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Symptoms of deficiency and initial growth of maize cultivated with biochar under nutrient omission

Sintomas de deficiência e crescimento inicial do milho cultivado com biocarvão sob omissão de nutrientes

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Highlights

Nutrient omission and biochar rates influenced maize growth and biomass.
Biochar reduced limitations of initial growth in maize under nutrient omission.
Biochar reduced visual symptoms in initial growth even under nutrient omission.

Abstract

Maize is the second largest agricultural crop in Brazil. It reaches high yields as supported by the intensive use of technologies, particularly mineral fertilization, which is normally costly. To lower production costs and improve crop productivity on small farms, the present study tested the efficiency of poultry litter biochar as a source of nutrients in the initial growth of BRS 2022 maize by the 'diagnosis by subtraction' method. The study was carried out in a greenhouse, using a completely randomized experimental design with a factorial arrangement (7×3). The following treatments were tested: complete nutrient solution (N, P, K, Ca, Mg, S, B, Cl, Cu, Fe, Mn, and Zn); complete nutrient solutions with omission of only nitrogen (-N), phosphorus (-P), potassium (-K), calcium (-Ca), and magnesium (-Mg); and complete absence of nutrients and three increasing rates of biochar (0, 5, and 10 t ha^{-1}). Absence of nutrients with biochar rates significantly influenced the growth and dry biomass production variables of the maize plants. Except for stem diameter and the ratio between shoot and root dry biomass, all variables were influenced by the interaction between nutrients

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and biochar rates. Nutrient omission limited maize growth; however, the application of biochar reduced these limitations and significantly improved all analyzed variables. In the treatments without fertilizer, maize growth was very low, with generalized symptoms of deficiency that would decrease with the application of biochar. Even in the treatment with complete fertilization, which showed some slight visual symptoms, these decreased with the application of biochar.

Key words: Diagnosis by subtraction. Visual diagnosis. *Zea mays.*

Resumo

A cultura do milho é a segunda maior produção agrícola do Brasil. Alcança altos rendimentos, apoiada no uso intensivo de tecnologias, em particular, a adubação mineral, normalmente onerosa. Na visão de baixar custos de produção e melhorar a produtividade da cultura na pequena propriedade rural, neste trabalho foi testado pelo método diagnose por subtração a eficiência do biocarvão da cama de frango como fonte de nutrientes ao crescimento inicial do milho BRS 2022. O estudo foi realizado em casa de vegetação, utilizando delineamento experimental inteiramente casualizado, em esquema fatorial (7x3), com os seguintes tratamentos: solução nutritiva completa (N, P, K, Ca, Mg, S, B, Cl, Cu, Fe, Mn, Zn); soluções nutricionais completas com a omissão de apenas nitrogênio (-N), fósforo (-P), potássio (-K), cálcio (-Ca) e magnésio (-Mg); com ausência completa de nutrientes e três doses crescentes de biochar (0, 5 e 10 t ha^{-1}). As variáveis de crescimento e produção de biomassa seca de plantas de milho foram significativamente influenciadas pela ausência de nutrientes e pelo efeito das doses de biocarvão. Com exceção do diâmetro do caule e da relação entre a parte aérea e a biomassa da raiz seca as interações também foram significativamente afetadas pelos tratamentos. A omissão de nutrientes limitou o crescimento do milho, no entanto, a aplicação do biocarvão diminuiu essas limitações e melhorou significativamente todas as variáveis analisadas. Nos tratamentos sem adubação, o crescimento do milho foi muito baixo, com sintomas generalizados de deficiência que diminuiriam com a aplicação do biocarvão. Até mesmo o tratamento com adubação completa que apresentou alguns leves sintomas visuais, houve redução a aplicação do biocarvão.

Palavras-chave: Diagnose por subtração. Diagnose visual. *Zea mays* L.

Introduction

Maize (*Zea mays* L.) is the second largest crop of importance in agricultural production in Brazil, only after soybean (Glycine max (L.) Merrill), which leads grain production in the country. According to the systematic survey of agricultural production in January 2020, the maize crop in Brazil occupies an area of around 17.7 million hectares, which are responsible for the production of about 96.1 million tons of grain (Instituto Brasileiro de Geografia e Estatística [IBGE], 2020). To achieve high yields, the nutritional requirements of maize must be fully met (Gondim et al., 2016). Nutrient deficiency causes nutritional disorders, which in turn may lead to a decline in production, resulting in low profits for farmers. These deficiencies are usually evidenced as decreased growth and visible abnormalities typical of each nutrient, during the development of the maize crop (Malavolta, 2006).

Several materials have been used as soil conditioners, including biochar. This is the term given to biomass subjected to the processes of decomposition, degradation, or alteration in composition by the action of heat (pyrolysis), which can be a fast or slow process, with little or no oxygen present. Many studies have confirmed the effectiveness of biochar in improving the physical-chemical properties of soil, maintaining its organic matter levels and increasing fertilizer use efficiency as well as agricultural production (Major et al., 2010). However, others (Sorensen & Lamb, 2016) not only showed no significance, but rather adverse effects of biochar application on crop yields.

In Brazil, due to the large availability of poultry litter, it has been used as a raw material for the manufacture of biochar. Nonetheless, the effect of this material in improving soil productive quality requires specific studies, which are still scarce. According to Fernandes et al. (2019), the chemical composition of this biochar includes essential elements for plant nutrition; however, it is not yet known how quickly these elements become available to plants.

The enhancement of methods to identify the nutritional status of plants, coupled with the need for improvements in the efficiency of use of the nutrients present in the soil or applied through fertilization to achieve high crop yields, led to the search for new technologies from the agronomic, economic, environmental, or operational standpoint. One of them is the 'diagnosis by subtraction' method, an efficient technique to study nutritional deficiencies in plants through a visual observation of the symptoms.

Thus, the present study was developed to characterize biometric traits and visual symptoms of macronutrient deficiency and their relationship with the initial growth of maize hybrid BRS 2022 cultivated with biochar.

Material and Methods

An experiment with BRS 2022 maize was implemented in greenhouse conditions at the Agricultural Engineering Department of the Center for Technology and Natural Resources at the Federal University of Campina Grande, located in the state of Paraiba, Brazil (7°15′18″ S, 35°52′28″ W, and ±550 m altitude). The experiment was laid out in a completely randomized design with a factorial arrangement (7 × 3) with the following treatments: complete nutrient solution (N, P, K, Ca, Mg, S, B, Cl, Cu, Fe, Mn, and Zn); complete nutrient solutions with omission of only nitrogen (-N), phosphorus (-P), potassium (-K), calcium (-Ca), or magnesium (-Mg); and complete absence of nutrients and three increasing rates of biochar (0, 5, and 10 t ha^{-1}). Three replicates were used.

The method used to detect nutrient availability in the poultry litter biochar for the initial growth of maize was biometric measurements and visual identification of nutritional symptoms using the 'diagnosis by subtraction' method on the plants, which were subjected to different nutrient deficiencies (Afrousheh et al., 2010). This technique consists of visually comparing the maize grown in a treatment that received all the essential macro- and micronutrients with those treatments with total or partial absence of a given element. The nutrient solutions were prepared according to Coelho (2007), considering the nutrient uptake curve of the maize crop until 40 days after sowing (DAS), which corresponded to one application per pot of: 2.072 g N, 0.238 g P_2O_5, 1.554 g K_2O, 0.391 g Ca, 0.162 g Mg, 0.157 g S, 0.001 g B, 0.001 g Cu, 0.005 g Mn, and 0.004 g Zn.

The biochar used in this study was produced at the Irrigation and Salinity Laboratory, where poultry litter biochar was subjected to slow pyrolysis at 350 °C in a muffle furnace. The poultry litter biochar showed the following attributes: pH = 9.44; EC = 7.33 dS m^{-1}; N = 2.25 %; P_2O_5 = 4.08%; K2O = 4.35%; Ca = 5.04%; Mg = 1.28%; S = 0.41%; B = 0.01%; Zn = 0.05%; Cu = 0.01%; Mn = 0.05%; Fe = 0.72%; moisture = 4.52%; organic carbon = 42.22%; and C/N ratio = 18.8. Table 1 describes the treatments tested in the present study.

Each experimental unit consisted of a Leonard pot (Vincent, 1970) filled with 1500 g of washed sand and biochar. The latter was used in amounts that followed each treatment, namely, 0, 5.19, and 10.38 g per pot. Depending on the chemical composition of the biochar, these amounts added to the pots corresponded to 0.12, 0.23, 0.21, 0.26, and 0.07 g of N, K_2O, P_2O_5, Ca, and Mg, respectively, for the treatment including 5.19 g per pot; and 0.23, 0.45, 0.42, 0.52, and 0.13 g of N, K_2O, P_2O_5, Ca, and Mg, respectively, for the treatment including 10.38 g per pot. The sand was previously immersed in 5% hydrochloric acid for 96 h to eliminate any organic matter or nutrient present in the sand and washed with distilled water until its pH reached neutrality and low electrical conductivity.

Four maize seeds, previously immersed in distilled water for 14 h, were sown in each experimental unit, germinating in approximately three days. When the seedlings reached the stage of two definitive leaves, approximately six days after emergence, thinning was performed, leaving only the most vigorous plant per experimental unit. After this, every two days, depending on the treatments, 25 and 50 mL of macronutrient and micronutrient solutions were applied, respectively. During the entire experimental period, the subtract was maintained at pot capacity and irrigated with distilled water.

Twenty days after germination (DAG), the volume of macronutrient solution was increased to 50 mL (deemed necessary due to the increase in air temperature that caused an increase in the evapotranspiration demand). The total solution volume of macro- and micronutrients applied after 40 DAG, depending on the treatments, corresponded to 750 and 1000 mL per plant, respectively. These volumes were determined considering the weight of the washed sand in each experimental unit at pot capacity. If there was drainage, the percolate solution was discarded.

The symptoms observed on the maize plants, caused by the nutrient omission treatments, were described and accompanied until their complete definition (40 DAG). At that moment, the plants were collected, shoots and roots were separated, and the following biometric measurements were performed: plant height, stem diameter, number of leaves, and leaf area. The harvested plant material was washed with deionized water and dried in a forced-air oven at 65 ºC until constant weight. This material was then used to determine the dry weight of shoots and roots.

Table 1
Treatments involving the combination of biochar rates and nutrient solutions

Treatment	Washed sand	Biochar (t ha^{-1})	N	P	K	Ca	Mg
1	+	0	-	-	-	-	-
2	+	5	-	-	-	-	-
3	+	10	-	-	-	-	-
4	+	0	+	+	+	+	+
5	+	5	+	+	+	+	+
6	+	10	+	+	+	+	+
7	+	0	-	+	+	+	+
8	+	5	-	+	+	+	+
9	+	10	-	+	+	+	+
10	+	0	+	-	+	+	+
11	+	5	+	-	+	+	+
12	+	10	+	-	+	+	+
13	+	0	+	+	-	+	+
14	+	5	+	+	-	+	+
15	+	10	+	+	-	+	+
16	+	0	+	+	+	-	+
17	+	5	+	+	+	-	+
18	+	10	+	+	+	-	+
19	+	0	+	+	+	+	-
20	+	5	+	+	+	+	-
21	+	10	+	+	+	+	-

+ and - presence and absence, respectively.

The experimental data were subjected to analysis of variance and, if significant by the F test ($P < 0.05$ and $p \leq 0.01$), the means were compared by Tukey's test at 5% significance, using SISVAR software (D. F. Ferreira, 2011). To meet the assumptions of normality and homogeneity of variances, the plant height , stem diameter, and shoot/root dry biomass ratio values were transformed in to $\frac{x^{2.2979}-1}{2.2979}$, $\frac{x^{2.0454}-1}{2.0454}$, and $\sqrt{x}$, respectively (Table 2 and Figures 1A, 2A, 2B, 2C and 2D).

Results and Discussion

Biometric measurements

According to analysis of variance, with exception of stem diameter (SD) and shoot/root dry biomass ratio (SDB/RDB), the interaction between nutrient omission and biochar rates influenced ($p \leq 0.01$) the variables analyzed in the experiment (Table 2).

Table 2

Analysis of variance for plant height (PH), stem diameter (SD), number of leaves (NL), leaf area (LA), dry biomass of the entire plant (TDB), shoot dry biomass (SDB), root dry biomass (RDB), and ratio between shoot and root dry biomass (SDB/RDB) in response to nutrient omission and biochar application

Source of variation	DF	Mean square							
		PH^1	SD^2	NL	LA	TDB	SDB	RDB	SDB/RDB^3
Nutrient (N)	6	21507696.2**	3649.3**	8.47**	6755342.7**	891.76**	378.68**	120.05**	0.152**
Biochar (B)	2	31280219.3**	9193.6**	5.44**	4521414.7**	623.96**	461.98**	12.74*	0.696**
N × B	12	4195140.5**	111.5^{ns}	0.79**	230161.3**	50.78**	18.64**	12.89**	0.019^{ns}
Error	42	1196386.4	108.4	0.21	58831.8	8.53	4.16	2.65	0.011
CV (%)		5.19	18.87	15.08	5.19	11.95	12.44	14.26	17.74
Mean		8.75	5796.06	69.06	8.75	2030.05	23.49	14.30	9.19

DF = degrees of freedom, CV = coefficient of variation, *, **, ^{ns} significant at the 5% and 1% levels and not significant, $(X^{2.2979} - 1)\ 2.2979^{-1}$, $(X^{2.0454} - 1)\ 2.0454^{-1}$, and $\sqrt{x}$, respectively.

The means of plant height (PH) and number of leaves (NL) of maize grown without N and P, in the absence of biochar, did not differ significantly between these treatments and the treatment without fertilization (Figures 1A and 1B).

Nitrogen omission in the absence of biochar considerably limited the growth of maize, since, at the end of the experiment, these plants had lower PH and NL than those under the complete solution. During this period, the maize was 38.2 cm in height (untransformed data) with seven leaves, corresponding to a reduction of 47.1 and 22.2%, respectively, of the values obtained with the plants grown in complete nutrient solution. According to Malavolta (2006), N restriction leads to a reduction in growth, given the importance of this nutrient in plant nutrition. Furthermore, the omission of N also reduced the production of total dry biomass (TDB; Figure 1D), shoot dry biomass (SDB; Figure 1E), and root dry biomass (RDB; Figure 1F) by 80.62, 84.77, and 75.12%, respectively, in comparison to the plants under the complete nutrient solution.

As also shown in Figure 1F, RDB decreased with the application of biochar in the complete treatment, reaching the lowest mean at 10 t ha^{-1}. This same behavior was found in the treatment with omission of Ca; except in this case there was no difference in the means between the different biochar rates. With the exception of NL and RDB, the treatments with N deficiency (-N) combined with 5 and 10 t ha^{-1} of biochar induced significant increases in all variables analyzed. For instance, the application of these rates of biochar increased PH, which was 54.9 and 54.3 cm, respectively (untransformed means). Likewise, TDB increased 109.9% and 162.7% with the biochar rates of 5 and 10 t ha^{-1}, respectively. These results show that the nitrogen content present in the poultry litter (2.25%) was probably used by the crop, but was not sufficient for the healthy development of maize.

+ and - presence and absence, respectively.

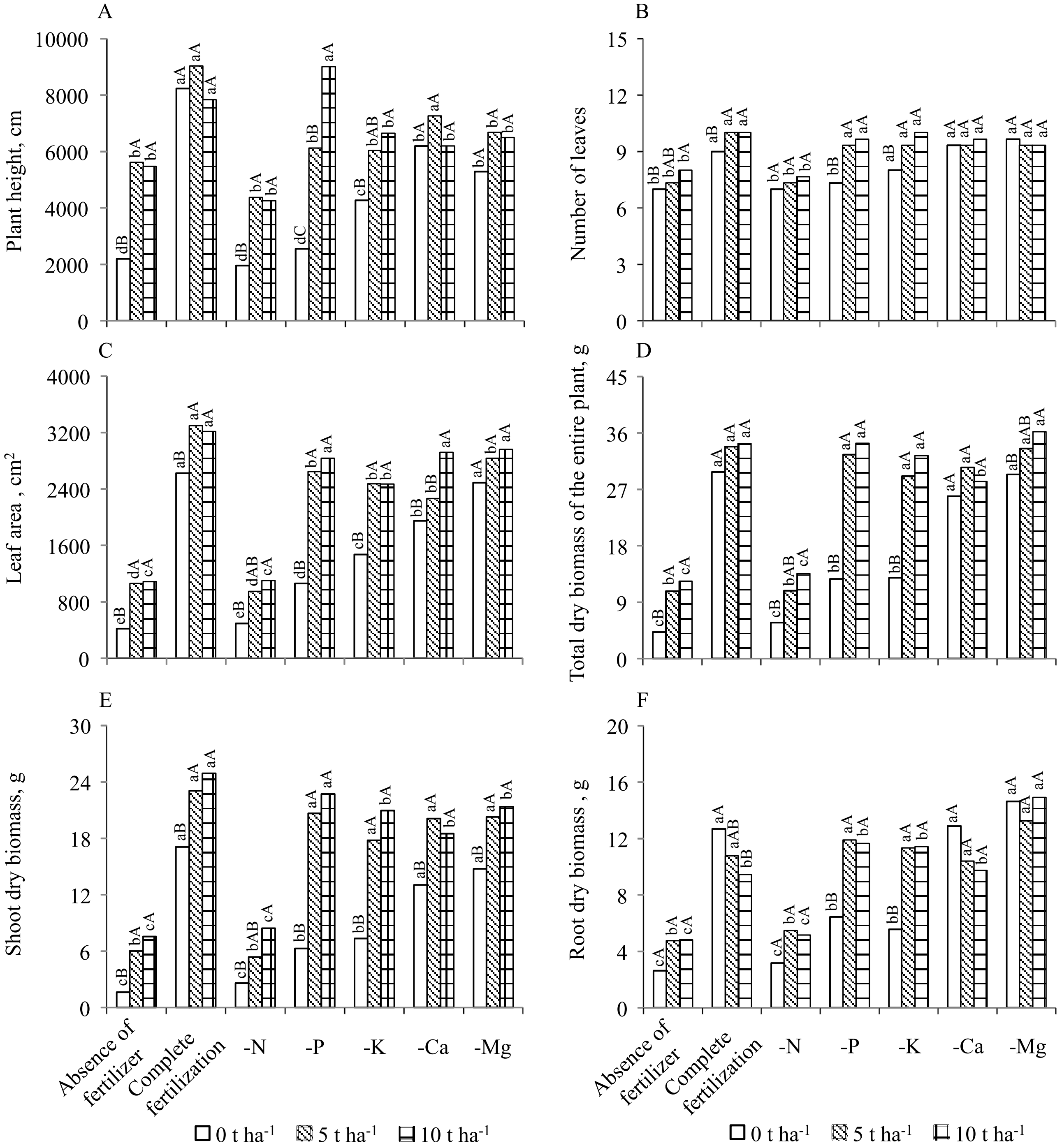

Figure 1. Plant height, number of leaves, leaf area, dry biomass of the entire plant, shoot dry biomass, and root dry biomass under the interaction between nutrient omission and biochar rates. Treatment means followed by the same lowercase letter do not differ between nutrient solutions under the same biochar rates, and treatment means followed by the same uppercase letter do not differ between rates under the same nutrient solution.

Although most authors found availability of N in response to the biochar mineralization process, many reported that biochar causes N immobilization in the soil. This is because increasing the carbon (C) content of the soil system through biochar application typically increases the C:N ratio, which in turn impacts soil microbial function and reduces plant-available N (Phillips et al., 2022).

After N, phosphorus was the second most limiting element. By comparing the treatment with the absence of P and the complete nutrient treatment, we observed significant reductions of 39.6, 22.2, 59.7, 57.2, 63.1, and 49.2% in PH, NL, leaf area (LA), TDB, SDB, and RDB, respectively.

Regarding SD (Figure 2A), P omission resulted in 12.37 mm (data not transformed), which is statistically higher than the 12.01 mm obtained with the complete nutrient treatment. These results corresponded to the isolated effect of the nutrient solutions; therefore, the contribution of the biochar rates explains the increase in SD in the -P treatment, which was higher than that seen in the complete nutrient treatment.

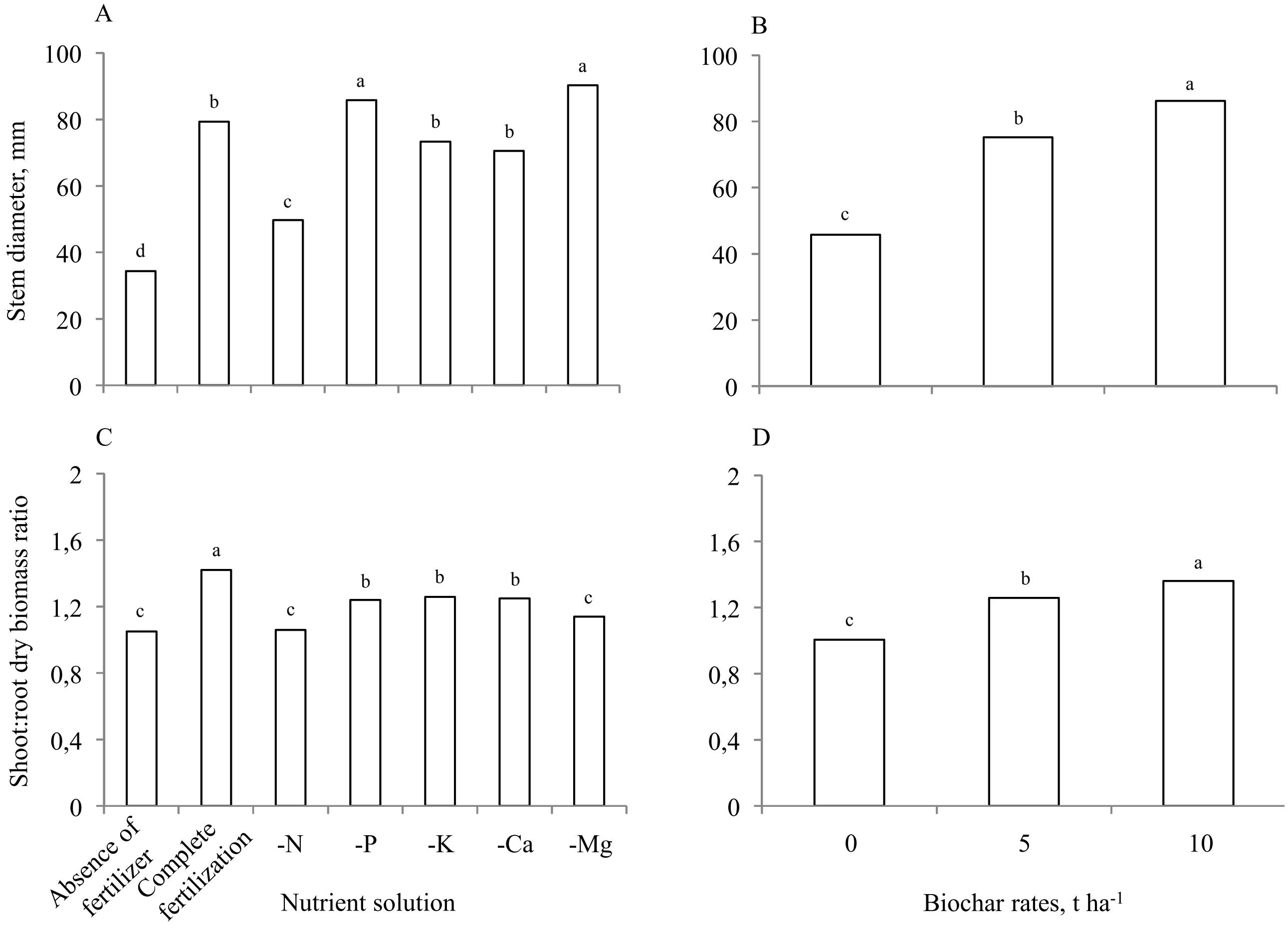

Figure 2. Stem diameter and ratio between shoot and root dry biomass as a function of the isolated effects of nutrient solution and biochar rates.

Compared with the absence of biochar treatment, the biochar rates in solution with -P significantly increased all analyzed variables; however, except for PH, the means did not differ between the rates of 5 and 10 t ha^{-1}. When we compare the absence of biochar with the application of 10 t ha^{-1} of the product, there were notable increases in PH, LA, TBM, SBM, and RDB, of the orders of 72.8 (untransformed data), 167.8, 170.4, 260.3, and 80.9%, respectively. Nevertheless, the means of these variables did not differ between the complete solution and that without P under 10 t ha^{-1} of biochar. These findings corroborate Petter et al. (2012), who observed biomass gains in eucalyptus seedlings with the use of biochar.

According to Xu et al. (2013), biochar has the potential to be a P source due to the high availability of this nutrient, which is directly related to the inorganic form in which it is found in the structures of biochar, associated with Al, Fe, Ca, and Mg. Parvage et al. (2013) found high levels of available P after adding biochar to the soil, describing that about 90% of the added P was recovered. Despite the high soil P availability provided by biochar, it is believed that it does not surpass the efficiency of mineral fertilizers. Nonetheless, it can improve the availability of this nutrient. In the -P treatment, the maize plants showed a SDB/RDM of 1.6 (untransformed data), which was statistically inferior to the result obtained with the complete nutrient treatment, but did not differ from the treatments with K and Ca omission (Figure 2C).

With the omission of K (the third most limiting element for the growth and production of maize) and absence of biochar, the maize plants showed means statistically lower than those obtained with the treatment including all the nutrients. The absence of K in the nutrient solution had negative effects on the vegetative development of the plant, whose PH, LA, TDB, SDB, and RDB decreased by 24.7, 43.9 56.6, 56.9, and 56.2%, respectively.

Biochar rates in the solutions with absence of K induced significant increases in NL, LA, TDB, SDB, and RDB, whose means did not differ between the rates of 5 and 10 t ha^{-1}, but were statistically higher than those obtained with the control. It is important to highlight that the biochar application rates of 5 and 10 t ha^{-1} increased TDB by 125.5% and 150.5%, respectively, in relation to the control. Plant height increased with the use of biochar. Still regarding the effect of biochar on SD (Figure 2B), SDB, and RDB (Figure 2D), the highest values were achieved with the use of 10 t ha^{-1} of biochar.

As regards the effect of K, it appears that the complete nutrient solution treatment and the treatment with omission of the element and 5 and 10 t ha^{-1} of biochar provided statistically similar means for NL, TDB, and RDB. This shows that the poultry litter biochar used in the present study increased the concentration of K available to the plants, corroborating Oram et al. (2014), who reported greater availability of K in the soil following the addition of biochar, which significantly increased the biomass of red clover. In contrast to other elements that can be volatilized or kept in relatively insoluble forms during pyrolysis, K is largely conserved and converted into salts with high solubility (Karim et al., 2017). Several other studies have indicated the potential of biochar as a substitute for a considerable proportion of conventional potassium fertilizers (Wang et al., 2018).

By analyzing the effect of biochar in the solutions without Ca and Mg on the behavior of maize, we observe that LA under omission of Ca, TDB under omission of Mg, and SDB in both treatments showed significant differences in their means with the application of biochar. Leaf area and SD in the solution without Ca were lower than those observed in the complete nutrient treatment. These results corroborate Gondim et al. (2016), who also found a significant decrease as induced by the absence of Ca when compared with the complete nutrient treatment.

Except for LA, the means of the variables analyzed under Ca and Mg omission in the absence of biochar were similar to each other. Additionally, with the exception of PH, SDB, and RDB, the means were statistically similar when compared with those found in the complete nutrient solution, showing that the lack of these nutrients did not limit biomass production. The Ca and Mg concentrations present in the substrate (washed sand), 1.0, and 0.5 cmolc dm^{-3}, respectively, apparently partly supplied the Ca and Mg required for the growth of maize. The most significant increase was seen for SDB, corresponding to 54.1% at the biochar rate of 5 t ha^{-1} under Ca omission and 44.9% at 10 t ha^{-1} under Mg omission. The explanation for this behavior may be related to the lower availability of Ca and Mg induced by the application of biochar. Chrysargyris et al. (2019) found a low concentration of Mg in forest wood biochar.

The increase in K concentration with biochar application may cause an antagonistic interaction with Ca and Mg, which could lead to a decrease in RDB. According to Savvas and Gruda (2018), high K concentrations can trigger deficiencies in Mg and Ca in the plant, reducing its growth.

Visual symptoms

Figure 3 illustrates the visual symptoms observed in the initial growth of maize, as determined by the 'diagnosis by subtraction' method, in response to the studied treatments. In the treatments without any fertilization, plant growth was very low, with general deficiency symptoms that decreased with biochar application (Figures 3A, 3B, and 3C). The maize grown in the solutions with complete fertilization had mild symptoms, which subsided with biochar application (Figures 3D, 3E, and 3F).

The first symptoms of N deficiency were observed 18 days after seed emergence. The plants showed a thin stem and chlorosis that started from the older leaves, and then there was a uniform loss of green color throughout the leaf blade (Figure 3G). As the deficiency developed during the growth cycle, N was mobilized from the lower leaves and translocated to the young leaves, making the lower leaves pale and brown. M. M. M. Ferreira (2012) described similar symptoms in maize hybrid BRS 1010 grown on sand and vermiculite substrate at a 1:1 ratio, with N omission.

Plants grown in the solutions without nitrogen (-N) exhibited the same symptoms of nitrogen deficiency when the biochar rates of 5 and 10 t ha^{-1} were added (Figures 3H and 3I). Even though the biochar used in this study has 2.3% N (low content of this element), it is not known whether it is in the mineralized form and available to plants.

Plants under P omission exhibited the symptoms of deficiency starting with a dark green color in the older leaves and purple shades in the tips and edges (Figure 3J). The predominant purplish color in the older leaves might be due to the photoassimilate accumulation in the tissues, which favors the synthesis of anthocyanin, a pigment that gives this color to the leaf blade. As stated by Gautam et al. (2011), this accumulation is very common in plants subjected to P deficiency. These symptoms of P deficiency were not detected in the plants grown in solutions with 5 and 10 t ha^{-1} of biochar (Figures 3K and 3L). This result indicates that part of P in the applied biochar is apparently in soluble form and readily available to plants. It is important to highlight that the composition of poultry litter biochar used in this study includes dibasic potassium phosphate. It is also noteworthy that the visual symptoms of P deficiency were observed only in the -P treatment with no biochar (Figure 3J), which suggests that biochar has an important concentration of available P. The symptoms decreased with the application of biochar.

The absence of K (-K) in the nutrient solution produced a small pale yellowish chlorosis in the older leaves (Figure 3M), with light brown necrosis reaching the leaf apices. The necrotic spots on the leaf edges are probably due to the accumulation of compounds such as putrescines, which trigger the production of oxidative compounds, resulting in cell death (Chen et al., 2016). Despite the higher growth of maize plants with the application of biochar, regardless of the rates applied, symptoms of K deficiency were also observed with their application. The intensity of these symptoms was lower when compared with those seen in the treatment involving K omission (Figures 3N, 3O).

In the initial stage of the deficiency, the plants subjected to Ca omission (-Ca) exhibited young leaves with a pale green color and then lesions ranging from yellow to white in the areas between the leaf nerves (Figure with 3P). Although the absence of Ca resulted in significant differences for some variables with biochar application (LA and SD), the presence of Ca in the washed sand (1.0 cmolc dm^{-1}) used in the experiment, even after washing with hydrochloric acid, contributed to the visual symptoms of deficiency not being severe. With the biochar rates of 5 and 10 t ha^{-1} (Figures 3Q and 3R), only mild chlorosis was observed in the older leaves, although these symptoms are not characteristic of Ca deficiency, since younger leaves are normally the first to be affected due to low mobility of this element in the phloem.

Although washed sand has a Mg concentration of 0.5 cmolc dm^{-3}, symptoms of deficiency of this macronutrient were observed in the maize plants in the solution with absence of Mg (-Mg). Initially, symptoms were observed in the older leaves as a pale-yellow chlorosis between the nerves in the middle section, from the edge to the center of the leaf, covering the entire leaf (Figure 3S). The symptoms progressed towards the upper leaves and brown rusty bands appeared on the older leaves, which occurred due to the translocation of the mobile Mg to the newer growing regions (Marschner, 1995). These symptoms were identified regardless of the biochar rate applied (Figures 3T and 3U).

Conclusions

The absence of nutrients and biochar significantly influenced the growth and dry biomass production variables of maize plants.

Except for stem diameter and the ratio between shoot and root dry biomass, all variables were influenced by the interaction between nutrients and biochar rates.

Biochar application significantly improved all analyzed variables and reduced the visual symptoms of nutritional deficiency.

In the treatments without any fertilization, the growth of maize was smaller and overall deficiency symptoms were more evident.

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