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EFFECT OF POULTRY LITTER BIOCHAR ON THE NUTRITIONAL STATUS OF CORN[1]

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ABSTRACT – Corn, one of the main grain crops in Brazil, needs to have its nutritional requirements fully satisfied to achieve high biological productivity. Thus, the objective of this work was to evaluate the influence of increasing doses of poultry litter biochar on nutrient concentrations in the leaves of hybrid corn BRS 2022 and in the soil after harvest. The experiment was carried out in a completely randomized design, with four replicates, evaluating six doses of biochar (0; 2.02; 4.05; 6.07; 8.10 and 10.12 t ha^{-1}) and the plots composed of one plant per pot with a volume of 20 dm^3. The collection of leaves for leaf diagnosis was carried out at the time of flowering, removing the opposite leaf from the ear base in the middle third region. These leaves were dried in a forced air circulation oven, 65 °C, for a period of 48 hours, ground, sieved through 20 mesh and analyzed for the concentrations of macronutrients in the leaf tissue. At the end of the experiment, 83 days after corn sowing, soil samples were collected as a function of the treatments and then analyzed chemically. Biochar application promoted an increase in the leaf contents of N, P and K, resulting in improvements in the nutritional status of plants for these nutrients. The chemical characteristics of the soil, analyzed after the corn harvest, revealed that there was an influence of the doses of biochar on the levels of calcium, organic carbon, potassium and phosphorus.

Keywords: *Zea mays* L.. Plant nutrition. Poultry waste.

EFEITO DE BIOCARVÃO NO ESTADO NUTRICIONAL DE MILHO E NAS PROPRIEDADES QUIMICAS DE SOLO PÓS-COLHEITA

RESUMO – O milho, uma das principais culturas de grãos do Brasil, necessita ter as suas exigências nutricionais plenamente satisfeitas para atingir elevadas produtividades biológicos. Dessa forma, objetivou-se com esse trabalho avaliar a influência de doses crescentes de biocarvão de cama de aviário nas concentrações dos nutrientes nas folhas do milho híbrido BRS 2022 e no solo após a colheita. O experimento foi conduzido em delineamento inteiramente casualizado, com quatro repetições, sendo seis doses de biocarvão (0; 2,02; 4,05; 6,07; 8,10 e 10,12 t ha^{-1}) e as parcelas constituídas por uma planta por vaso com volume de 20 dm^3. A coleta de folhas para diagnose foliar foi realizada na época do florescimento, sendo retirada a folha oposta e da base da espiga na região do terço médio. Essas folhas foram secas em estufa de circulação forçada de ar a 65 °C por um período de 48 horas, moídas, peneiradas em 20 mesh e analisadas em relação a concentração dos macronutrientes no tecido foliar. No final do experimento, 83 dias após a semeadura do milho, amostras de solo foram coletadas em função dos tratamentos e em seguida analisadas quimicamente. A aplicação do biocarvão promoveu aumento nos teores foliares de N, P e K, refletindo em melhorias no estado nutricional das plantas para estes nutrientes. As características químicas do solo, analisadas após a colheita do milho revelou que houve influência das doses de biocarvão nos teores de cálcio, carbono orgânico, potássio e fósforo.

Palavras chave: *Zea mays* L.. Nutrição de plantas. Resíduo avícola.

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INTRODUCTION

The poultry sector generates an excess of organic waste, poultry litter, composed of sugarcane bagasse (with the presence of lignin and cellulose), feces and chicken feed, and also with a high concentration of phosphorus and nitrogen, which has been used as a source of organic matter and nutrients in agricultural soil. However, when inadequately applied to the soil, it can cause unwanted impacts on the environment, such as ammonia volatilization, soil acidification, contamination of surface water by nitrogen and/or phosphorus leaching. Therefore, poultry litter has been used in the production of biochar through the pyrolysis process, characterized by carbonization of the substrate in the absence or at low concentration of oxygen (CHAVES et al., 2020).

Biochar can be prepared from different types of agricultural waste, e.g. stems of rattlebox (*Sesbania punicea*), chickpea (*Cicer arietinum*), and corn cobs (*Zea mays*), wheat straw (*Triticum aestivum*), sugarcane bagasse (*Saccharum officinarum*) and animal manure (TASIM et al., 2019). Biochar can be used as an organic fertilizer for the cultivation of several crops, including corn, a herbaceous plant, belonging to the Poaceae family. Corn is grown in all parts of the globe, and the world's largest producers are the United States, China and Brazil, occupying the third place with an estimated average production of 93.6 million tons for 2022/23 (BRASIL, 2013). Its economic importance is related to the various forms of use, from animal feed to high-tech industry. It is a cereal of great importance, especially for the low-income population.

In a study carried out under field conditions, Glaser et al. (2014) found that the application of biochar from green seedlings when combined with 200 kg ha^{-1} of N significantly increased water retention capacity and corn production. Several studies have already been conducted with other crops using poultry litter biochar. For instance, Coomer (2013) achieved better results of cotton growth using 3 t ha^{-1}; for 'biquinho' pepper (*Capsicun chinense*), 5 t ha^{-1} of biochar were recommended (TITO et al., 2020); doses from 100 to 150 g/plant were more adequate for the number of leaves, root length, fresh and dry biomass of leaves and roots of radish plants (*Raphanus sativus* L.) (CAVALCANTE et al., 2021); in the production and quality of melon (*Cucumis melo L.*) seedlings, 12 t ha^{-1} was considered the ideal dose for the development of these seedlings (LAURENTINO et al., 2021); similarly, 19 m^3 ha^{-1} of poultry litter biochar during 45 days after sowing were recommended for the growth of bell pepper (*Capsicum annuum* L.) (LIMA et al., 2019). As for corn crop, Inal et al. (2015) applied 0, 2.5, 5, 10 and 20 g kg^{-1} of biochar and observed that plant growth and leaf concentrations of N, P, K, Zn, Cu and Mn increased according to the doses, revealing that this biochar can be effectively used as a source of these nutrients.

In order to achieve high yields, corn needs to have its nutritional requirements fully met, since high yields imply a large extraction of nutrients.

The identification of the nutritional status of the plant can be made based on the observation of characteristic symptoms of a disorder, as well as through leaf chemical analysis. This analysis can indicate whether the fertilizers applied to the soil are actually being used, whether the nutrients supplied are balanced according to the requirements of the crop and whether there are deficiencies or toxicity of nutrients, that is, it may reflect what the plant can actually extract of nutrients from the soil. However, it is not always possible to verify the relationship between the supply of nutrients through the soil and the leaf contents of the elements, because these contents are influenced by several factors related to the plant, chemical and physical attributes of soils, climate, pests and diseases, among others. Thus, chemical analysis of the soil after crop harvest makes it possible to assess what was detected by leaf analysis, whether the contents in the soil are consistent with the nutritional status of the crop (RESENDE, 2014).

Based on the above, the objective of this study was to evaluate the influence of increasing doses of poultry litter biochar on the nutritional status of BRS 2022 hybrid corn and on the chemical properties of the soil after crop harvest.

MATERIAL AND METHODS

The experiment was conducted in an agricultural greenhouse belonging to the Academic Unit of Agricultural Engineering of the Center for Technology and Natural Resources of the Federal University of Campina Grande (UFCG), in Campina Grande-PB, Brazil, with the following dimensions: 4 m x 8 m x 3 m width, length and height, respectively (Figure 1). Samples of the soil (*Argissolo Acinzentado* - Ultisol) used in the experiment were collected in the arable layer (0-0.2 m depth) in the municipality of Lagoa Seca-PB (07º 09' 22.42" S; 35º 52' 09.64" W).

Figure 1. Satellite photograph of the greenhouse used in the experiment, located on Campus 1 of UFCG. Source: Google Earth software.

These samples were chemically characterized according to Teixeira et al. (2017) and showed the following results: pH (H_2O) = 5.35; organic carbon = 18.8 g kg^{-1}; P = 1.27 mg kg^{-1} and $cmol_c$ kg^{-1}: Ca = 2.78; Mg = 1.26; Na = 0.11; K = 0.17; H+ Al = 3.27 and CEC = 7.59. The percentages of base saturation and aluminum saturation corresponded to 56.91 and 9.24%, respectively.

The biochar used in this study was produced in the Laboratory of Irrigation and Salinity - LIS of UFCG, from poultry litter generated in the rearing of broilers, under slow pyrolysis at 350 °C for 3h, using a muffle furnace, with the following chemical attributes: pH = 9.44; EC = 7.33 dS m^{-1}; C/N = 18.76 and the following nutrients expressed in %: P_2O_5 = 4.08; K_2O = 4.35; Ca = 5.04; Mg = 1.28; S = 0.41; Fe = 0.72; Mn = 0.05; Cu = 0.01; Zn = 0.05; B = 0.01 and organic carbon = 42.22. According to the X-ray Diffraction analysis, this biochar had inorganic components in its constitution, such as sylvite (KCl), potassium aluminosilicate ($KAlSiO_4$), calcite ($CaCO_3$), feldspar compounds [Orthoclase ($KAlSi_3O_8$)] and potassium phosphate (K_2HPO4).

The design used was completely randomized with six treatments and four replicates, totaling 24 experimental units. The treatments corresponded to the application of increasing doses of biochar (0; 2.02; 4.05; 6.07; 8.10 and 10.12 t ha^{-1}) for cultivation of corn (*Zea mays* L.), BRS 2022 hybrid. These doses were applied with the objective of increasing soil base saturation to 63, 69, 75, 81 and 87%, respectively.

The experiment was conducted using plastic containers with 20 dm^3 capacity, filled with approximately 23 kg of soil. After incorporation of the biochar doses, according to the treatments, the soil was irrigated until it reached 90% of field capacity (FC), in order to ensure the germination and development of seedlings. Sowing was performed by placing three seeds of BRS 2022 corn per pot at 0.05 m depth and distributed equidistantly. After germination, around ten days after sowing (10 DAS), thinning was performed, leaving one plant per experimental unit. Regardless of biochar doses, nitrogen fertilization equivalent to 90 kg ha^{-1} (in the form of ammonium sulfate) was split into three portions and applied in phenological stages V2 (vegetative stage - second leaf), V4 (vegetative stage - fourth leaf) and V8 (development stage - eighth leaf).

Irrigation was performed by drip, automated through the Arduino MEGA2560, with sensors that measure the ambient temperature and soil moisture (hygrometer). The moisture sensor measured soil moisture in real time; based on this information, the Arduino activated the irrigation system when the soil had a moisture content below 70% FC and turned it off when the moisture content reached 90% FC.

Leaf collection for foliar diagnosis was performed at the time of flowering, removing the opposite leaf from the ear base in the middle third region, when 50% of the plants had already produced the tassel, according to the method described by Malavolta, Vitti and Oliveira (1997). These leaves were dried in a forced air circulation oven with temperature adjusted to 65 °C for a period of 48 hours, ground, sifted through a 20 mesh and analyzed for the concentrations of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S) in the leaf tissue (CARMO et al., 2000).

At the end of the experiment, 83 days after corn sowing, soil samples were collected as a function of the treatments and then chemically analyzed for the concentrations of calcium, magnesium, phosphorus and potassium according to Teixeira et al. (2017). Nitrogen concentration was estimated by dividing the organic carbon content by ten.

Once the assumptions of normality and homogeneity of variances were met, the collected data were subjected to analysis of variance and, when significant effect was verified by the F test, the means of the variables under biochar doses were analyzed using polynomial regression. Statistical analysis was performed using the statistical software SISVAR according to Ferreira (2011).

RESULTS AND DISCUSSION

The concentrations of nutrients analyzed in the leaf tissue were discussed based on the critical contents suggested by Büll (1993), that is, 27.5, 1.9, 17.5, 2.3, 1.5 and 1.5 g kg^{-1} for N, P, K, Ca, Mg and S, respectively. As the values of P, K, Ca, Mg and S were transformed, for better understanding of the results, the same procedure was also performed for the critical values of Büll (1993) (Figure 3), considering the mathematical model adopted for each nutrient (Table 1).

Table 1. Summary of the analysis of variance for the nutrients nitrogen, phosphorus, potassium, calcium, magnesium and sulfur analyzed in the leaf tissue of BRS 2022 corn plants as a function of the application of increasing doses of poultry litter biochar.

Source of variation	Degrees of freedom	Mean square					
		N	P$^{(1)}$	K$^{(2)}$	Ca$^{(3)}$	Mg$^{(4)}$	S$^{(5)}$
Dose	5	76.77**	3.83**	23101.68**	0.037**	0.110**	0.022**
Linear	1	4.73^{ns}	13.69**	104072.40**	0.158**	0.384**	0.047**
Quadratic	1	217.22**	1.68^{ns}	4421.86^{ns}	0.026^{ns}	0.126**	0.010**
Deviation	3	53.96**	1.27^{ns}	2338.04^{ns}	0.001^{ns}	0.013^{ns}	0.017**
Error	18	7.15	0.49	1269.013	0.006	0.012	0.001
CV (%)		9.13	44.63	23.48	7.48	14.05	4.86
Overall mean		29.3 g kg^{-1}	1.6 g kg^{-1}	151.7 g kg^{-1}	1.1 g kg^{-1}	0.8 g kg^{-1}	0.7 g kg^{-1}

^{**,*,ns} Significant at 1%, 5% and not significant, respectively; $^{(1), (2), (3), (4), (5) \text{ and } (6)}$ Data transformed into: $\frac{x^{1.9949}-1}{1.9949}$; $\frac{x^{1.8939}-1}{1.8939}$; $\frac{x^{-0.5303}-1}{-0.5303}$; $\frac{x^{-0.7323}-1}{-0.7323}$ and $\frac{x^{-0.9343}-1}{-0.9343}$, respectively.

The highest nitrogen (N) concentration in corn leaf tissue corresponded to 32.82 g kg^{-1} under biochar application of 5.28 t ha^{-1} (Figure 2A). Regarding the critical content, according to Büll (1993), the use of biochar at doses from 1.03 to 9.52 t ha^{-1} was sufficient for the concentration of this nutrient to vary within a range considered adequate. It is common for biochars to have low N concentration in their constitution, so the content of this nutrient was influenced by the chemical fertilization performed in the experiment. Even with nitrogen fertilization, under 5.28 t ha^{-1} of biochar there was an increase in leaf N concentration of 19.34% when compared to the critical content.

In relation to Figure 2A, the quadratic behavior indicates a supposed antagonistic interaction between K and N or immobilization of N at the highest doses of biochar, decreasing the absorption of this nutrient by the plant. According to Jiuxin et al. (2012), an imbalance between N and K caused by the excessive addition of K can lead to N deficiency in the plant due to dilution effect caused by plant growth and vice versa. According to Hawkesford et al. (2011), K competes with several cations for the absorption sites in the plasma membrane, mainly with ammonium (NH_4^+), Ca^{2+} and Mg^{2+}. In addition, there is evidence that the giant reed (*Arundo donax* L.) biochar can increase the immobilization of N in the soil (ZHENG et al., 2013). After applying corn straw biochar to the soil, Xiao et al. (2017) observed increments in the adsorption of inorganic N by the soil and in the biological immobilization of N due to microbial activity.

The phosphorus (P) content in corn leaf tissue increased at a rate of 0.2177 g kg^{-1} for each t ha^{-1} of biochar applied (0.111 g kg^{-1}, not transformed), and its highest average was 2.67 g kg^{-1} of P (2.52 g kg^{-1}, not transformed), obtained with 10.12 t ha^{-1} of biochar (Figure 2B). This figure also showed that, between the doses of 3.79 and 10.12 t ha^{-1}, the leaf P content was within the range above the critical reference value (BÜLL, 1993). However, doses higher than those tested in this study may lead to an excessive concentration of P, which according to Gott et al. (2014) corresponds to values greater than 3.8 g kg^{-1}. The increase in P content verified in this study was associated with the biomass used to produce biochar, that is, poultry litter, which contained phosphate compounds in its constitution. Similarly, Sabijon and Sudaria (2018) verified an increase in P concentration in corn plants with the use of poultry litter biochar, whose values were 0.99, 4.22, 4.41 and 4.33 g kg^{-1} P with treatments of 0, 20, 40 and 60 g kg^{-1}, respectively.

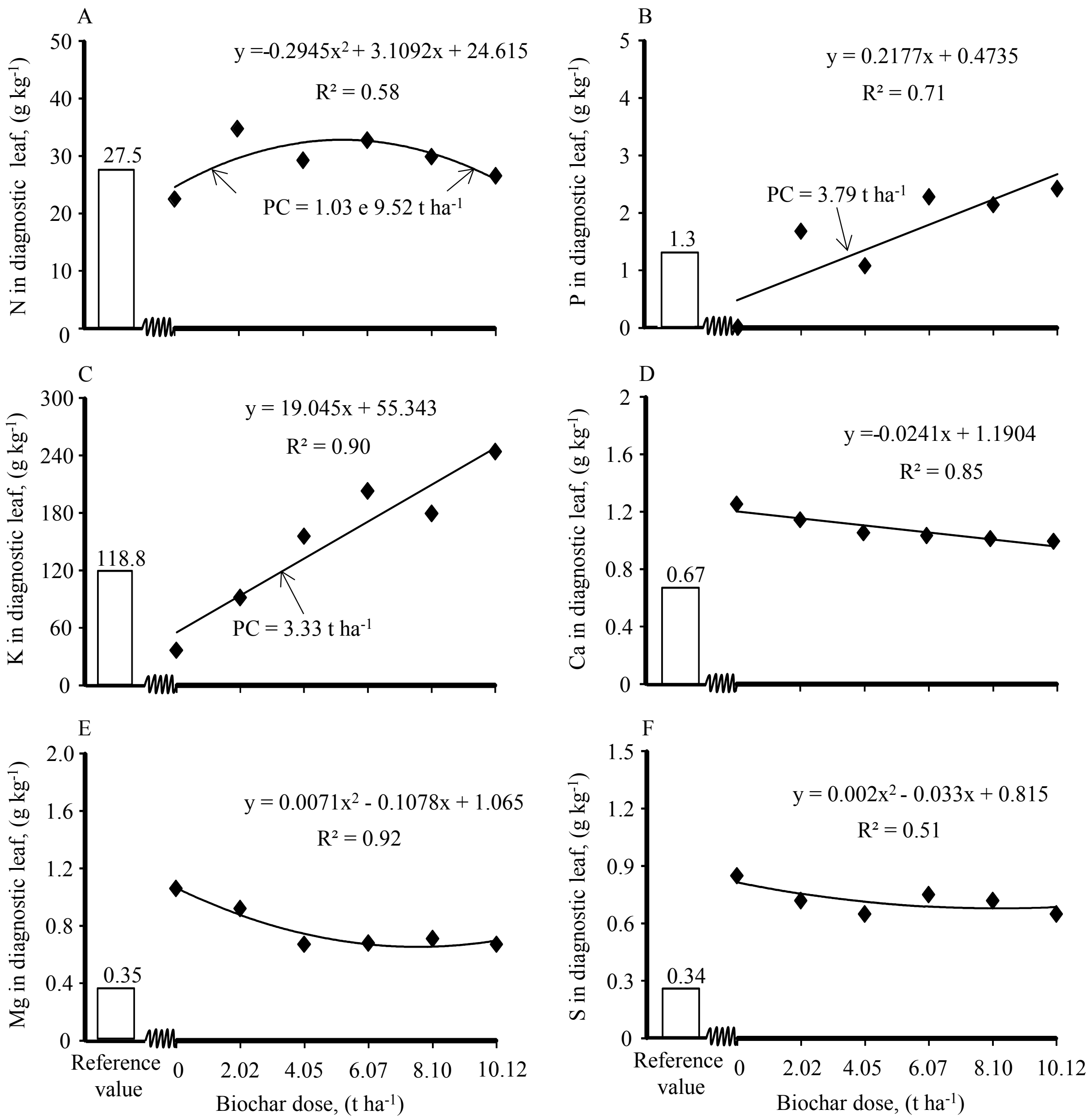

Figure 2. Concentrations of nutrients analyzed in the leaf tissue of BRS 2022 corn as a function of the application of different doses of poultry litter biochar. The values of the columns correspond to the critical contents of nutrients according to Büll (1993), whose non-transformed values are: 27.5, 1.9, 17.5, 2.3, 1.5 and 1.5 g kg^{-1} for N, P, K, Ca, Mg and S, respectively, and CP is the minimum dose required for nutritional deficiency to occur or not to occur.

As observed for P, the potassium (K) content in corn leaf tissue also increased linearly at a rate of 19.045 g^{-1} of biochar applied (1.389 g kg^{-1}, not transformed), and its highest average was 248.07 g kg^{-1} of K (25.78 g kg^{-1}, not transformed), obtained with 10.12 t ha^{-1} of biochar (Figure 2C). This Figure also showed that, between the doses of 3.33 and 10.12 t ha^{-1}, the K content in the leaf tissue was within the range above the critical reference value (BÜLL, 1993). Corn has excess leaf K when its values are higher than 28.9 g kg^{-1} (GOTT et al., 2014). This value would be achieved in this study with an overestimated biochar dose of 13.27 t ha^{-1}.

Calcium, magnesium and sulfur (S) showed similar behavior, that is, their contents decreased with the use of biochar (Figures 2D, 2E and 2F). Despite these reductions, the plant did not show, regardless of the biochar dose applied, deficiency of any of these secondary macronutrients.

The lowest concentrations corresponded to 0.95 g kg^{-1} (3.75 g kg^{-1}, not transformed, when applying 10.12 t ha^{-1}), 0.656 g kg^{-1} (2.44 g kg^{-1}, not transformed, when applying 7.59 t ha^{-1}) and 0.68 g kg^{-1} (2.95 g kg^{-1}, not transformed, when applying 8.25 t ha^{-1}) for Ca, Mg and S, respectively.

The decrease in Ca and Mg contents may have occurred due to the excess of K absorbed by the plant, which compromises the absorption of Ca and

Mg. Excess K in the soil may result in an antagonistic effect, in which K reduces the absorption of Ca and Mg (HAWKESFORD et al., 2011). This effect was observed in corn sprouts cultivated with doses of biochar produced from upper branches of eucalypt trees (*Eucalyptus camaldulensis*) (BUTNAN et al., 2015). According to these authors, the use of this biochar altered the nutritional proportions of K, Ca and Mg in corn sprouts. In this study, biochars increased the K:Ca and K:Mg ratios in the leaf tissue, which ranged from 1.1:1 (0 t ha^{-1}) to 6.1:1 (10.1 t ha^{-1}) for calcium and from 1.1:1 (0 t ha^{-1}) to 9.7:1 (10.1 t ha^{-1}) for magnesium. The reduction in absorption of Ca and Mg can directly affect photosynthesis and, as a result, reduce plant growth (KALAJI et al., 2014).

The results suggest that, although the poultry litter biochar contains in its constitution Ca (5.04%) and Mg (1.28%), the addition of this input does not guarantee the immediate availability of these cations for absorption by corn plants. Therefore, it is suggested that the reduction in absorption was attributed to the slow release of Ca and Mg due to the strong bond with biochar and/or to the antagonistic effect promoted by K. In the latter, the antagonistic effects will occur when there is a high absorption of K by corn tissue with restriction to the absorption of Ca and Mg (BUTNAN et al., 2015). These results suggest caution when biochars containing considerable K content are applied with mineral K fertilizers.

Regarding soil chemical characterization, phosphorus, potassium, calcium and organic carbon were influenced by biochar after the harvest of BRS 2022 hybrid corn (Table 2).

Table 2. Summary of the analysis of variance for phosphorus (P), potassium (K), calcium (Ca), organic carbon (C), hydrogen potential (pH), potential acidity (H+Al), magnesium (Mg), sodium (Na) and cation exchange capacity (CEC) in the soil analyzed after cultivation of BRS 2022 corn fertilized with different doses of poultry litter biochar.

SV	DF	Mean square								
		P	$K^{(1)}$	Ca	C	pH	H+Al	Mg	$Na^{(1)}$	CEC
Dose	5	547.9^{**}	32.90^{**}	0.27^{**}	8.84^{**}	0.20^{ns}	0.15^{ns}	0.17^{ns}	1.10^{ns}	0.79^{ns}
Linear	1	2506.1^{**}	107.30^{**}	0.87^{**}	37.48^{**}	-	-	-	-	-
Quadratic	1	75.6^{ns}	21.34^{**}	0.22^{*}	0.67^{ns}	-	-	-	-	-
Deviation	3	52.6^{ns}	11.95^{*}	0.09^{ns}	2.01^{ns}	-	-	-	-	-
Residual	18	25.36	2.51	0.04	1.57	0.12	0.28	0.18	0.49	0.44
CV (%)		25.37	13.08	7.67	11.64	5.86	42.21	22.98	20.65	10.73
Overall mean		19.85 mg dm^{-3}	12.12 $cmol_c$ dm^{-3}	2.66 $cmol_c$ dm^{-3}	10.78 g dm^{-3}	5.93	1.26 $cmol_c$ dm^{-3}	1.86 $cmol_c$ dm^{-3}	3.42 $cmol_c$ dm^{-3}	6.19 $cmol_c$ dm^{-3}

SV = Source of variation; DF = Degree of freedom; ^{**,*,ns} Significant at 1%, 5% and not significant, respectively; $^{(1)}$ Data transformed into 1/x.

According to Wang et al. (2019), applications of corn straw biochar in amounts greater than 40 t ha^{-1} promoted improvements in soil CEC, organic carbon, total nitrogen and available K for three consecutive years of cultivation, and their levels were proportional to the amount of biochar applied.

The phosphorus content available in the soil increased at a rate of 2.95 mg dm^{-3} per ton of biochar applied per hectare, and its highest concentration corresponded to 34.80 mg dm^{-3} with the dose of 10.12 t ha^{-1}, which represented, when compared to the control, an increase of 611.64% of P (Figure 3A). Although the soil used in this study is an *Argissolo* (Ultisol) of loamy sand texture with low available phosphorus content, after corn cultivation, with the application of doses higher than 2.64 t ha^{-1}, the soil had higher P concentrations when compared to the content (12.7 mg dm^{-3}) observed before the experiment was installed. According to Madiba et al. (2016), chicken manure and wheat straw biochars in the soil increased mycorrhizal colonization, water retention and phosphorus P availability in the soil. DeLuca et al. (2015) found that, when biochar with high pH and CEC is applied, phosphorus adsorption by iron and aluminum oxides is blocked, increasing the availability of P in the soil. According to Wang et al. (2019), corn straw biochar alters the relative distribution of phosphorus forms in the soil available to plants.

Regarding the potassium content, to meet the statistical assumptions of normality, its data were transformed to 1/x, so the behavior observed in Figure 3B is the inverse of what was verified in practice, that is, considering the non-transformed data, the lowest K content corresponded to 0.07 $cmol_c$ dm^{-3} with 1.77 t ha^{-1} of biochar. From this dose, the availability of potassium in the soil increased to 0.13 $cmol_c$ dm^{-3} under 10.12 t ha^{-1} of biochar. Despite the observed increase, regardless of the biochar dose applied, after corn harvest, the K concentration in the soil was lower than that observed before the experiment began (0.17 $cmol_c$ dm^{-3}). This result shows that the amount of K absorbed by the plant was proportional to the amount of biochar applied, corroborating what has been discussed previously.

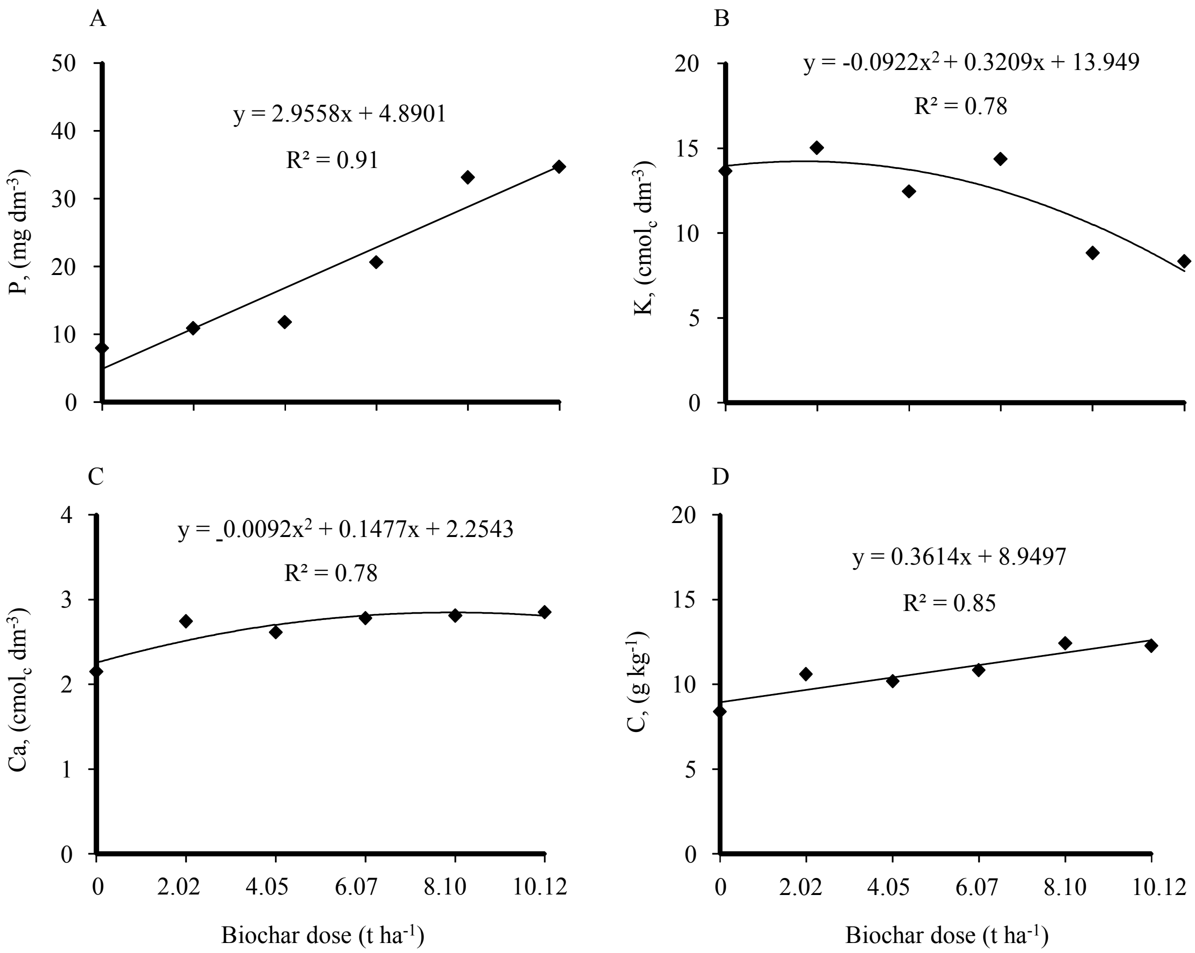

Figure 3. Values of phosphorus (P), potassium (K), calcium (Ca) and organic carbon (C) after sowing of BRS 2020 corn as a function of doses of poultry litter biochar.

Biochar also influenced the calcium content in the soil, whose highest concentration corresponded to 2.85 $cmol_c$ dm^{-3} with the dose of 8.03 t ha^{-1} (Figure 3C). This increase corroborates the previously discussed hypothesis, that is, that there was antagonism between K and Ca during the absorption by the plant; this is because the Ca content in leaf tissue decreased with biochar doses, while Ca content in the soil increased at the end of the experiment.

There was an increase in soil organic carbon content at a rate of 0.3614 g kg^{-1} per tons of biochar applied per hectare. The highest estimated mean, that is, 12.61 g kg^{-1} (10.12 t ha^{-1} of biochar), was 40.9% higher when compared to that obtained in the control treatment (Figure 3D). Considering the initial concentration of C (10.9 g kg^{-1}), real increments of this element were observed from the application of 5.39 t ha^{-1}, indicating that there was mineralization of organic matter at the lowest doses of biochar. This mineralization was probably favored by the increase in soil microbial activity because of the C/N ratio of the biochar used in this study (18.76). According to Wang et al. (2019), the stability of biochar is due to its high carbon content, complex aromatic structure and high levels of carboxylic esters, causing it to have high chemical and microbiological stability in the soil environment.

The fractions of the elements nitrogen, calcium, magnesium, phosphorus and potassium in the form absorbed or unavailable for the plant, the initial and final concentrations in the soil and the contents present in the biochar as a function of the different doses applied were presented in Figure 4. When compared to the initial concentration, there was a slight increase in soil nitrogen content (final concentration) after the end of the experiment and, except for the control treatment, the final N concentration was virtually the same, regardless of the biochar dose applied. Still regarding nitrogen, there was an increase of this nutrient in the soil proportional to the application of biochar; however, the fraction absorbed by the plant did not follow the same behavior, with not much variation between the treatments that received biochar. This result showed that, although biochar contains N in its composition, its availability to the plant is uncertain, because it is difficult to predict which fraction of organic N is susceptible to mineralization and the speed with which it is mineralized. These results corroborate those reported by Sara and Shah (2018), who evaluated the residual effect of biochar on soil properties and corn yield under different cropping systems and verified that there were no considerable differences in soil mineral nitrogen between the control treatment and the treatment that received the highest level of biochar (80 t ha^{-1}).

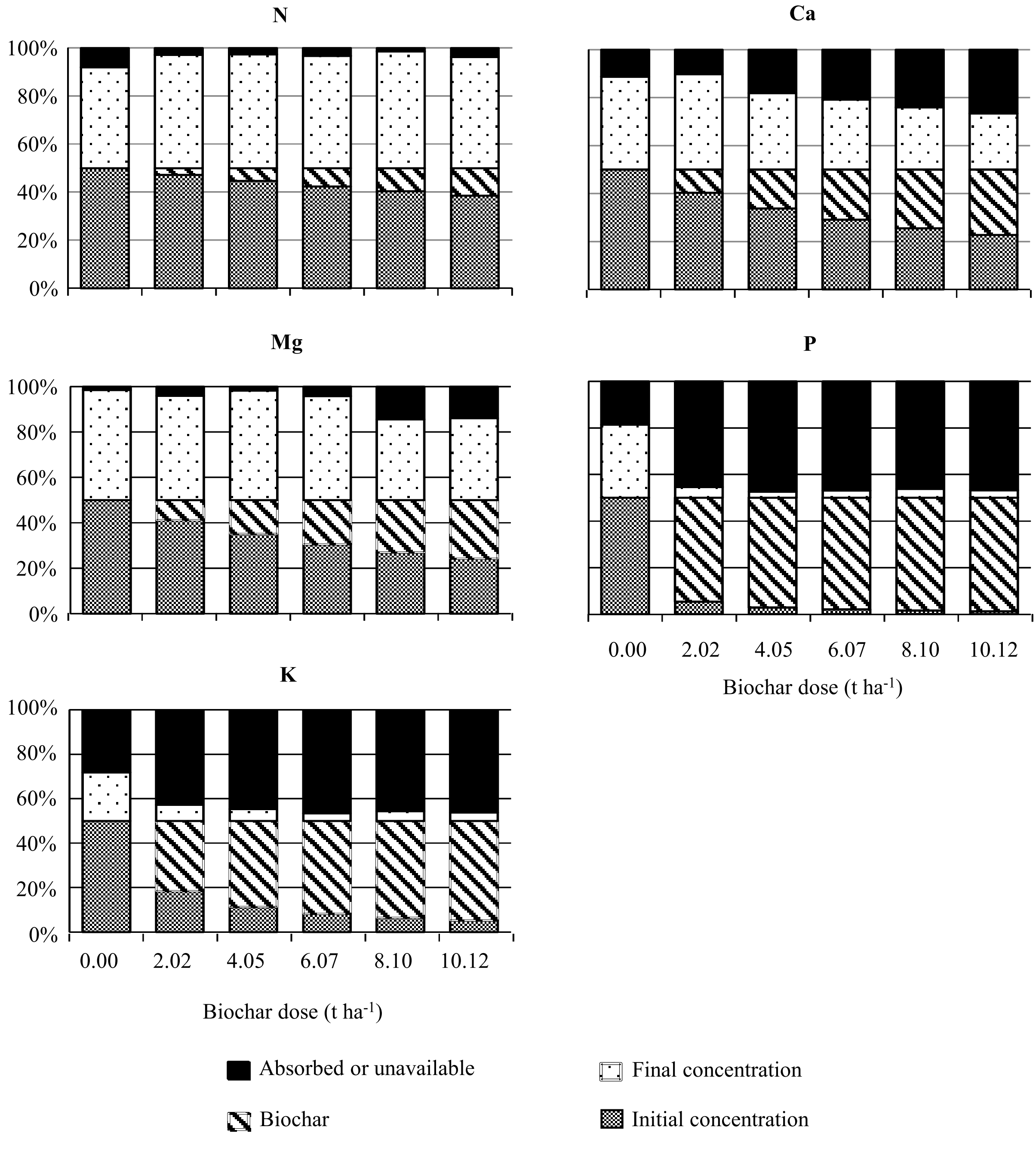

Figure 4. Fraction of the elements in the absorbed or unavailable form for the plant, final and initial concentration in the soil and in the poultry litter biochar as a function of the different doses of the biochar applied.

Although the biochar increased the fraction of Ca and Mg in the soil, the availability of these nutrients is believed to be related to the time of biochar decomposition. More recent studies have demonstrated the potential for poultry litter mineralization of 49.7% (ANDRADE et al., 2015). However, little is known about the mineralization of poultry litter biochar. Thus, although this input contains Ca and Mg in its constitution, even increasing the absorbed or unavailable fraction, these nutrients were believed to be preferably in the unavailable form, because their contents decreased in the leaf tissue of corn despite the addition of Ca in the soil, at the end of the experiment, due to the application of biochar. Another factor that also contributed to the lower availability of nutrients was the antagonistic effect of potassium on the elements Ca and Mg.

The fraction of phosphorus and potassium nutrients from the biochar increased as a function of the doses applied, which can be explained by the presence of inorganic compounds which are sources of phosphorus and potassium, such as: potassium phosphates, potassium aluminosilicate and potassium chloride. Same behavior was observed for the absorbed or unavailable fraction. However, in the case of phosphorus, as in the leaf tissue of corn, there was also an increase in the P fraction in the soil after the experiment (final concentration), which was higher when compared to the initial one with the application of the highest doses of biochar. Much of the K fraction made available by the biochar was absorbed by corn, so that even with the application of biochar, the final concentration of K in the soil was lower than the concentration observed at the beginning of the experiment.

CONCLUSIONS

Application of increasing doses of poultry litter biochar in BRS 2022 hybrid corn promoted an increase in leaf contents of N, P and K, resulting in improvements in the nutritional status of plants for these nutrients.

The chemical characteristics of the soil, analyzed after harvest of BRS 2022 corn, revealed that there was influence of poultry litter biochar doses on the contents of calcium, organic carbon, potassium and phosphorus.

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