

Biochar and poultry litter compost: Impact on soil fertility and production of corn AG1051

Biocarvão e composto de cama de aviário: Impacto na fertilidade do solo e produção do milho AG1051

Gilvanise Alves Tito¹, Lúcia Helena Garófalo Chaves^{1*}, Josely Dantas Fernandes¹, Laysa Gabryella de Souza Laurentino¹, Andre Alisson Rodrigues da Silva¹, Gustavo Tomio Magalhães Kubo¹, Lauter Silva Souto¹

ABSTRACT

The sustainability of agricultural production has been demonstrated to be progressively associated with the use of organic fertilizers to improve soil properties and crop production. In this study, the effects of biochar and organic compost, both derived from poultry litter, on soil nutrient availability and the growth and production of the corn cultivar AG1051 were evaluated. The experiment was laid out in a completely randomized design, with ten treatments, including different doses of biochar and organic compost (0, 2.5, 5.0, 7.5, and 10 t ha⁻¹) and three replications. Soils from different treatments were placed in pots (20 kg per pot) and incubated. After incubation, samples taken from all experimental units were subjected to chemical analysis. At the end of the plant growth cycle, the properties of plants, except for ear development, were investigated, and then, to determine the dry mass of leaves and the stalk, plant samples were placed in an oven at 65 °C. The results indicated that organic compost produced from poultry litter was added at 10 t ha⁻¹ increased the concentrations of calcium (Ca), magnesium (Mg), phosphorus (P), hydrogen (H), and the sum base cations in the soil and enhanced soil cation exchange capacity (CEC), promoting the growth and production components of corn plants, compared to biochar. However, future studies should focus on the residual effects of such organic amendments, and a techno-economic analysis also needs to be performed to predict the conversion of different compounds into biochar.

Index terms: *Zea mays*; organic fertilizer; nutrient suppliers.

RESUMO

A sustentabilidade da produção agrícola está cada vez mais associada ao uso de fertilizantes orgânicos que melhoram as propriedades do solo e a produção das culturas. Este estudo avaliou os efeitos do biocarvão e do composto orgânico, ambos provenientes de cama de aviário, na disponibilidade de nutrientes no solo e no crescimento e produção do milho (AG1051). O experimento foi conduzido em delineamento inteiramente casualizado, com três repetições, utilizando dez tratamentos, representados por doses crescentes de biocarvão e composto orgânico (0; 2,5; 5,0; 7,5 e 10 t ha⁻¹), com três repetições. Os tratamentos foram incubados em vasos contendo aproximadamente 20 kg de solo. Após a incubação, amostras de cada unidade experimental foram quimicamente analisadas. No final do ciclo, as plantas foram avaliadas e, com exceção da produção de espigas, foram colocadas em estufa a 65°C para determinação da fitomassa seca de folhas e do colmo. Os resultados obtidos no presente estudo indicam que a utilização do composto orgânico de cama de aviário na dose de 10 t ha⁻¹ aumentou a concentração de cálcio, magnésio, fósforo, hidrogênio, soma de base e melhorou a capacidade de troca de cátions do solo, promovendo incremento no crescimento e nos componentes de produção do milho, em relação ao biocarvão. O uso de composto orgânico de cama de aviário na dose de 10 t ha⁻¹ pode ser utilizado em substituição ao biocarvão, tendo em vista a melhoria nos atributos químicos do solo, ao custo de produção e aos benéficos a cultura do milho.

Termos para indexação: *Zea mays*; adubação orgânica; fornecedores de nutrientes.

Introduction

To improve soil fertility, especially for the production of crops with high global demand like corn, the strategies promoting fertilizer replacement, e.g., the use of organic compost, biochar, and other inputs that favor the retention of water and nutrients in the soil, which consequently contributes to a significant increase in crop productivity, are required to be adopted. These practices reduce reliance on chemical fertilizers, minimize the negative environmental impacts, and follow sustainable agriculture principles (An et al., 2022).

Biochar is a material rich in carbon obtained through pyrolysis in the absence of or under low oxygen (Amalina et al., 2022) that improves soil conditions due to its high porosity and water and nutrient retention capacity (Razzaghi, Obour, & Arthur, 2020). It also functions as a soil conditioner, which enhances its cation exchange capacity (CEC) and provides

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¹Universidade Federal de Campina Grande, UFCG, Centro de Tecnologia e Recursos Naturais, CTRN, Unidade Acadêmica de Engenharia Agrícola Campina Grande, PB, Brasil

Corresponding author: lhgarofalo@hotmail.com

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a habitat for beneficial microorganisms, that are important contributors to soil nutrient cycling (Khan et al., 2024).

Organic compost, on the other hand, is a natural fertilizer rich in organic matter and nutrients essential for plants, such as nitrogen (N), phosphorus (P), and potassium (K) (Hakimi et al., 2024) that is produced by the decomposition of organic waste under controlled conditions by the action of microorganisms (Rastogi, Nandal, & Khosla, 2020). It has been extensively used to improve soil structure, increase water retention, and contribute to more intense biological activity in the soil, which together promote the healthy growth of plants (Rivier et al., 2022).

The great ability of both these inputs to improve soil fertility, reduce dependence on mineral fertilizers, promote sustainable agriculture, and contribute to the mitigation of methane emissions from organic waste has been observed (Klinglmair & Thomsen, 2020; Hassan et al., 2023). The evaluation of biochar and compost, particularly those derived from the same raw material, like poultry litter, provides valuable comparative insights into the best management practices for different soil and crop types.

Poultry litter, which is used for floor covering in poultry sheds, is produced in large amounts, and thus, it is an abundant and easily accessible waste material. It has significant potential as a raw material for the production of both biochar and organic compost.

As one of the widely cultivated crops in Brazil, corn occupies a prominent place in the agricultural sector of this country (Klein & Luna, 2022). Its economic importance is evidenced by not only its use as one of the main sources of food for humans and animals but also its wide application for the production of biofuels, starches, and other industrial products (Padhan et al., 2024). Corn productivity can be improved by adopting effective management practices, such as the use of organic inputs and biochar (Mendes et al., 2021b).

The comparative analysis of the effects of the application of poultry litter-derived biochar and organic compost on soil nutrient availability and productivity of the corn hybrid AG1051 is the focus of the present study.

Material and Methods

The experiment was carried out in a greenhouse under controlled environmental conditions at the Agricultural Engineering Academic Unit (UAEA), Federal University of Campina Grande (UFCG) in Campina Grande, Paraíba, Brazil.

The soil used in this experiment was collected from the surface soil layer (0-20 cm) and classified as Ustults. First, it was air-dried and sieved by a 2.0-mm mesh after transport to the laboratory. Next, its physical and chemical characteristics were evaluated according to the method proposed by Teixeira et al. (2017), and the following results were obtained: soil texture classification as open sand; sand content = 869.6 g kg⁻¹, silt content = 90.4 g kg⁻¹, and clay content = 40.0 g kg⁻¹, bulk density = 1.46 g cm⁻³, particle

density = 2.69 g cm⁻³, total porosity = 45.73 %, pH (H₂O) = 5.42, Ca = 2.20 cmol_c kg⁻¹, Mg = 2.40 cmol_c kg⁻¹, Na = 0.04 cmol_c kg⁻¹, K = 0.11 cmol_c kg⁻¹, H + Al = 2.38 cmol_c kg⁻¹, OM = 17.9 g kg⁻¹, P = 3.8 mg kg⁻¹, and CEC = 7.13 cmol_c kg⁻¹.

The poultry litter was composted in an 80L container for 120 days to produce organic compost. During this period, humidity was maintained around 60 %. To produce biochar, poultry litter was pyrolyzed in a muffle furnace at 350 °C for 3 hours, as seen in Figure 1.



Figure 1: The Jung® muffle furnace used for the production of poultry litter biochar through the pyrolysis process.

After sieving the compost and biochar through a 2.0-mm mesh sieve, their chemical characterization was performed according to the Manual of Official Analytical Methods related to Fertilizers and Correctives (Ministry of Agriculture, Livestock, and Supply Brasil, (2017). The analyses found the following results for compost: total nitrogen = 24.00 g kg⁻¹, P₂O₅ = 5.71 %, K₂O = 4.19 %, Ca = 6.22 %, Mg = 1.08 %, pH = 9.37; organic carbon = 237.30 g kg⁻¹, C/N ratio = 9.93, and cation exchange capacity (CEC) = 82.47 cmol_c kg⁻¹. The analysis of biochar, however, yielded the following results: total nitrogen = 30.6 g kg⁻¹, P₂O₅ = 5.76 %, K₂O = 6.61 (%), Ca = 5.27 %, Mg = 1.08 %; pH = 8.97, organic carbon = 400.2 g kg⁻¹, C/N ratio = 13.08, and CEC = 58.61 cmol_c kg⁻¹. Figure 2 shows the poultry litter compost and biochar.

The experiment was conducted in a completely randomized design (CRD), with a total of 30 experimental units assigned to different treatment groups with three replications. The treatments were different doses of biochar and organic compost derived from poultry litter, i.e., 0, 2.5, 5.0, 7.5, and 10 t ha⁻¹. Each experimental unit corresponded to each pot containing 20 kg of soil to which the respective treatment was allocated.

The treated soils were incubated for 25 days so that they could fully come into contact with compost and/or biochar. After the incubation period, the chemical analysis of samples taken from all experimental units was performed to evaluate different properties including the contents of magnesium (Mg), sodium (Na), potassium (K), sum of bases (SB), hydrogen (H), organic matter (OM), and phosphorus (P), cation exchange capacity (CEC), hydrogen potential (pH), and electrical conductivity (EC) (Teixeira et al., 2017).

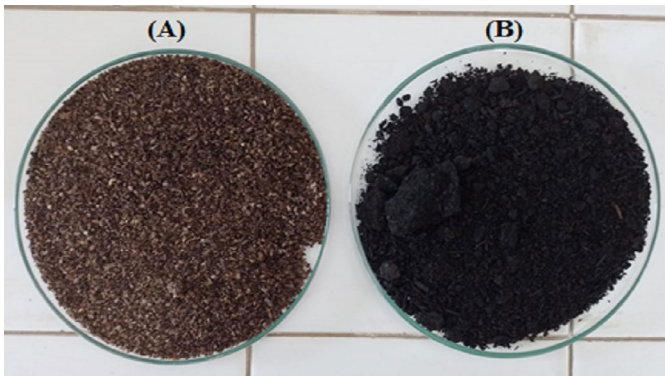


Figure 2: Poultry litter compost (A) and biochar (B) used in this study.

Thereafter, three seeds of the corn hybrid AG 1051 were sown in each experimental unit. After 12 days of sowing, seedlings were thinned to one per experimental unit. Irrigation was carried out to secure sufficient water supply, with soil moisture being maintained close to the field capacity. To avoid their interference with the applied compounds, mineral fertilizers were not applied to experimental units.

Green corn was harvested 85 days after sowing, and its growth and production components were evaluated. Plant height (PH), ear insertion height (EIH), and ear length were measured with a 30-cm graduated ruler, while for the measurement of stalk diameter (SD) and ear diameter (ED), a digital caliper was used. Samples were placed in a forced air circulation oven at 65 °C until reaching constant weight, and then, fresh phytomass of leaves (FPL), stems (FPS), and ears (FPE), as well as dry phytomass of leaves (DPL) and stems (DPS) were measured using an analytical balance.

The dimensional structure of the results was evaluated using principal components analysis (PCA) by synthesizing the relevant information from linear combinations of the original set of variables into a new dataset with a lower number of dimensions, defined by the eigenvalues ($\lambda \geq 1.0$ of the correlation matrix that explain more than 10 % of the total variance (Govaerts et al., 2007).

After the reduction of dimensions, the multivariate analysis of variance (MANOVA) of the data of original variables of

each principal component was performed using Hotelling's test (Hotelling et al., 1947) at the probability level of 0.05 to investigate the statistically significant mean differences among the treatments (biochar and compost) at different doses, as well as their interactions. Each principal component (PC) contained only variables with a correlation coefficient above or equal to 0.6 (Hair et al., 2009). Data standardization was performed by subtracting the mean and then dividing by the standard deviation for each value (from each plot) of all evaluated variables (soil chemical parameters and corn production components). The average values of the variables from each treatment are presented in tables as the original ones. Statistica software v. 7.0 was the statistical analysis software package used.

Results and Discussion

The results of the present study revealed that the organic compost treatment at 10 t ha⁻¹ (CD5) stood out among the other treatments, with the higher values of the contents of Mg (4.36 cmolc kg⁻¹), S (9.94 cmolc kg⁻¹), H (1.30 cmolc kg⁻¹), and P (430.70 mg kg⁻¹), CEC (11.24 cmolc kg⁻¹), and EC (2.16 dS m⁻¹) (Table 1). When comparing the CD5 treatment with BDC (biochar treatment at the same dose), increases of 24.57 % (0.86 cmolc kg⁻¹) in Mg content, 15.31 % (1.32 cmolc kg⁻¹) in S content, 36.84 % (0.35 cmolc kg⁻¹) in H content, 99.94 % (214.51 mg kg⁻¹) in P content, 17.45 % (1.67 cmolc kg⁻¹) in CEC, and 8 % (0.16 dS m⁻¹) in EC were achieved, demonstrating a beneficial effect of compost compared to biochar at the same application dose of 10 t ha⁻¹. (CD5) was the best treatment in terms of Ca and Mg levels, which may be due to the chemical composition of organic compost, which is rich in these nutrients. These results indicate the potential of this compound for use as an ideal input to soils deficient in basic cations since it can contribute to the improvement of soil fertility within a short period.

As seen in Table 1, BD5 treatment achieved the highest values of Na (0.87 cmol_c kg⁻¹), K (2.23 cmol_c kg⁻¹), OM (28.4 g kg⁻¹), and pH (6.73), increases of 12.99 % (0.10 cmol_c kg⁻¹), 34.33 % (0.57 cmol_c kg⁻¹), 48.43 % (8.97 g kg⁻¹), and 6.83 % (0.43) in the values of these parameters in soils treated with biochar, respectively, in comparison to compost-treated soils at the same application level.

The organic compost and biochar treatments at 0 t ha⁻¹ (BD1 and CD1, respectively; control) exhibited no difference. Moreover, Na (0.38 cmol_c kg⁻¹), K (0.14 cmol_c kg⁻¹), S (5.81 cmol_c kg⁻¹), MO (15.70 g kg⁻¹), P (2.20 mg kg⁻¹), and pH (5.37) had their lowest values compared to those in other treatments. In principal component 2 (PC2), application of 10 t ha⁻¹ organic compost (CD5) to soils resulted in the highest value of Ca (3.16 cmol_c kg⁻¹), which showed an average increase of 49.06 % (1.04 cmol_c kg⁻¹) compared to the value obtained for the BD5 treatment.

Table 1: The values of the original mean of variables in different treatments.

Treatments	Mean Values										
	Ca	Mg	Na	K	S	H	CEC	OM	P	pH	EC
BD1	2.75	2.54	0.38	0.14	5.81	2.27	8.08	15.70	2.20	5.37	1.31
BD2	2.50	2.43	0.42	0.62	5.96	1.82	7.78	15.77	86.13	5.75	1.08
BD3	2.65	2.77	0.51	1.22	7.15	1.59	8.74	21.43	161.33	6.00	1.21
BD4	2.79	2.82	0.77	2.17	8.65	1.02	9.67	28.60	172.93	6.50	1.99
BD5	2.12	3.50	0.87	2.23	8.62	0.95	9.57	28.40	216.17	6.73	2.00
CD1	2.75	2.54	0.38	0.14	5.81	2.27	8.08	15.70	2.20	5.37	1.31
CD2	2.90	2.61	0.40	0.40	6.31	2.08	8.39	18.20	66.90	5.50	1.42
CD3	3.03	3.17	0.51	0.68	7.16	1.91	9.40	19.27	173.20	5.83	1.44
CD4	2.98	3.34	0.56	1.13	8.02	1.23	9.25	18.70	277.00	6.21	1.60
CD5	3.16	4.36	0.77	1.66	9.94	1.30	11.24	19.43	430.70	6.30	2.16

B (biochar) and C (compound); D1 (dose 1 - 0 t ha⁻¹), D2 (dose 2 - 2,5 t ha⁻¹), D3 (dose 3 - 5,0 t ha⁻¹), D4 (dose 4 - 7,5 t ha⁻¹), and D5 (dose 4 - 10 t ha⁻¹); Ca (calcium - cmolc kg⁻¹), Mg (magnesium - cmolc kg⁻¹), Na (sodium - cmolc kg⁻¹), K (potassium - cmolc kg⁻¹), S (sum of bases), H (hydrogen - cmolc kg⁻¹), CEC (cation exchange capacity - cmolc kg⁻¹), OM (organic matter - g kg⁻¹), P (phosphorus - mg kg⁻¹), pH (hydrogen potential), and EC (electrical conductivity - dS m⁻¹).

Poultry litter biochar, at all doses except for 0 t ha⁻¹, demonstrated a greater liming potential than compost, thus more efficiently reducing the active acidity of soils (Table 1). The accumulated ash in biochar samples and its porosity can justify the increase observed in pH values (Fernandes et al., 2022a, b). These results are in agreement with those presented by Mendes et al. (2021a), reporting an increase in soil pH and fertility. Furthermore, the calcite (CaCO₃) present in calcitic limestone, which is used in poultry diets, was found to impart alkalinity to the poultry litter biochar (Domingues et al., 2017; Chaves et al., 2020; Fernandes et al., 2022b).

The increase in Ca content and CEC of the soil following the addition of the highest level of poultry litter compost (6.22 % and 82.47 cmol_c kg⁻¹, respectively), presented in Table 1, is because of their higher values in this composted poultry litter. Although the Mg and P contents in the soil were practically the same in both the compost and biochar treatments, the former produced higher values.

The increase in pH and exchangeable bases in the soils receiving biochar and organic compost may explain the increase in available P concentration in all treatments. These results corroborate those reported by Mahmoud et al. (2023), who confirmed an improvement in NPK availability in soils with poultry manure amendment, and by Mendes et al. (2021a), who also found a higher level of soil available P after biochar application when compared to the control treatment. Fernandes et al. (2022c), however, reported that the application of biochar derived from poultry litter can reduce P adsorption, despite its lower content, with a greater released amount of this element by biochar than that adsorbed by the soil at 37.2, 49.6, and 62.0 t ha⁻¹.

Concerning potassium (K), the highest content in the soil observed at the highest dose of biochar, as shown in Table 1, can be justified by its higher concentration in biochar composition (6.61%), compared to that in compost (4.19%). Similarly, Schulz and Glaser (2012) showed an increase in soil K content upon biochar application.

The differences in pH and concentrations of exchangeable cations between the applied treatments can be the reason for significant enhancements of soil CEC (Table 1). Generally, both the individual and the combined application of biochar and compost result in significant increases in soil CEC. Likewise, Lin, Watts and Runion (2022) found increases in CEC of poultry manure-treated soils. Olakayode, Akinde and Egbebi (2020) concluded that the highly porous nature and larger surface area of biochar contribute to the increase in soil CEC observed after its application. A study conducted by Chang et al. (2016) indicated that the increase in soil CEC over time with biochar addition may be associated with its surface oxidation and a larger number of negatively charged surface functional groups.

Statistical analysis of soil properties showed a greater increase in organic matter content as a result of the application of poultry litter-based biochar (Table 1). This was the expected result since the organic carbon concentration was higher in biochar than in compost (400.2 and 237.30 g kg⁻¹, respectively). The enhancement of soil porosity and organic carbon in plots treated with biochar in a study carried out by Phares et al. (2020) corroborates our observations.

An accumulation of C in the soil over time and a reduction in the depletion rate of organic matter were noted when organic residues were applied (Schulz & Glaser, 2012). However, the

relatively rapid degradation of organic wastes, such as compost and manure, which are a means of terrestrial C sequestration, which causes the release of carbon dioxide, is one of the disadvantages of their use (Ayilara et al., 2020). Besides the enhancing effect on its content in the soil, as seen in Table 1 in the present study, the addition of biochar also increased the persistence of carbon (C) due to the presence of recalcitrant compounds. Greater mineralization of C-CO₂ in organic compost treatments, as well as more effective mitigation of the “greenhouse” effect by poultry litter-derived biochar, were found by evaluating the organic carbon mineralization of biochar and organic compost produced from poultry litter in Ustults in a study conducted by Tito et al. (2021).

According to Kaiser (1960), the dimensionality reduction of multidimensional original variables results in the retention of two principal components (PC1 and PC2) with eigenvalues (λ) higher than 1.0 ($\lambda \geq 1.0$). The percentage of the total variance explained by both components was 91.04 %, of which 72.87 % was contributed by PC1, while the remaining variance (18.17 %) was explained by PC2. The interaction between the two substrates and their doses (S \times D) exerted significant influences on PC1 and PC2 (Table 2).

Table 2: The calculated eigenvalues, percentage of total variance explained, and multivariate analysis of variance (MANOVA) results for the standardized variables and the two principal components.

Variables	Principal components	
	PC1	PC2
Eigenvalues (λ)	8.22	1.98
Percentage of total variance (S ² %)	72.87	18.17
Hotelling test (T ₂) for substrates (S)	0.01	0.01
Hotelling test (T ₂) for doses (D)	0.01	0.01
Hotelling test (T ₂) for interaction (S \times D)	0.02	0.01

Variables with correlation coefficients greater than 0.7 ($r > 0.7$) were considered highly correlated. Those with the greatest discriminatory power in PC1, including magnesium (Mg), sodium

(Na), potassium (K), sum of bases (S), hydrogen (H), organic matter (OM), phosphorus (P), cation exchange capacity (CEC), hydrogen potential (pH), and electrical conductivity (EC) are represented in Table 3. In PC2, the only parameter with a correlation coefficient exceeding 0.7 was Ca content. In general, variables with the same sign are directly proportional, indicating that with an increase in the value of one variable, that of the other also increases, or vice versa, whereas the variables with opposite signs show an inverse proportion, demonstrating an increase in the value of one variable when that of another decreases (Veloso et al., 2023).

Figures 3A and 3B represent the two-dimensional projections of the effects of different treatments and evaluated variables in the first and second principal components (PC1 and PC2, respectively).

The distinct roles that biochar and organic compost play in improving soil quality suggest complementary rather than competitive relations between them. Since biochar possesses a highly porous structure and is resistant to degradation, it provides greater carbon sequestration and enhances organic matter over a longer period, whereas poultry litter compost releases nutrients such as Ca and Mg faster, promoting more immediate responses of plant growth variables. This contrast was also observed in studies conducted by Fernandes et al. (2022c) and Mendes et al. (2021b), who found a “slow-release” effect of biochar, which results in the improvement of soil structure and fertility over a long time, while compost is considered a “fast-acting fertilizer”, which offers benefits in a shorter time.

The determination of the effects of various treatments on corn plants found that plants grown in compost-treated soils at 10 t ha⁻¹ (CD5) outperformed those in other treatments, showing the highest values of parameters in principal component 1 (PC1) including SD (29.59 mm), EIH (93.5 cm), ED (56.64 mm), EL (30.93 cm), FPL (140.09 g), FPSC (312.98 g), FE (240.07 g), FSF (53.96 g), and FSC (82.87 g) (Table 4). The results yielded by the comparison between the CD5 and BD5 treatments indicated increases of 7.03 % (1.94 mm) in SD, 16.15 % (13.0) in EIH, 6.71 % (3.56 mm) in ED, 10.46 % (2.93 cm) in EL, 15.05 % (18.33 g) in FVF, 8.28 % (23.94 g) in BFC, 30.39 % (55.96 g) in FE, 13.86 % (6.57 g) in FSF, and 19.18 % (13.34 g) in FSC, which implies the beneficial effect of compost at an application level of 10 t ha⁻¹ (CD5) compared to its biochar counterpart (BD5).

Table 3: Correlation coefficients (r) between the standardized variables and their associated principal components.

Principal component	Correlation coefficients (r)										
	Ca	Mg	Na	K	S	H	CEC	OM	P	pH	EC
PC1	0.01	-0.82	-0.97	-0.94	-0.98	0.92	-0.90	-0.77	-0.86	-0.96	-0.92
PC2	0.91	0.47	-0.19	-0.31	0.18	0.25	0.40	-0.55	0.42	-0.24	0.10

PC1 – principal component 1 and PC2 – component principal 2; Ca (calcium - cmolc kg⁻¹), Mg (magnesium - cmolc kg⁻¹), Na (sodium - cmolc kg⁻¹), K (potassium - cmolc kg⁻¹), S (sum of bases), H (hydrogen - cmolc kg⁻¹), CEC (cation exchange capacity - cmolc kg⁻¹), OM (organic matter - g kg⁻¹), P (phosphorus - mg kg⁻¹), pH (hydrogen potential), and EC (electrical conductivity - dS m⁻¹).

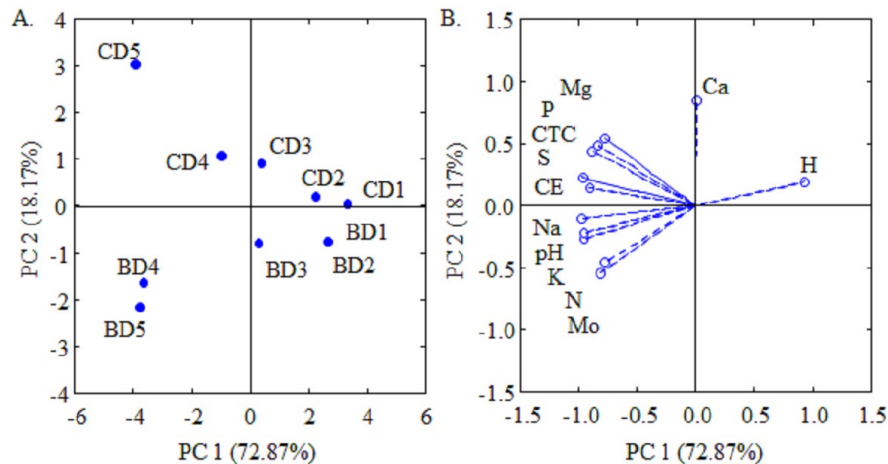


Figure 3: Two-dimensional projections of the principal component scores for the substrates and their doses (A) and the evaluated soil variables (B) in the two principal components (PC1 and PC2, respectively); CD1, CD2, CD3, CD4, and CD5 indicate different doses of poultry litter compost including 0, 2.5, 5.0, 7.5, and 10 t ha⁻¹, respectively, while BD1, BD2, BD3, BD4, and BD5 correspond to different doses of poultry litter biochar (0, 2.5, 5.0, 7.5, and 10 t ha⁻¹, respectively).

Table 4: Average values of the original mean of variables in different treatments.

Treatments	Mean values									
	PH	SD	EIH	ED	EL	GPL	GPS	GPE	DPL	DPS
BD1	103.50	19.57	47.33	29.91	23.00	75.96	127.33	80.10	25.28	32.12
BD2	106.00	24.37	76.67	45.52	27.83	103.46	276.37	166.62	39.50	75.98
BD3	156.67	28.36	92.67	50.64	26.67	117.67	316.27	202.63	46.43	81.81
BD4	160.33	29.04	92.33	49.62	27.83	135.25	316.52	184.67	53.03	77.43
BD5	163.17	27.58	80.50	53.08	28.00	121.76	289.04	184.11	47.39	69.53
CD1	164.00	20.96	48.00	30.25	25.50	78.85	128.17	90.19	26.92	33.14
CD2	167.83	26.48	78.00	39.58	26.50	118.52	273.32	184.83	44.65	73.15
CD3	169.67	26.11	78.00	47.12	27.00	121.90	290.74	166.52	49.13	74.26
CD4	174.50	25.34	89.33	51.41	30.07	129.67	281.00	211.47	49.21	80.09
CD5	175.33	29.52	93.50	56.64	30.93	140.09	312.98	240.07	53.96	82.87

B: (biochar) and C: (compost); D1: (dose 1 - 0 t ha⁻¹), D2: (dose 2 - 2.5 t ha⁻¹), D3: (dose 3 - 5.0 t ha⁻¹), D4: (dose 4 - 7.5 t ha⁻¹), and D5: (dose 4 - 10 t ha⁻¹); PH: (plant height - cm), SD: (stem diameter - mm), EIH: (ear insertion height), ED: (ear diameter - mm), EL: (ear length - cm), GPL: (green phytomass of leaves - g), GPS: (green phytomass of the stalk - g), GPE: (green phytomass of ears - g), DPL: (dry phytomass of leaves - g), and DPS: (dry phytomass of the stalk - g).

These results demonstrated the positive and more rapid influence of organic compost on early plant growth, which can be due to the compost-induced release of essential nutrients, such as N, P, and K, which are ready for absorption by the roots of corn and stimulate the growth of its vegetative parts. This compound also supports a greater accumulation of nutrients in storage organs, which favors the development of reproductive organs like the ear. Biochar, however, which possesses a slower nutrient release performance, promoted the stability of phytomass dynamics and facilitated the gradual development of the plant throughout its growth cycle. These results indicate

that the organic compost may particularly be advantageous to the rapid growth of the plant, while biochar acts as a continuous source of plant nutrients during its entire growth cycle, which is consistent with previous studies carried out by Kebede, Berhe and Zergaw (2023) and Mendes et al. (2021b).

Control plants (BD1) exhibited the lowest values of the parameters SD (19.57 mm), EIH (47.33 cm), ED (29.91 mm), EL (23.0 cm), FVF (75.96 g), BFC (127.33 g), FE (80.10 g), FSF (25.28 g), and FSC (32.12 g) (Table 4).

The main purpose of the multivariate analysis of variance (MANOVA) (Table 5) is to reduce the dimensionality of

multidimensional original variables to two principal components (PC1 and PC2) with $\lambda \geq 1.0$. Table 5 displays the eigenvalues and proportion of total variation jointly explained by both components (92.44 %), with PC1 accounting for 81.65 % of the total variance, whereas the remaining variance (10.79 %) was explained by PC2. The significant influence of the interaction between the two substrates and their doses ($S \times D$) on the two principal components (PC1 and PC2) was also recorded.

Table 5: Eigenvalues, percentage of total variance explained, and multivariate analysis of variance (MANOVA) for the standardized variables and the two principal components.

Variables	Principal components	
	PC1	PC2
Eigenvalues (λ)	8.58	1.76
Percentage of total variance ($S^2\%$)	81.65	10.79
Hotelling test (T2) for substrates (S)	0.01	0.01
Hotelling test (T2) for doses (D)	0.01	0.01
Hotelling test (T2) for interaction	0.01	0.03

Variables with correlation coefficients above 0.7 ($r > 0.7$) were considered highly correlated and maintained in the database. Stalk diameter (SD), ear insertion (EIH), ear diameter (ED), ear length (EL), fresh phytomass of leaves (FPL), fresh phytomass of the stalk (FPS), fresh phytomass of ears (FPE), dry phytomass of leaves (DPL), and dry phytomass of the stalk (DPS) were the variables in PC1 having the highest correlation coefficients (Table 6). However, in PC2, the only variable with a correlation coefficient higher than 0.7 was plant height (PH).

As shown in Figure 4, PC2 demonstrated a similar trend to PC1, with plants grown in the soil under the organic compost treatment at 10 t ha^{-1} (CD5) exhibited the highest value of plant height (175.33 cm), indicating an increase of 7.45 % (12.16 cm) compared to that obtained for plants cultivated in the biochar-amended soil at the same dose (BD5), while the lowest PH value (103.50 cm) was recorded for plants grown in the untreated soil (0 t ha^{-1} ; BD1) (Table 4).

In general, each increasing dose of both the organic compost and biochar was observed to improve the soil and plant variables. These results agree with those presented by Mendes et al. (2021b) who found a significant effect of the application of poultry litter-based biochar on the growth and production of

Table 6: Correlation coefficients (r) between standardized variables and their associated principal components.

Principal component	Correlation coefficients (r)									
	PH	SD	EIH	ED	EL	FPL	FPS	FPE	DPL	DPS
CP1	-0.60	-0.95	-0.98	-0.95	-0.86	-0.98	-0.96	-0.97	-0.98	-0.95
CP2	0.79	-0.01	-0.13	-0.11	0.12	0.07	-0.20	-0.03	0,03	-0.22

CP1 -- principal component 1 and CP2 - principal component 2; PH: (plant height - cm), SD: (stalk diameter - mm), EIH: (ear insertion height), ED: (ear diameter - mm), EL: (ear length - cm), FPL: (fresh phytomass of leaves - g), FPS: (fresh phytomass of the stalk - g), FPE: (fresh phytomass of ears - g), DPL: (dry phytomass of leaves - g), and DPS: (dry phytomass of the stalk - g).

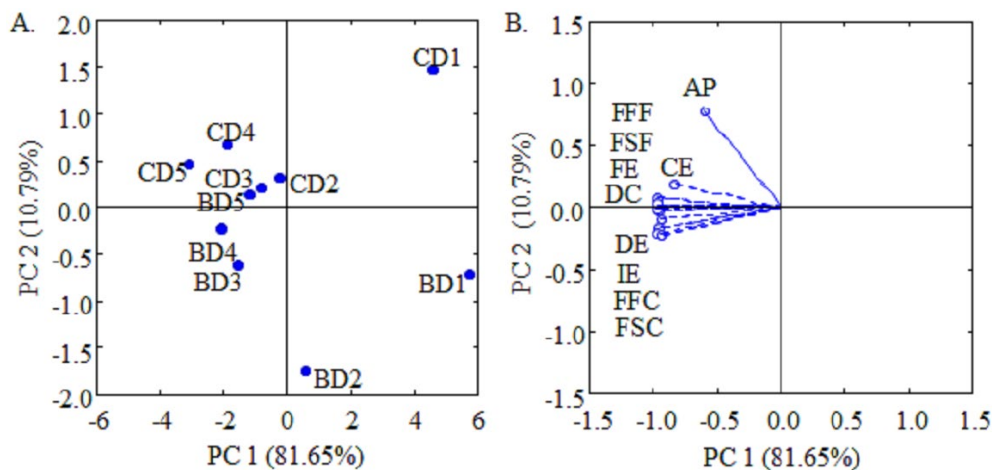


Figure 4: Two-dimensional projections of the principal component scores for the two substrates and their doses (A) and the evaluated corn variables (B) in the two principal components (PC1 and PC2); CD1, CD2, CD3, CD4, and CD5 correspond to 0, 2.5, 5.0, 7.5, and 10 t ha^{-1} of poultry litter-derived compost, respectively, whereas BD1, BD2, BD3, BD4, and BD5 signify different poultry litter biochar treatments (0, 2.5, 5.0, 7.5, and 10 t ha^{-1} , respectively).

corn hybrid BRS 2022, with the best results achieved at the application rate of 6.4 t ha⁻¹. Campos et al. (2017) also found the linear response of corn plants to organic fertilization with poultry litter at a level up to 7.5 t ha⁻¹, resulting in the highest production of green and dry matter of corn plants.

The favorable effects of compost in comparison to biochar are directly associated with the higher Ca, Mg, and P contents in the soil. The probable reason for this is the easier decomposition of this material, which enhances its effect, particularly immediately after its application to the soil, ultimately contributing to the availability of these essential nutrients for crops. The reports on the use of biochar have revealed that this compound exerts its effects on the soil, and consequently on crop yields over time, not immediately after its addition. On the other hand, the accumulation of organic matter in the soil at higher levels as a result of the application of biochar occurs due to its ability to convert carbon dioxide into stable aromatics with higher resistance to degradation compared to the organic compost, which corresponds with the findings published by Brassard, Godbout and Raghavan (2016) and Qambrani et al. (2017).

Conclusions

The addition of poultry litter-based organic compost to the soil at 10 t ha⁻¹ increased the Ca, Mg, P, H, sum of bases in the soil and CEC, increasing growth and production components of corn plants compared to poultry litter biochar. Organic compost at an application rate of 10 t ha⁻¹ can be used as a substitute for biochar, aiming at improving the chemical properties of the soil and reaping the benefits of corn production.

Author Contributions

Conceptual idea: Tito, G. A.; Chaves, L.H.G.; Fernandes, J.D.; Methodology design: Tito, G. A.; Chaves, L.H.G.; Fernandes, J.D.; Data collection: Tito, G. A.; Laurentino, L.G.S.; Data analysis and interpretation: Fernandes, J. D.; Silva, A.A.R.; Kubo, G.T.M.; Souto, L.S.; Writing and editing: Tito, G. A.; Chaves, L.H.G.; Fernandes, J. D.; Laurentino, L.G.S.; Silva, A.A.R.; Kubo, G.T.M.; Souto, L.S.

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