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Agronomic response of the cowpea and soil quality bioindicators to the application of biochar[1]

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ABSTRACT - Biochar can promote crop production and soil quality. However, its characteristics depend on the waste used in its production and its effects may vary according to the species being cultivated and the management adopted. The aim of this study was to evaluate the application of biochar from animal waste on soil quality and the agronomic characteristics of the cowpea. An experiment was set up to test three types of biochar (bovine-BB, swine-SB and poultry-BP), with added fertiliser (BBF, SBF and BPF) and two control treatments, including the addition of calcium magnesium oxide (CT) and calcium magnesium oxide with fertiliser (CTF), giving a total of eight treatments with four replications. There was a respective increase of up to 102.94%, 1048%, 1560% and 360.22% in stem diameter, number of pods, number of grains per pod and stem dry matter from adding the biochar. The poultry biochar increased each of the above parameters even with no added fertiliser. There was no difference in basal soil respiration or β-glucosidase enzyme activity, whereas organic carbon (TOC), total nitrogen (TN), microbial carbon and soil labile carbon were greater with biochar. BBF gave the highest TOC content (24.40 g kg^{-1}), while BP and BPF increased TN by around 61%. The application of biochar + fertiliser contributed to an average reduction of 56% in the soil metabolic quotient. Poultry biochar favoured both the agronomic characteristics of the cowpea and soil quality, while bovine biochar showed more marked results with the addition of fertiliser.

Key words: Carbon. Plant growth. Soil conditioner. Nitrogen. *Vigna unguiculata*.

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INTRODUCTION

The cowpea [*Vigna unguiculata* (L.)] is of socioeconomic importance, especially for developing countries. In Brazil, for example, cowpea production has been on the increase in recent years, with a significant advance in planted area, and crop production reaching 625.2 thousand tons of grain in the 2020/2021 harvest (CONAB, 2021). However, average crop productivity is considered poor due to the low level of technology adopted.

Little or no fertiliser is used in cowpea production, making mineral deficiency a limiting factor for productivity, despite the crop being well adapted to low-fertility soils (Guerra *et al*., 2020). This is due to much of cowpea production being focused on subsistence farming, where little mineral fertiliser is purchased by producers. In this context, soil improvers based on animal and plant waste are seen as a viable alternative (Melo *et al*., 2021).

Biochar, resulting from the pyrolysis of biomass residue under little or no oxygen, is used as a potential soil conditioner. Soil conditioners are able to provide nutrients and increase organic matter and as such can provide greater aggregate stability and reduce the chances of soil compaction and erosion thereby improving water and nutrient retention. Thus, in addition to playing an important role in carbon sequestration, biochar promotes soil fertility. It can also promote the growth of microorganisms in the rhizosphere and of arbuscular mycorrhizal fungi (Alkharabsheh *et al*., 2021; Ippolito *et al*., 2020).

Each of the physical, chemical and biological improvements afforded the soil by the use of biochar can be important in cowpea cultivation. However, the effect of biochar on such soil attributes as pH, cation exchange capacity (CEC), organic carbon content and nutrient adsorption capacity depend on the characteristics of the material from which the biochar originates (Ippolito *et al*., 2020). For example, biochar produced from chicken litter provides better mineralisation of the soil organic matter and greater biological activity in the soil than those based on sawmill waste (Ameloot *et al*., 2015). In fact, biochar of animal origin has more nutrients, while biochar of plant origin has a higher carbon content (Alkharabsheh *et al*., 2021).

It is also important to evaluate whether the use of a particular biochar combined with conventional fertiliser increases the efficiency of fertiliser application, i.e. whether there is an increase in nutrient uptake expressed as an increase in crop productivity. According to Alkharabsheh *et al*. (2021), not only do biochars contain N, P, K, Ca, Mg, S and other essential nutrients for plants, but they also contain functional groups that generate a high CEC, increasing retention, reducing nutrient leaching and allowing plants to absorb more ammonium (NH_4^+), K, Ca and Mg.

The hypothesis is that the application of biochars from different types of animal waste favours cowpea production and improves soil quality, intensifying the benefits generated by mineral fertilisers and with different responses between biochars. The aim, therefore, was to assess the impact of different animal waste biochars, both with and without mineral fertiliser, on cowpea production and the biological quality of the soil.

MATERIAL AND METHODS

Study location and conducting the experiment

The experiment was conducted in a controlled environment (greenhouse), in an experimental area of the Institute of Agricultural Sciences of the Federal University of Minas Gerais, in the district of Montes Claros (16°40’3.17” W; 43°50’40.97” S, altitude 646 m), between October 2020 and October 2021. The climate in the region is type Aw (Köppen), tropical savannah, with rainy summers and dry winters. Data from the local weather station show an average temperature of 24.3 °C, with an average rainfall of 843 mm. The average, maximum and minimum daily temperatures for the period from planting (15 October 2020) to harvest (4 January 2021) are shown in Figure 1.

The experimental design was of randomised blocks with four replications, including three types of biochar (Bovine - BB; Swine - SB; and Poultry - PB), biochar with added fertiliser (BBF, SBF and PBF) and two controls (Calcium magnesium oxide - CT and Calcium magnesium oxide + fertiliser - CTF), giving a total of eight treatments.

The biochars were produced from the following animal waste by pyrolysis at a temperature of 450 ºC and an average residence time of 45 minutes: bovine waste from lactating cows in confinement, fed sorghum silage with corn-based concentrate and soya meal; swine waste from pregnant sows, fed a diet based on soya and cornmeal; and poultry waste from laying hens, fed on soya and maize. The cattle, pigs and hens also received essential minerals in their diet. After producing the biochars, all the material resulting from the pyrolysis process was crushed (< 0.5 mm) and the pH, electrical conductivity (EC), moisture, ash content and macro- and micronutrient content were determined for chemical characterisation (Table 1) as per the method of the Ministry of Agriculture and Livestock (Brazil, 2017) for organic fertilisers. The carbon (total C) (Table 1) was determined by wet oxidation as per Yeomans and Bremner (1988).

Figure 1 - Mean, maximum and minimum daily temperature during the months of the greenhouse experiment. A: October 2020; B: November 2020; C: December 2020; D: January 2021

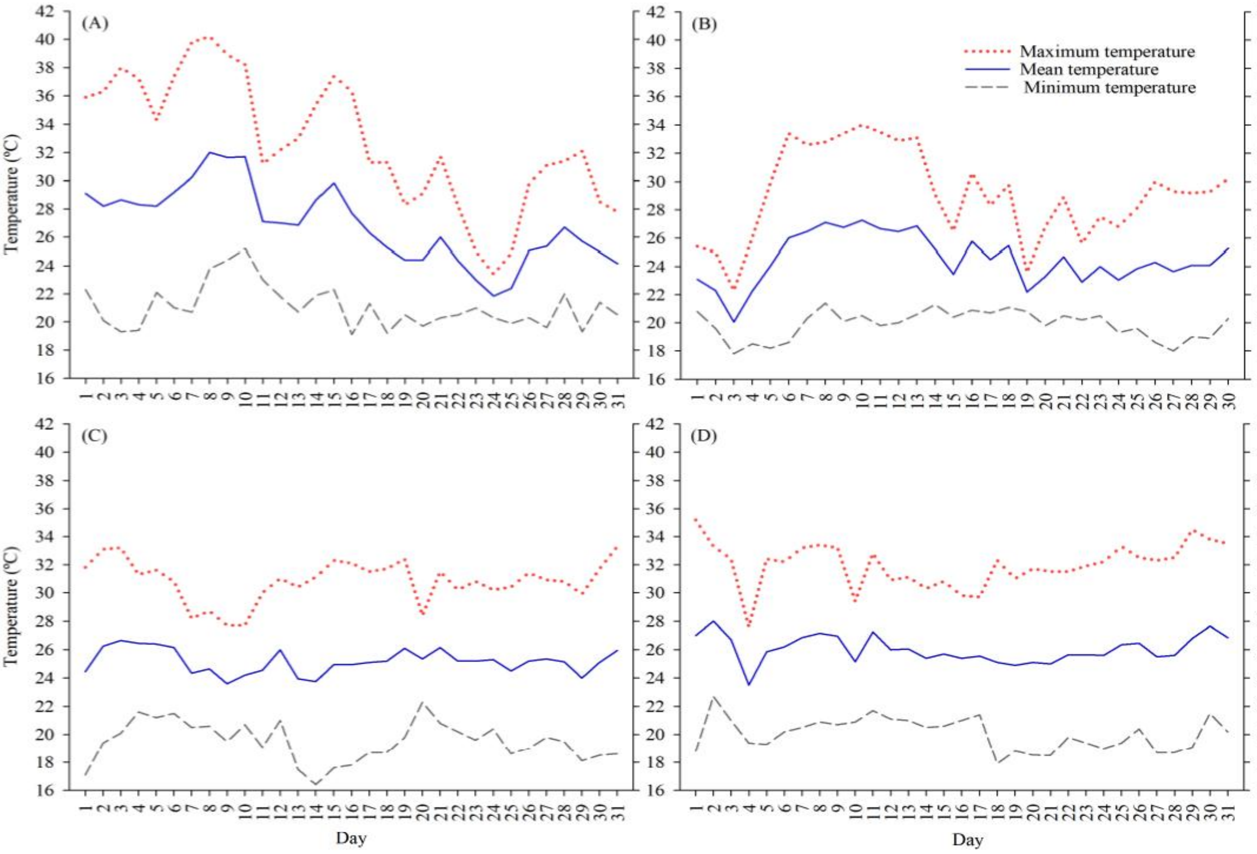


Table 1 - Characterisation of the biochars from animal waste (Bovine – BB, Swine – SB and Poultry - PB) used to fertilise the cowpea

Attribute	Biochar		
	BB	SB	PB
Moisture (%)	4.37	3.40	5.61
pH	8.87	8.83	9.55
EC (mS cm^{-1})	1.950	1.108	5.270
Ash (%)	40.10	55.41	43.21
Total C (g kg^{-1})	46.70	30.06	31.52
Total N (g kg^{-1})	33.77	43.72	64.02
P (g kg^{-1})	11.39	72.37	48.82
K (g kg^{-1})	20.77	15.47	27.95
Ca (g kg^{-1})	15.42	86.87	79.79
Mg (g kg^{-1})	3.20	9.58	6.95
Zn (mg kg^{-1})	221.13	1478.74	380.06
Cu (mg kg^{-1})	46.13	205.47	59.27
Mn (mg kg^{-1})	276.47	758.70	441.67
Fe (g kg^{-1})	12.25	7.50	3.71

The cowpea (*Vigna unguiculata* (L.) Walp.) 'BRS Cauamé' was grown in pots under controlled lighting in soil collected from an area of native vegetation (Cerrado biome) located near the area of the study. The soil was classified as a dystrophic Red Yellow Latossol (Ferrasol) of clayey texture, with the following chemical and physical attributes: pH (water) = 3.80; P Mehlich-1 (mg dm^{-3}) = 1.11; K (mg dm^{-3}) = 14.00; Ca (cmol$_c$ dm^{-3}) = 0.44; Mg (cmol$_c$ dm^{-3}) = 0.20; Al (cmol$_c$ dm^{-3}) = 1.18; H+Al (cmol$_c$ dm^{-3}) = 5.90; Organic matter (g kg^{-1}) = 23.40; Sand (g kg^{-1}) = 460.00; Silt (g kg^{-1}) 100.00; Clay (g kg^{-1}) 440.00.

The soil was previously sieved (mesh < 4 mm) and added to three-litre pots. To raise the base saturation to 60%, calcium magnesium oxide (PRNT 180%) was added to the soil in the treatments with no added biochar. In the treatments that included mineral fertiliser, the fertiliser was applied when planting, using 20 mL of macronutrient solution and 10 mL of micronutrient solution per pot to supply the soil with 90.32 mg kg^{-1} N, 300 mg kg^{-1} P, 222.5 mg kg^{-1} K, 40 mg kg^{-1} S, 4.0 mg kg^{-1} Zn, 0.82 mg kg^{-1} B, 1.33 mg kg^{-1} Cu, 1.55 mg kg^{-1} Fe, 3.66 mg kg^{-1} Mn and 0.15 mg kg^{-1} Mo. Fertilisation was determined based on the recommendation of Novais, Neves and Barros (1991). The sources used for the macronutrients N, P, K and S were ammonium phosphate ($NH_4H_2PO_4$), potassium phosphate (KH_2PO_4) and potassium sulphate (K_2SO_4). For the micronutrients Zn, B, Cu, Fe, Mn and Mo, the following respective compounds were applied: zinc sulphate ($ZnSO_4.7H_2O$), boric acid (H_3BO_3), copper sulphate ($CuSO_4.5H_2O$), iron chloride ($FeCl_2.6H_2O$), manganese chloride ($MnCl_2.4H_2O$) and sodium molybdate ($Na_2MoO_4.2H_2O$); all the nutrients were from pure reagents used in analysis. In the treatments with biochar, a dose of 3% (v/v) relative to the soil was added. After incorporating the added materials, the soil was incubated for 15 days until sowing the cowpea.

Eight seeds were sown per pot, leaving two plants in each pot after thinning; this was carried out 10 days after sowing (DAS). Top dressing was applied at 25 DAS, with the addition of 45 mg dm^{-3} nitrogen in the form of urea. The pots were irrigated with distilled water regularly throughout the experiment to maintain water levels at field capacity (between 70% and 80% of the maximum water retention capacity). The amount of water to be applied was determined by weighing the pots daily.

Evaluating the agronomic characteristics

Agronomic evaluation of the cowpea was carried out at the beginning of the reproductive phase (65 DAS), by collecting the mature pods; the remaining pods were harvested at the end of the cycle (82 DAS) when the plants were also collected. The entire aerial part of the plant was cut at the collar to determine the average height (cm), average stem diameter (mm), average number of nodes, root length (cm), average number of pods per plant and average number of grains per pod. The plants were divided into stem, leaves, roots and grains, packed in paper bags, weighed and placed in a forced air circulation oven at 65 °C to constant weight to obtain the dry weight of the leaves, stem, roots and grains.

Sampling the soil and evaluating the biological attributes

At the end of the evaluations, a sample of soil was collected from each pot. These were homogenised, air-dried and sieved using a 2-mm mesh (ADFE); the fine roots were later separated to carry out the analyses. A part of the samples was then ground, weighed and sieved using a 0.150-mm mesh to determine the levels of total organic carbon (TOC) and total nitrogen (TN). TOC was determined using the wet oxidation method with external heating (Yeomans; Bremner, 1988); TN was obtained using Kjeldahl digestion followed by steam distillation (Mendonça; Matos, 2017).

Labile carbon (LC) was determined by oxidation of the carbon contained in the sample using a 0.033 mol L^{-1} solution of potassium permanganate ($KMnO_4$) and quantified by colorimetry using a spectrophotometer at a wavelength of 565 nm (Shang; Tiessen, 1997).

Microbial carbon (Cmic) was quantified using the fumigation-extraction method (Vance *et al.*, 1987). Basal soil respiration (BSR) was determined by quantifying the mineralisable carbon through the release of CO_2 (C-CO_2), captured in a 0.5 mol L^{-1} solution of NaOH (Silva; Azevedo; de-Polli, 2007). The C-CO_2 was quantified at intervals of 24, 48, 72, 96 and 120 hours, giving a total of 13 assessments (approximately 40 days) after incubating the samples at room temperature (25 ºC for the period of respirometry). In addition, the microbial quotient (qMic) was calculated as the ratio between Cmic and TOC and the metabolic quotient (qCO_2) was calculated as the ratio between BSR and Cmic. β-glucosidase enzyme activity was quantified by colorimetric determination of the *p*-nitrophenol released by the enzymes as soon as the soil was incubated, using a buffered solution of specific substrates (Tabatabai, 1994).

Statistical analysis

The Shapiro-Wilk test was used to verify whether the values of each variable met the assumption of normal distribution, while the Cochran and Bartlett test was used to verify the homogeneity of variance. Once the normality and homogeneity of variance were verified, analysis of variance (ANOVA) was applied using the F-test ($p \leq 0.05$). When significant, the mean values were compared by Scott-Knott test ($p \leq 0.05$) using the R software (R Development Core Team, 2019).

RESULTS AND DISCUSSION

Agronomic characteristics

The treatments with biochar or calcium and magnesium oxide, whether with (CTF, BBF, SBF and PBF) or without fertiliser (CT, BB, SB and PB) had no effect on the height, root length or number of nodes of the cowpea (Table 2). The average diameter of the stem ranged from 3.4 to 6.9 mm (Table 2), with the highest values seen in the treatments with biochar combined with fertiliser (BBF, SBF and PBF), and in the treatment where only poultry biochar (PB) was applied.

Biochars from animal waste generally have more nutrients, especially from chicken manure. Their properties vary according to the biomass of each material, which is influenced by the management, production techniques and diet of the animals that produce the waste (Alkharabsheh *et al*., 2021; Ameloot *et al*., 2015; Ippolito *et al*., 2020). As there is a greater concentration of nutrients in the soil after applying the biochar, a positive effect on stem diameter was expected (Adekiya, 2022). Compared to CT, the present study showed increases from 21.36% (BBF) to 61.17% (PBF) in the TN content of the soil with the application of biochar (Table 5), which contributed to the PBF treatment obtaining the greatest percentage increase in stem diameter (Table 2).

As was seen in the present study (Table 2), when evaluating the effects of the individual and combined application of biochar and fertiliser on the properties of the soil and the growth and yield of the cowpea, Adekiya (2022) found that the combination of biochar + mineral fertiliser significantly favoured the growth and production parameters of the species under study.

The number of pods per plant was lower for CT and SBF in relation to the other treatments that included biochar (Table 3); this was also seen in the number of grains per pod, where average values ranged from 0.25 to 2.75 and from 1.25 to 20.75, respectively.

A small number of pods per plant was seen in all the treatments and a small number of grains per pod in CT, while the other treatments showed a higher number of grains per pod than found in the literature. For example, an average number of 10 pods per plant and eight grains per pod was reported for the cultivar under study (Cauamé) (Públio Júnior *et al*., 2017). The occurrence of high temperatures is one of the main explanations for reduced productivity, as they can cause the spontaneous abortion of flowers, retention of pods and reduction in the number of seeds per pod (Cavalcante Junior *et al*., 2016); this may have contributed to the reduced number of pods per plant in the present study.

The treatments that included biochar, whether combined or not with fertiliser, outperformed CT (SD, NPP, NGP and MSC). This can be attributed to the amount of nutrients in the biochars (Table 1), which also have the potential to correct acidity, helping to raise the pH of the soil used in the present study, for which the chemical characterisation indicated high acidity (3.8). As the pH of biochars from animal waste is high and may be alkaline, it can be said that their effect is similar to that of liming, where pH levels rise, acidity is reduced and the CEC of the soil improves (Alkharabsheh *et al*., 2021). This effect improves the productivity indicators, which explains the higher values (NGP) found in the treatments with biochar, except for SBF, which may have had a toxic effect due to the dose, leading to a reduction in physiological parameters and, consequently, a loss of productivity (Costa *et al*., 2024).

Table 2 - Plant height (PH), root length (RL), stem diameter (SD) and number of nodes per plant (NN) in cowpea fertilised with different biochars from animal waste

Treatment	PH	RL	SD	NN
	------------------------ cm	------------------------	mm	-
CT	67.2 a	30.8 a	3.4 c	11.12 a
CTF	80.0 a	31.6 a	5.5 b	11.12 a
BB	60.7 a	30.5 a	5.3 b	11.87 a
BBF	88.0 a	30.8 a	6.8 a	11.75 a
SB	68.1 a	29.6 a	5.4 b	10.87 a
SBF	87.1 a	34.5 a	6.6 a	12.62 a
PB	70.1 a	30.5 a	6.4 a	10.62 a
PBF	84.2 a	24.1 a	6.9 a	11.87 a
CV (%)	25.89	20.03	8.23	20.52

CT: correction; CTF: correction + fertiliser; BB: bovine biochar; BBF: bovine biochar + fertiliser; SB: swine biochar; SBF: swine biochar + fertiliser; PB: poultry biochar; PBF: poultry biochar + fertiliser. Mean values followed by the same letter in a column do not differ by Skott-Knott test at 5% probability

Table 3 - Number of pods per plant (NPP) and number of grains per pod (NGP) in cowpea after the application of different biochars from animal waste

Treatment	NPP	NGP
CT	0.25 c	1.25 c
CTF	1.87 a	16.37 a
BB	2.50 a	16.87 a
BBF	2.75 a	18.25 a
SB	2.87 a	20.75 a
SBF	1.25 b	10.00 b
PB	2.25 a	15.87 a
PBF	2.12 a	16.25 a
CV (%)	29.94	39.60

CT: correction; CTF: correction + fertiliser; BB: bovine biochar; BBF: bovine biochar + fertiliser; SB: swine biochar; SBF: swine biochar + fertiliser; PB: poultry biochar; PBF: poultry biochar + fertiliser. Mean values followed by the same letter in a column do not differ by Skott-Knott test at 5% probability

Zn, Cu and Mn were mentioned by Shen *et al.* (2020) as the most abundant potentially toxic elements found in biochars derived from swine manure. In fact, based on the characterisation of the biochars used in the present study (Table 1), the concentrations of Zn, Cu and Mn were high, with the highest values in SB. The combination of swine biochar and mineral fertiliser may therefore have had a toxic effect and reduced the productivity of the cowpea. According to Shen *et al.* (2020), pyrolysis temperatures between 500 °C and 700 °C contribute to greater detoxification of swine waste by reducing the bioavailability and toxicity of the Zn, Cu and Mn found in biochar. In the present study (Table 1), the pyrolysis temperature did not reach 500 ºC, which may have favoured the bioavailability and toxicity of the above chemical elements.

When evaluating the effect of biochar from animal manure on the common bean, Torres *et al*. (2023) also found an increase in productivity. In addition, the authors found that the biochar functioned as a conditioner for the chemical properties of the soil, acting as a corrector of soil acidity and a source of nutrients.

There was no statistical difference between treatments for leaf, root or grain dry weight (Table 4). In relation to CT, however, there was a respective average increase of 115%, 90% and 744% in the treatments that included biochar, and 140%, 113% and 567% in the treatments with biochar and fertiliser. For stem dry matter, each of the treatments showed a better response than CT, with values ranging from 0.98 to 4.28 g per plant (Table 4).

Applying biochar to the soil can promote an increase in photosynthetic rates, which increases the efficiency of fertiliser use, leading to a greater production of plant biomass (Yeboah *et al*., 2020), a result of the biochar acting as a soil conditioner. In this respect, biochars derived from animal waste provide more nutrients compared to those from plant waste, which helps to increase the dry weight of the plant (Ippolito *et al*., 2020; Torres *et al*., 2023). Therefore, in addition to improving the productivity parameters of agricultural crops through the use of biochar from animal waste, there should also be an improvement in the attributes related to soil quality, thereby achieving greater sustainability in production systems.

Soil attributes

The treatment with bovine biochar combined with fertiliser (BBF) gave the highest levels of TOC, while the lowest values were seen in the controls (CT and CTF), with average values of 24.4 (BBF), 14.07 (CT) and 13.5 g kg^{-1} (CTF) (Table 5). The application of swine and poultry biochars, with and without added fertiliser (SB, SBF, PB and PBF), resulted in higher levels of TN, with values that ranged from 1.48 to 1.66 g kg^{-1} (Table 5). CTF, BB and BBF showed a higher C/N ratio, while the remaining treatments showed no differences (Table 5).

The lower concentration of TOC in the soils treated with SBF and PBF may be a result of the raw material used in the production of this type of biochar, as these residues are poor in lignin, while residues rich in this component tend to incorporate more C into the soil (Sarfaraz *et al*., 2020). When characterising the biochars used in this study (Table 1), it was found that those originating from swine and poultry waste (SB and PB) had a smaller total C content, affecting the levels of TOC in the soil. Even so, all of the biochar treatments had significantly higher levels of TOC than did the control treatment (Table 5).

Table 4 - Dry weight of the leaves (LDW), stem (SDW), roots (RDW) and grain (GDW) in cowpea after the application of different biochars from animal waste

Treatment	LDW	SDW	RDW	GDW
	g plant^{-1}			
CT	1.76 a	0.93 b	0.56 a	0.30 a
CTF	4.67 a	2.83 a	1.22 a	1.63 a
BB	3.45 a	2.82 a	1.29 a	2.63 a
BBF	4.37 a	4.28 a	1.36 a	2.27 a
SB	4.55 a	2.83 a	1.11 a	3.23 a
SBF	4.04 a	3.22 a	1.17 a	1.69 a
PB	3.35 a	3.35 a	0.79 a	1.74 a
PBF	4.29 a	3.94 a	1.05 a	2.04 a
CV (%)	33.04	37.71	38.13	52.53

CT: correction; CTF: correction + fertiliser; BB: bovine biochar; BBF: bovine biochar + fertiliser; SB: swine biochar; SBF: swine biochar + fertiliser; PB: poultry biochar; PBF: poultry biochar + fertiliser. Mean values followed by the same letter in a column do not differ by Skott-Knott test at 5% probability

Table 5 - Total organic carbon (TOC) and total nitrogen (TN), C/N ratio and labile carbon (LC) in soil under cowpea cultivation with the application of different biochars from animal waste

Treatment	TOC	TN	C/N	LC
	g kg^{-1}		-	g kg^{-1}
CT	14.07 d	1.03 b	13.61 b	1.86 b
CTF	13.15 d	0.75 c	17.41 a	1.76 b
BB	22.45 b	1.26 b	17.77 a	2.33 a
BBF	24.40 a	1.25 b	19.86 a	2.32 a
SB	21.26 b	1.48 a	14.34 b	2.51 a
SBF	18.30 c	1.54 a	12.00 b	2.40 a
PB	21.52 b	1.65 a	13.08 b	2.74 a
PBF	19.03 c	1.66 a	11.57 b	2.66 a
CV (%)	7.88	12.33	11.41	11.00

CT: correction; CTF: correction + fertiliser; BB: bovine biochar; BBF: bovine biochar + fertiliser; SB: swine biochar; SBF: swine biochar + fertiliser; PB: poultry biochar; PBF: poultry biochar + fertiliser. Mean values followed by the same letter in a column do not differ by Skott-Knott test at 5% probability

Higher levels of labile carbon (LC) were found in the biochar treatments, both with and without added fertiliser, compared to the control treatments (CT and CTF), with average values ranging from 1.76 to 2.74 g kg^{-1} (Table 5). The higher values for LC in the biochar treatments can be explained by the increase in TOC and the ash content of the applied materials. For the most part, raw materials with a high ash content have lower levels of stable carbon (Enders *et al*., 2012). In addition, the stability of a biochar is directly linked to its C/N ratio (Fatima *et al*., 2021), as seen in the present study, where most of the treatments with a higher LC content (SB, SBF, PB and PBF) showed the lowest values for the C/N ratio (Table 5).

As also seen for BSR, there was no difference between the treatments for Cmic; yet, qCO_2 was higher in the CT treatment compared to the other treatments (Table 6). There was also no significant difference in the activity of the β-glucosidase enzyme (Figure 2). However, in relation to CT, the PB and PBF treatments afforded a respective increase of 60.52% and 74.91% in the average value of the enzyme.

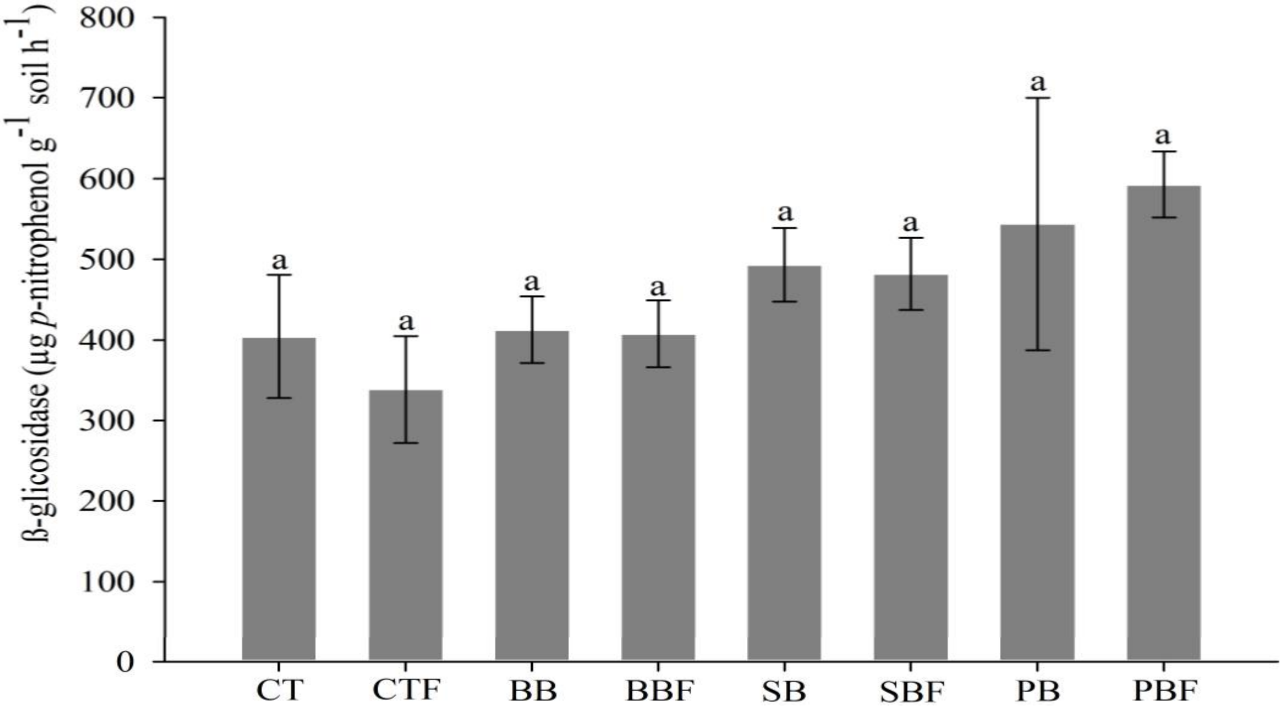
Song *et al*. (2018) pointed out that applying biochar to the soil can increase or reduce microbial and enzyme activity, depending on the type of soil sampled and other experimental conditions, with a direct effect on soil basal respiration. Other factors to be considered are the C/N ratio, nutrients, pH and amount of material added to the soil (Abujabhah *et al.*, 2018). The higher qCO_2 in CT in relation to the other treatments (Table 6) showed that there was less efficient use of the soil Cmic, while the biomass in the CTF, BB, BBF, SB, SBF, PB and PBF treatments was more efficient, since basal soil respiration is linked to carbon use efficiency (Martin *et al.*, 2015). It can therefore be concluded that CT results in a greater loss of carbon in the form of CO_2 through respiration and incorporates less carbon into microbial tissue compared to the other treatments under study. This is due to the lower production of plant biomass and the lower levels of TOC and LC provided by the soil fertility management (correction with calcium and magnesium oxide only).

Table 6 - Microbial carbon (Cmic), basal respiration (BSR) and metabolic quotient (qCO_2) of the soil under cowpea cultivation with the application of different biochars from animal waste

Treatment	Cmic	BSR	qCO2
	mg kg^{-1}	mg C-CO_2 kg^{-1}	mg C-CO_2 g^{-1} Cmic-C h^{-1}
CT	330.0 a	5.09 a	0.66 a
CTF	487.5 a	2.83 a	0.25 b
BB	525.0 a	3.95 a	0.33 b
BBF	457.5 a	2.95 a	0.26 b
SB	450.0 a	3.03 a	0.40 b
SBF	517.5 a	2.61 a	0.34 b
PB	555.0 a	3.27 a	0.24 b
PBF	570.0 a	3.02 a	0.27 b
CV (%)	17.82	37.99	40.00

CT: correction; CTF: correction + fertiliser; BB: bovine biochar; BBF: bovine biochar + fertiliser; SB: swine biochar; SBF: swine biochar + fertiliser; PB: poultry biochar; PBF: poultry biochar + fertiliser. Mean values followed by the same letter in a column do not differ by Skott-Knott test at 5% probability

Figure 2 - β-glucosidase enzyme in the soil under cowpea cultivation with the application of different biochars from animal waste. CT: correction; CTF: correction + fertiliser; BB: bovine biochar; BBF: bovine biochar + fertiliser; SB: swine biochar; SBF: swine biochar + fertiliser; PB: poultry biochar; PBF: poultry biochar + fertiliser



Enzyme activity in the soil is considered a sensitive indicator of soil quality and can be used in short- to long-term studies. As it is a sensitive indicator, β-glucosidase activity is easily affected by the temperature, humidity and pH of the soil (Foster *et al*., 2018). In the present study, there was no difference between treatments for β-glucosidase (Figure 2), this is because the addition of biochar to the soil tends to increase the enzyme activity related to N and P cycling and reduce the activity of enzymes involved with C sequestration and cycling (Irfan *et al*., 2019). Due to the surface area and porosity of biochar, its application can lead to stabilisation of the organic carbon in the soil, reducing the activity of the β-glucosidase enzyme (Azeem *et al*., 2019). An increase in soil pH also leads to a reduction in the activity of the β-glucosidase enzyme (Günal *et al*., 2018) as was seen in this study. This was probably due to the corrective effect of the biochar.

CONCLUSIONS

1. The addition of biochar from different types of animal waste had a positive effect on the production indicators of the cowpea and the biological quality of the soil. The mean stem diameter, number of pods per plant, number of grains per pod, stem dry weight, total and labile organic carbon, microbial quotient and total nitrogen were the most responsive variables to the application of biochar;
2. The use of poultry biochar favoured the agronomic characteristics of the cowpea and the quality of the soil, while bovine biochar gave more marked results when combined with fertiliser. Combining swine biochar with fertiliser reduced the number of pods per plant and the number of grains per pod, showing that, at the dose used in the present study, this biochar should not be applied together with mineral fertiliser for managing the cowpea.

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