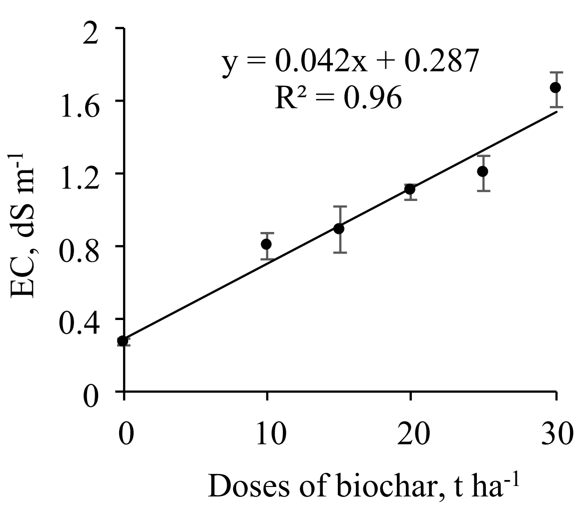

Figure 1 - Electric conductivity as a function of the application of the biochar doses.

The electrical conductivity did not change significantly as a function of the analyzed soil layers. This may be associated with the concentration and solubility of the nutrients present in the biochar that promoted, as well as increased salinity, an increased flow of solutes and leaching of salts to deeper soil layers.

These results differ from those found in the literature (Yue *et al.*, 2016), who verified a higher concentration of salts in the superficial layer and decreasing with depth. It is known that materials with high electrical conductivity, that is, with high salinity, must be handled with caution, because if applied to the soil in large quantities can cause toxicity in plants (Song and Guo, 2012).

Soil pH

Biochar promoted an increase in soil pH mainly in the first soil layer, whose highest estimated value corresponded to 7.87 with the application of 26.17 t ha^{-1} (Figure 2A). In the literature were found results that corroborate those obtained in the present research, like in the study of Rombolà *et al*. (2015) who observed an increase in soil pH in response to application of chicken bed biochar.

The alkalinity of biochar favored this increase. Moreover, the presence of calcium (Ca^{2+}) and bicarbonate (HCO_3^-) may have promoted the formation of calcium carbonate ($CaCO_3$) in the soil, increasing the concentration of hydroxyls (OH^-) (Sappor *et al*., 2017). In relation to Figure 2A, in the depth of 10-20 cm, the soil pH increased with the addition of 0.0075 units (t ha^{-1}) of applied biochar.

The lower influence of the biochar doses on the pH variation observed in the second soil layer shows that the chemical reactions occur preferentially in the superficial layer, where the biochar was applied. This caused, with the exception of the control, a statistical difference of this attribute of the soil between the depths analyzed within each biochar dose applied.

Calcium and magnesium content

The lowest concentration of calcium (0.48 $mmol_c$ L^{-1}) was found in the topsoil (0-10 cm) with the use of 10.16 t ha^{-1}, but when higher doses were applied, there was an increase in the content of this nutrient, which had a mean of 4.02 $mmol_c$ L^{-1} at a dose of 30 t ha^{-1} (Figure 2B). In the second soil layer, the highest concentration of Ca was estimated at 2.4 $mmol_c$ L^{-1}, with 11.63 t ha^{-1} of biochar. Also, in relation to Figure 2B, it was verified that the depth

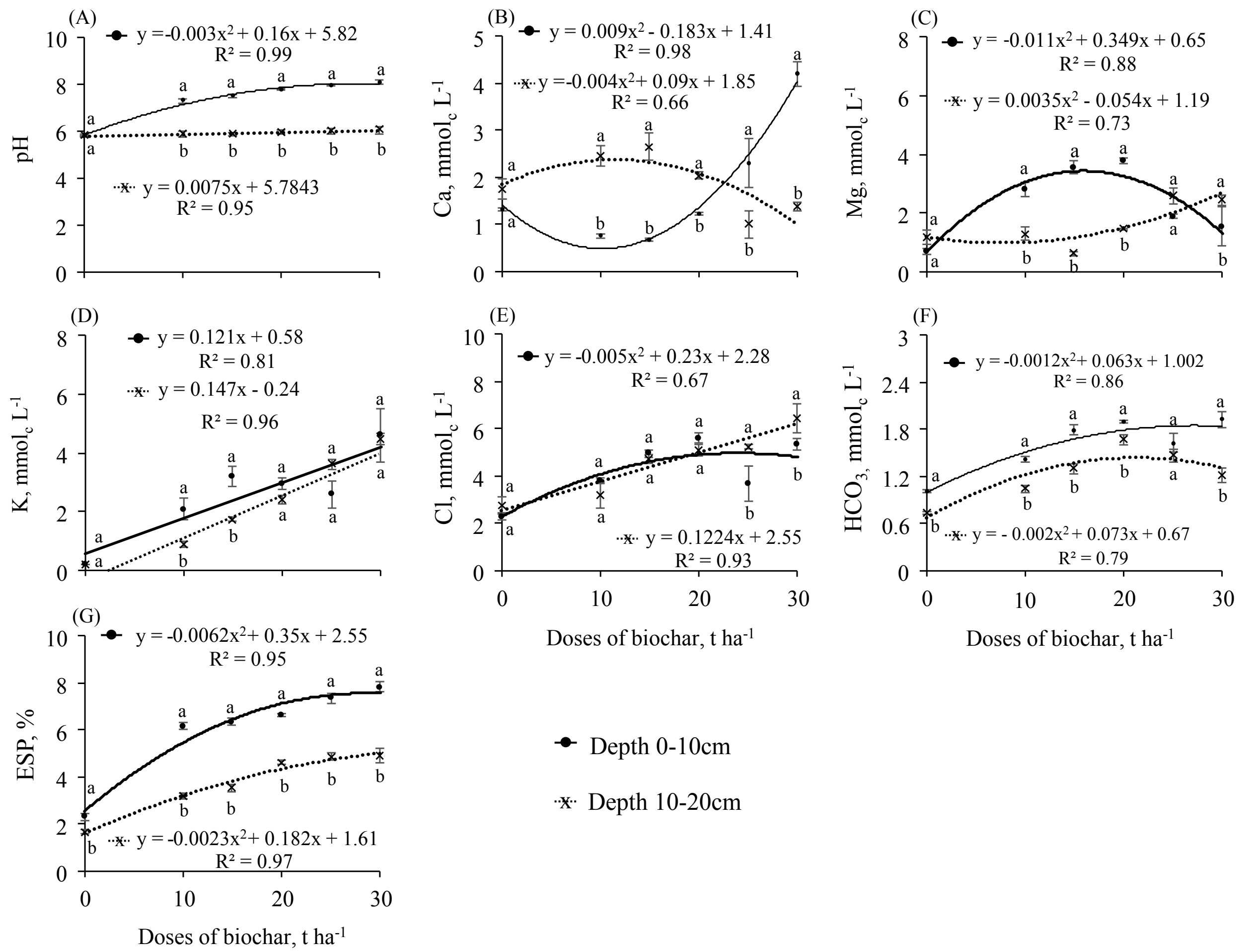

Figure 2 - Behavior of the chemical parameters in the first and second layers of the soil column as a function of the increasing doses of biochar. The vertical bars represent the standard error and the averages followed by the same lowercase letter do not differ statistically between the depths within the same dose of biochar.

promoted significant difference, except in the absence of biochar. In the surface layer, the highest concentrations of Ca occurred only with the use of the two largest biochar.

The mean values of magnesium content, regardless of the analyzed depth, presented the opposite behavior to that observed for calcium (Figure 2C), that is, the increase in calcium concentration in the saturation extract decreased to magnesium, and vice versa. This behavior may be the result of antagonism between these nutrients, so that calcium had preference to be precipitated.

The addition of bivalent cations, such as Ca^{2+} and Mg^{2+}, is essential in the recovery of soils affected by salts, compensating for excess exchangeable Na^{+}. The biochar used in this research is shown to be able to play a positive role in this respect. These results corroborate Major *et al*. (2010) who observed higher availability of $Ca^{2+}$and Mg^{2+} after addition of biochar at a rate of 20 t ha^{-1} to a Latosol.

Potassium content

Potassium showed similar behavior at both depths, ie, at 4.20 and 4.17 $mmol_c$ L^{-1}, for the first and second soil layers, respectively, with 30 t ha^{-1} of biochar (Figure 2D). Also with respect to this figure, K concentrations differed between the depths at the 10 and 15 t ha^{-1} dosages. The exchangeable cations present a retention energy to the soil colloids following a lyotropic series ($Al^{3+} > Ca^{2+} > Mg^{2+} > NH_4^{+} > K^{+} > H^{+} > Na^{+}$)

that considers the charge and the size of the ion hydrated; in this series, potassium, being a monovalent cation, occupies the fifth place (Duarte *et al*., 2013). As biochar increased soil salinity due to the availability of nutrients, potassium competed with calcium and magnesium at the exchange sites, thus, increases in the concentration of K in the saturation extract at the two depths as a function of the applied doses evidenced the mobility of the same in the leach column.

According to Walker and Bernal (2008), the use of chicken litter improves the chemical properties of a soil affected by salts, increasing both CEC and soluble and exchangeable K^{+}, so potassium competes with Na^{+} in terms of adsorption limiting their entry into exchange places.

Chloride and bicarbonate content

Biochar also promoted increases in chloride and bicarbonate content. The maximum chloride concentration in the first soil layer corresponded to 5.02 $mmol_c$ L^{-1}, with 24.15 t ha^{-1}, and in the subsequent layer, its content increased proportionally with the application of the doses, whose unit increase corresponded to 0.1224 $mmol_c$ L^{-1}, per t ha^{-1} of applied biochar (Figure 2E). Chloride accumulation can promote a competitive effect with nitrate and sulfate by exchange sites in the soil-plant system, which may affect crop productivity (Santos *et al*., 1984). As for bicarbonate (Figure 2F), their means were adjusted independently of depth to the second-order polynomial regression model, whose maximum values corresponded to 1.83 and 1.45 $mmol_c$ L^{-1} in the first and second layers respectively. According to Garg and Garg (1980) the carbonate / bicarbonate can lead to sodification of the soil, besides decreasing the concentration of calcium and magnesium in the soil due to the precipitation of these. In addition, it can affect nutrient uptake by increasing pH, decreasing the availability of soil nutrients (Paliwal *et al*., 1978).

Exchangeable sodium percentage (ESP)

In relation to the percentage of exchangeable sodium (ESP), the application of biochar significantly increased this parameter in both layers of soil analyzed, reaching maximum values of 7.74% and 5.23% in the first and second depth, respectively, representing an increase of 203.53% and 224.18% when compared to the absolute control (Figure 2G).

Still in relation to Figure 2G, the ESP averages were higher in the first depth differing significantly from those recorded in the second layer regardless of the applied dose. The result obtained in this research differs from Chaganti *et al*. (2015), who found a significant reduction of soil ESP with the use of biochar, when evaluating the remediation of saline-sodic soils with organic inputs.

Sodium content and sodium adsorption ratio (SAR)

Sodium and sodium adsorption ratio (SAR) presented similar behavior, that is, their contents were higher in the treatments that received the biochar, presenting as higher averages 0.40 and 0.27 $mmol_c\ L^{-1}$, respectively, with use of 30 t ha^{-1} (Figures 3A and 3C). When the influence of the layers was analyzed, the Na^+ and SAR concentrations were higher in the depth of 10-20 cm (Figures 3B and 3D). This result suggests that sodium showed good mobility within the leaching column. This is because the enrichment of exchangeable sites of the soil profile with Ca^{2+} and Mg^{2+} may decrease the exchangeable Na^+ concentration at these sites, making it soluble in the soil solution and therefore more susceptible to leaching.

Due to the increase in sodium, the indicators exchangeable sodium (ESP) and sodium adsorption ratio (SAR) presented higher averages in the treatments that received the biochar, which provides greater possibility of soil sodicity problems, which suggests caution in its use. These results corroborate Subhan *et al*. (2015) who reported increase in SAR due to high Na^+ concentrations in the biochar produced from cotton stems.

Salt affected soils are generally classified based on the electrical conductivity of the saturated extract (CEse), the exchangeable sodium percentage (ESP) and the pH (Richard, 1954). Based on these properties, the soil used in this research was classified as normal, at the end of the experiment, because it presented an ECse <4 dS m^{-1}, an ESP <15 and a pH less than 8.5. However, even if there are

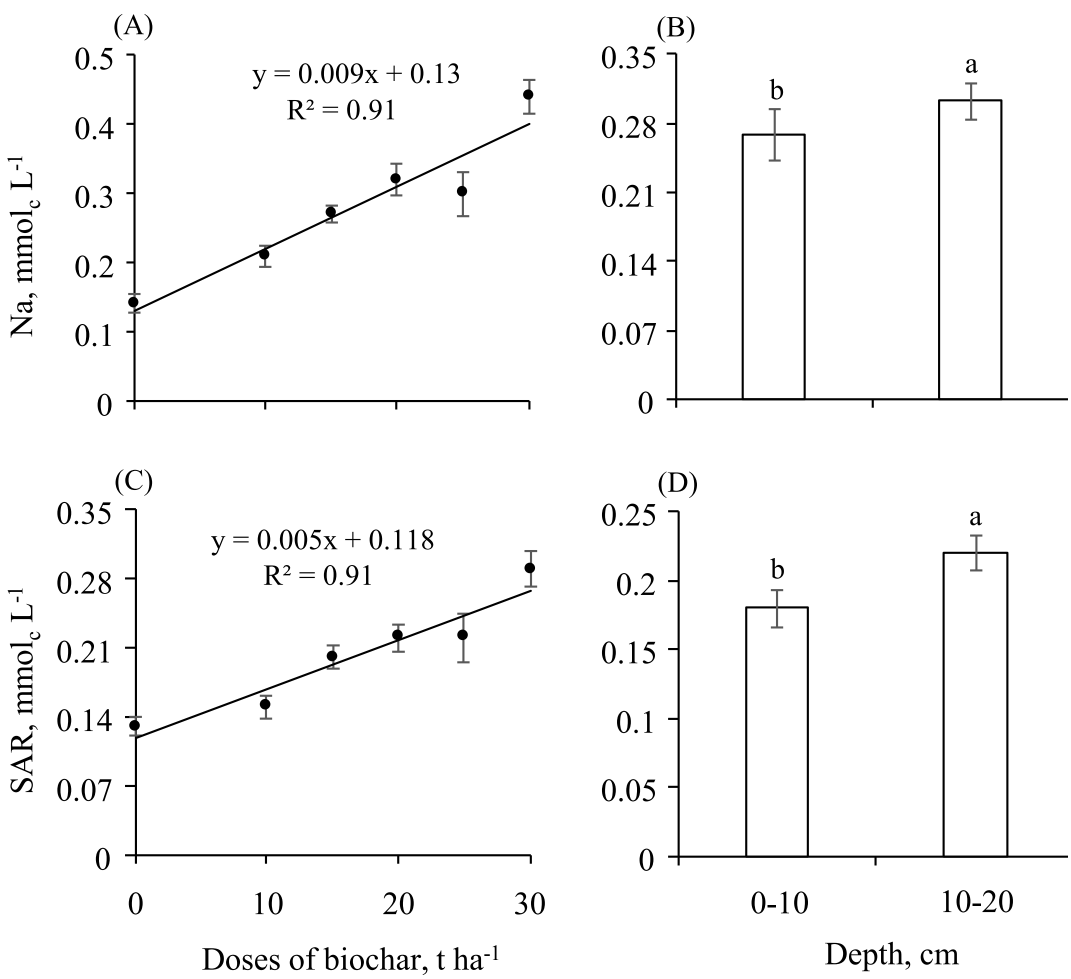

Figure 3 - Sodium content (A) and sodium adsorption rate (SAR) (C) as a function of the doses of biochar and of the depths analyzed in the leaching column. In Figures (B) and (D) we can see the comparison of means with the test t.

no salt problems, the increase in all parameters analyzed in a short period (30 days) points to caution regarding the use of biochar studied.

The results found in the literature are contradictory. Zhang *et al*. (2016), after evaluating the influence of different types of biochar in the chemical properties of two soils, a sandy and a clay one, verified increase of salinity for both soils. However, Lashari *et al*. (2013), showed a significant decrease in soil pH and salt and sodium contents with the application of a biochar. Therefore, the raw material used to produce the biochar is the key factor that determines its effectiveness as an organic soil conditioner. Current data on salinization or recovery of salt/sodic affected soils with biochar are inconsistent and it is difficult to compare the existing studies in the literature with each other. This is probably due to the large variation between the biochar composition and the diversity of soils used in the different studies. In addition, there is a lack of long-term field experiments to verify the mechanisms observed in controlled conditions like experiments in pots or incubation studies.

CONCLUSION

Biochar increased all the salinity parameters analyzed, however, regardless of the applied dose and depth analyzed, the soil was still classified as a non-saline. However, the increase in all the analyzed parameters points to a careful use of the biochar studied.

Further research is needed to evaluate the effect of different doses of chicken litter biochar for a longer incubation period, using soils with different salinity levels, in order to verify possible changes in soil physicochemical properties.

The composition of the raw material used to produce the biochar is a key factor that determines its effectiveness as an organic soil conditioner.

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