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Original Article

Restoration of degraded pasture of *Urochloa decumbens* through different managements using mineral fertilizers and biochar[1]

Recuperação de pastagem degradada sob *Urochloa decumbens* por diferentes manejos utilizando fertilizantes minerais e biochar

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HIGHLIGHTS:

The use of biochar had no influence on dry matter yield, when compared to mineral fertilizer treatments during the second year of use.
The use of biochar associated with mineral fertilizer during the first year increases the dry matter yield of Urochloa decumbens.
The management strategies to restore degraded pasture are important to reduce dependence on mineral fertilizers.

ABSTRACT: Residues generated in sugarcane production such as biochar, originated from bagasse burning, are used as a fertilizer source, which can increase forage dry matter yield, as well as improving soil chemical attributes. The objective of this study was to evaluate the effects of using biochar from sugarcane bagasse burning and mineral fertilization, as well as their association, on the dry matter yield of *Urochloa decumbens* and on the chemical attributes of the soil. The design was randomized blocks, which consisted of eight treatments and four blocks. The treatments were: T1- mineral fertilization; T2- fertilization with limestone plus mineral fertilizer; T3- liming; T4- biochar; T5- biochar plus mineral fertilizer; T6- liming plus biochar; T7- double fertilization with biochar and T8- control. Association of mineral fertilizer and biochar was able to increase dry matter yield by up to 131% when compared to the control treatment during the first year. The use of fertilization strategies in the restoration of degraded area under *U. decumbens* does not interfere with soil chemical attributes, except for sulfur.

Key words: organic residue, soil fertility, dry matter

RESUMO: Resíduos gerados pela produção de cana-de-açúcar como o biochar, proveniente da queima do bagaço podem ser utilizados como fonte de fertilizante, podendo incrementar a produção de matéria seca de forrageira, bem como, dos atributos químicos do solo. O objetivo deste trabalho foi avaliar a utilização de biochar da queima do bagaço da cana-de-açúcar e da adubação mineral e associação de ambos, na produtividade de matéria seca de *Urochloa decumbens*, e nos atributos químicos do solo. O delineamento utilizado foi em blocos casualizados, composto por oito tratamentos, com quatro repetições. Os tratamentos foram: T1- adubação mineral; T2- adubação com calcário + fertilizante mineral; T3- calagem; T4- biochar; T5- biochar + adubação mineral; T6- calagem + biochar; T7- duas vezes a dose com biochar e T8- controle. A associação de fertilizante mineral com biochar foi capaz de aumentar a produção de matéria seca em até 131% quando comparado ao tratamento controle no primeiro ano. O emprego de diferentes estratégias de fertilização na recuperação de área degradada sob uso de *Urochloa decumbens*, não interfere nos atributos químicos do solo, com exceção do elemento enxofre.

Palavras-chave: resíduo orgânico, fertilidade do solo, matéria seca

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Introduction

The state of Goiás is among the main agricultural producers. In recent decades, there has been a considerable increase in the production of sugarcane, intended for the production of sugar, energy and especially ethanol. Goiás is the largest producing state in the central-west region. In the period from 2010 to 2019, the sugarcane planted area went from 155,007 ha in 2010 to 226,200 ha in 2019 (Silva, 2023).

Biochars can have varied composition, as well as the raw material for their manufacture, such as rice straw, maize stem, sugarcane bagasse, forest residues, sewage sludge and others (Zhang et al., 2021; Rubio et al., 2023). These residues are normally burned at temperatures ranging from 200 to over 1,000 °C (Wang et al., 2016; Matos et al., 2018). The use of biochar can increase soil fertility by supplying some cations such as Ca, Mg, K, Mn, Zn and Cu and also due to the presence of other nutrients such as P and N (Li et al., 2021; Tian et al., 2021; Zhang et al., 2021; Ferreira et al., 2023).

Destinations of biochar include the use of ash as an alternative source to mineral fertilization, as well as the association between the two forms of fertilization (Li et al., 2021; Tian et al., 2021). Thus, the use of biochar appears as a fertilization strategy, and it can be applied as a source of fertilizer in forage sorghum as well as in the species *Urochloa* ssp. and *Panicum* spp. (Latawiec et al., 2019; Bezerra et al., 2022).

The use of biochar has been reported in some crops and in rapeseed (*Brassica napus*) associated with mineral fertilizers (Matos et al., 2018; Tian et al., 2021). In the forage sorghum crop, the use of biochar increased the production, panicle weight and P and Ca contents (Bezerra et al., 2022). The use of biochar from the burning of *Gliricidia sepium* branches and leaves, used as fertilizer in the species *Urochloa* ssp. and *Panicum* spp., had a positive effect on dry matter yield (Matos et al., 2018; Sales et al., 2018; Li et al., 2021).

Although some sources of ash are reported in the literature, studies on the use of biochar produced from the burning of sugarcane bagasse as a fertilization strategy in the substitution of or association with conventional mineral fertilizers are still incipient. Therefore, the objective of this study was to evaluate the effects of using biochar from sugarcane bagasse burning and mineral fertilization, as well as their association, on the dry matter yield of *U. decumbens* and on the chemical attributes of the soil.

Material and Methods

The study was conducted between 2020 and 2022, in the municipality of Mineiros, GO, Brazil. This location has altitude of 850 m and coordinates of 17° 27' 16.14" S latitude and 52° 36' 9.85" W longitude. The climate of the region is Aw type, humid tropical. The average annual rainfall ranges from 1,200 to 1,500 mm, and the average annual temperature is 23.3 °C. During the experimental period, temperature and rainfall were monitored, and the results are presented in Figure 1.

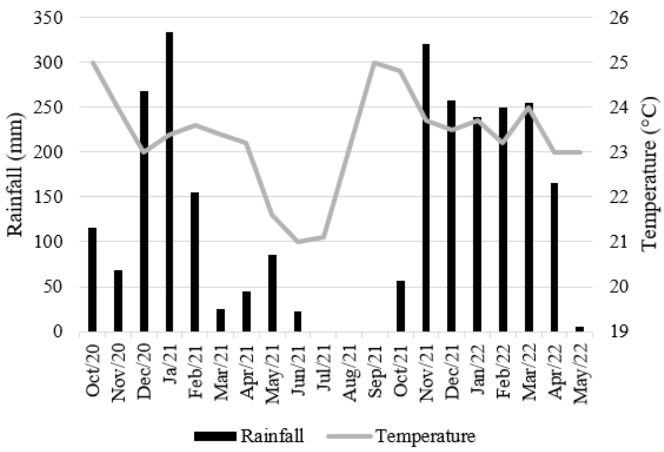


Figure 1. Distribution of accumulated annual rainfall and average air temperature during the experimental period

The experimental area had been cultivated with *U. decumbens* pasture for more than 10 years, in an extensive grazing system with annual stocking rate of 0.4 animal units (AU) ha^{-1}. The soil used in this study was classified as Entisol (United States, 2014), containing 56 g kg^{-1} of clay, 17 g kg^{-1} of silt and 927 g kg^{-1} of sand in the 0-0.20 m layer. For chemical characterization of each treatment, a sample was collected from the 0-0.2 m layer (Table 1), and the chemical analyses were performed according to Teixeira et al. (2017).

The experiment was conducted in a randomized block design with eight treatments and four replicates, totaling 32 experimental units. The experimental plots had dimensions of 3 × 3 m, totaling 9 m². The treatments consisted of different management systems, with correction methods and fertilization sources (Table 2). For the chemical replacement of fertilizer with ash, the treatments were based on the P contents present in the residue.

The different types of agricultural management consisted of correction methods and sources of fertilization for degraded pasture of *U. decumbens*. The study area had been implemented more than 10 years before and was degraded. The treatments were applied according to the recommendations of Martha Júnior et al. (2007). The recommended quantities were 50 kg ha^{-1} of P_2O_5 and 70 kg ha^{-1} of K_2O, and, in order to obtain a production that meets a stocking rate of 5 AU ha^{-1}, 250 kg ha^{-1} of nitrogen were split into 5 portions of 50 kg ha^{-1} and applied after each cut, distributed in each plot manually.

Soil fertilization treatments were manually applied to the plots at the beginning of the rainy season of 2020 and 2021 (October to November). Treatments containing ash and chemical fertilizers, as well as the first urea dose (except in the control treatment), were applied at the beginning of the rainy season following standardized mowing, with dry matter yields

Table 1. Chemical attributes of the soil in the experimental area, in the 0-0.2 m layer

pH $CaCl_2$	OM	P	K	Ca	Mg	Al	H+Al	SB	CEC	V
	(g dm^{-3})	(mg dm^{-3})		($cmol_c$ dm^{-3})						(%)
4.7	18.0	1.0	31.28	0.6	0.2	0.1	3.8	0.88	4.68	18.80

OM - Organic matter; P - Phosphorus; K - Potassium; Ca - Calcium; Mg - Magnesium; Al - Aluminum; SB - Sum of bases; CEC - Cation exchange capacity; V% - Base saturation

Table 2. Description of the different management systems adopted

Treatments (T)	Description
T1	Mineral fertilization. 2020/21 season and 2021/22 season: mineral fertilization with application of 250 kg ha^{-1} of single superphosphate (50 kg ha^{-1} of P_2O_5) + 117 kg ha^{-1} of KCl (70 kg ha^{-1} of K_2O).
T2	Mineral fertilization and dolomitic limestone – mineral fertilization with application of 250 kg ha^{-1} of single superphosphate (50 kg ha^{-1} of P_2O_5) + 117 kg ha^{-1} of KCl (70 kg ha^{-1} of K_2O) + dolomitic limestone at dose of 1,600 kg ha^{-1} applied at the beginning of the rainy season of 2020. Limestone with a RNV of 80% was applied to increase the base saturation to 50%.
T3	Soil acidity corrective – dolomitic limestone with 1,600 kg ha^{-1} applied at the beginning of the rainy season of 2020.
T4	Biochar from sugarcane bagasse. 2020/21 season: application of 13,500 kg ha^{-1} of ash from sugarcane bagasse and 78 kg ha^{-1} of KCl. 2021/22 season: application of 10,344 kg ha^{-1} of ash from sugarcane bagasse.
T5	Mineral fertilization and fertilization with biochar from sugarcane bagasse. 2020/21 season: application of 13,500 kg ha^{-1} of ash from sugarcane bagasse + Mineral fertilization containing: 250 kg ha^{-1} of single superphosphate (50 kg ha^{-1} of P_2O_5) + 117 kg ha^{-1} of KCl (70 kg ha^{-1} of K_2O). 2021/22 season: application of 10,344 kg ha^{-1} of ash from sugarcane bagasse + Mineral fertilization containing: 250 kg ha^{-1} of single superphosphate (50 kg ha^{-1} of P_2O_5) + 117 kg ha^{-1} of KCl (70 kg ha^{-1} of K_2O).
T6	Soil acidity corrective and biochar from sugarcane bagasse. 2020/2021 season: application of dolomitic limestone at a dose of 1,600 kg ha^{-1}, application of 13,500 kg ha^{-1} of ash from sugarcane bagasse + 78 kg ha^{-1} of KCl. 2021/2022 season: 10,344 kg ha^{-1} of ash from sugarcane bagasse.
T7	Twice the dose of biochar. Application of 27,000 and 20,688 kg ha^{-1} of ash from sugarcane bagasse, respectively in the 2020/21 and 2021/22 seasons.
T8 (Control)	Absence of application of any form of fertilizer.

assessed until April 2022. All treatments, except the control, received application of 555 kg ha^{-1} of urea split into five portions of 111 kg ha^{-1}. For the recommendation of the biochar used, the moisture content of this residue was disregarded, so that its application was based on dry matter.

The chemical composition of the biochar used is presented in Table 3, and the analyses were carried out according to Teixeira et al. (2017).

In October of each year, a standardization mowing was carried out using a backpack brushcutter, leaving a residual grazing height of 0.15 m, and the residues were removed from the experimental area with a rake. Treatments containing ash, chemical fertilizers and the first dose of urea (except in the control treatment) were applied at the beginning of the rainy season after the standardization mowing. The inputs were distributed manually on the day the experiment was set up. After their application, the cuts began to be performed, using a manual brushcutter, with weekly evaluations, always respecting the entry height of 0.30 m and exit height of 0.15 m for forage grazing. Therefore, the number of cuts between treatments ranged from five to eight, respecting a cutting height of 0.3 m. The experiment lasted a total of 576 days.

Grass dry matter yield was obtained manually, in an area delimited by a rectangular metal sampling unit with the dimensions of 1.0 × 1.0 m (usable area of 1.0 m^2). The sampling unit was positioned in predetermined locations, avoiding the collection of successive samples in the same areas. All the fresh matter harvested was placed in properly identified plastic bags and immediately weighed. Then, a subsample was collected, weighed, placed in an identified paper bag and dried in an oven with air circulation at 65 °C for 72 hours. After drying, the subsamples were weighed again to obtain the dry matter content and then the dry matter yield (kg ha^{-1}).

To determine soil nutrient contents, after 576 days of the experimental area implementation, disturbed samples were collected using a probe-type auger, at 0-0.2 m depth, at the end of the rainy season of 2022, in April, at eight points of each experimental unit, forming one composite sample per plot. The samples were air-dried and sieved through a 2-mm mesh for subsequent determination of organic carbon, T (cation exchange capacity), pH, P, K, Ca, Mg, Al, H+Al, S, Fe, Mn, Cu and Zn contents, according to Teixeira et al. (2017).

The data were subjected to analysis of variance, and treatment means were compared by Tukey test at $p \leq 0.05$. The multivariate technique of canonical variables was applied. Correlation analysis between the variables was also performed. The analyses were performed in the Rbio® program with interface of the R program (Bhering, 2017).

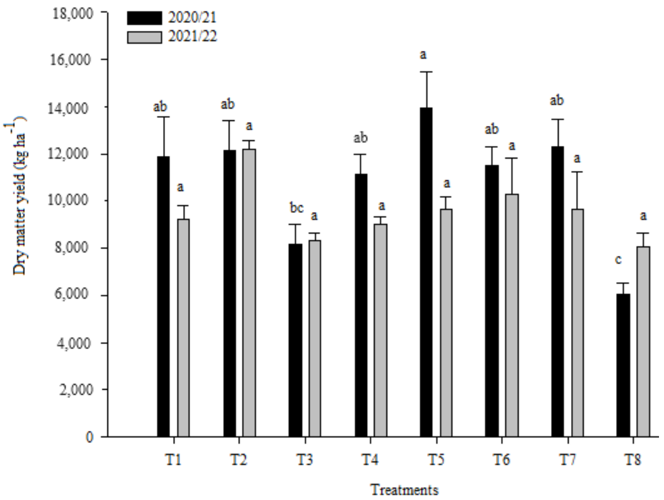
Results and Discussion

Figure 2 shows the *U. decumbens* dry matter (DM) production results, affected only in the 2020/21 season, with values ranging from 6,032.6 to 13,957.4 Mg ha^{-1} per year. No significant difference between treatments was observed for the 2021/22 season.

The dry matter yield of *U. decumbens*, in the year 2020/21, when biochar was associated with mineral fertilizers (T5), was 131% higher than that of the control treatment (T8) and

Table 3. Chemical composition of the biochar used as a fertilizer source in a pasture area under *Brachiaria brizantha cv. Marandu* in the 2020/21 and 2021/2022 seasons

N	P_2O_5	K_2O	Ca	Mg	C-organic	Dry matter	pH	C:N
(g kg^{-1})						%	H_2O	
Biochar used in the 2020/2021 season								
10.5	2.6	3.6	4.8	1.4	56.4	83.5	7.1	5.4:1
Biochar used in the 2021/2022 season								
6.7	6.9	9.9	12.8	2.7	97.2	70.2	6.8	15:1
		Fe	Mn	Cu	Zn	B		
		(mg kg^{-1})						
		441.9	349.5	35.6	90.4	25		



T1 - Mineral fertilization; T2 - Fertilization with limestone plus mineral fertilizer; T3 - Liming; T4 - Biochar; T5 - Biochar plus mineral fertilizer; T6 - Liming plus biochar; T7 - Double fertilization with biochar and T8 - Control. Means followed by the same letter in columns do not differ by the Tukey test ($p \leq 0.05$)

Figure 2. Dry matter yield of *U. decumbens* using ash from the burning of sugarcane bagasse, as source of fertilizer, and conventional mineral fertilizers, fertilizers between the 2020/21 and 2021/22 seasons

50% higher than that of the treatment with only limestone (T3). Treatments T1, T2, T4, T6 and T7 were intermediate between T5 and T3. The control treatment (T8) was inferior to all treatments that used some form of fertilization. This result demonstrates that both the use of mineral fertilizers and the use of biochar from sugarcane bagasse burning were efficient to increase the production of *U. decumbens*. Thus, it is possible to replace conventional fertilizers in the first year of their use.

Similar results were found with *Panicum*, for which the association of biochar from the burning of *Gliricidia sepium* branches and leaves with mineral fertilizers increased yield by 25.5% when compared to the control treatment (Latawiec et al., 2019). For the same species used in our study (*Urochloa* ssp.), the same authors observed that the use of biochar associated with the inoculant *Azospirillum brasilense* increased dry matter yield by 27% compared to the control treatment. In both species (*Urochloa* ssp. and *Panicum* spp.), dry matter yield was influenced only in the first cut, at 68 days after sowing, and the effect did not remain in subsequent cuts.

The enrichment of biochar with mineral fertilizers, such as NPK, leads to an increase in the rate of decomposition of this residue, consequently reducing the stability of biochar decomposition in the soil (Winarso et al., 2020). Therefore, when mineral fertilizers are added to organic residues, they can contribute to the release of nutrients to plants. In this context, the higher dry matter yield of *U. decumbens* in the first year, in the treatment T5, can be explained by the greater release of nutrients, through the stimulation of biochar decomposition, because mineral fertilizers were used together with chemical fertilizers. The use of organic residues can favor crop yield, by supplying nutrients that chemical fertilizers do not provide, as well as promoting better synchronization in the release of nutrients when organic fertilizers are applied along with chemical fertilizers, which may increase the resistance of agronomic systems, offering positive effects when conditions are less favorable (Chen et al., 2018). Positive effects when the use of biochar favors crop yield may be related to increased microbial activity, increased water retention, increased pH, and supply of nutrients (Latawiec et al., 2019; Zhang et al., 2021; Santos et al., 2022).

At 576 days after the beginning of the experiment in the experimental area, except for sulfur (S) content, the other chemical attributes of the soil were not influenced by different forms of management for the restoration of *U. decumbens* (Tables 4 and 5).

The S contents in the T1 treatment were approximately 30% higher than those found in T7, T3 and T4. The S contents in the soil in the treatments T2, T6 and T8 were intermediate between those of T1 and T7, T3 and T4. The higher S contents observed in the T1 treatment may be related to the use of single superphosphate as a source of fertilizer for P supply, which also contains 12% sulfur.

In a study evaluating the dry matter yield of *Urochloa* ssp. and *Panicum* spp., using mineral fertilizers and biochar produced from *Gliricidia sepium* residues, it was observed that the use of 15 tons of biochar increased soil pH and the contents of the nutrients P, K, Ca and Mg (Latawiec et al., 2019). These results differ from the ones found in this study, where the use of biochar caused an increase in the dry matter yield of *U. decumbens*, only when associated with mineral fertilizers, with no differences in the chemical attributes of the soil, except for sulfur (S). The use of biochar is able to increase the contents of cations in the soil such as Ca, Mg and K, consequently increasing base saturation (Zhang et al., 2021). For the same soil class (*Quartzipsamment*) evaluated in this study, Bezerra et al. (2022) evaluated the addition of 12.5 Mg ha^{-1} of biochar produced from cashew branches and observed increase in

Table 4. Soil chemical attributes after 576 days, under different fertilization strategies in the area under *U. decumbens*, using biochar from the burning of sugarcane bagasse and conventional mineral fertilizers

Treatments	pH	OM (g dm^{-3})	P (mg dm^{-3})	K (mg dm^{-3})	S (mg dm^{-3})	Ca (cmol$_c$ dm^{-3})	Mg (cmol$_c$ dm^{-3})	T (cmol$_c$ dm^{-3})	V (%)
T1	5.1 a	16.5 a	7.1 a	12.5 a	6.1 a	2.1 a	0.4 a	5.0 a	48.6 a
T2	5.2 a	15.3 a	7.3 a	25.0 a	5.1 ab	2.2 a	0.4 a	5.0 a	52.1 a
T3	5.3 a	16.8 a	2.7 a	13.5 a	4.7 b	2.3 a	0.5 a	5.0 a	57.0 a
T4	5.4 a	17.1 a	4.6 a	27.5 a	4.7 b	2.4 a	0.5 a	4.8 a	58.0 a
T5	5.4 a	15.4 a	5.5 a	27.5 a	5.0 ab	2.1 a	0.5 a	4.8 a	55.5 a
T6	5.2 a	17.0 a	6.8 a	25.0 a	5.1 ab	2.4 a	0.4 a	5.0 a	56.4 a
T7	5.4 a	14.6 a	8.1 a	32.5 a	4.7 b	2.3 a	0.5 a	5.1 a	56.0 a
T8	5.3 a	16.9 a	3.4 a	23.3 a	5.7 ab	2.3 a	0.4 a	5.1 a	53.8 a

Means followed by the same letter in the columns do not differ by Tukey test ($p \leq 0.05$). OM - Organic matter; P - Phosphorus; K - Potassium; S - Sulphur; Ca - Calcium; Mg - Magnesium; T - Total cation exchange capacity; V - Base saturation; T1 - Mineral fertilization; T2 - Fertilization with limestone plus mineral fertilizer; T3 - Liming; T4 - Biochar; T5 - Biochar plus mineral fertilizer; T6 - Liming plus biochar; T7 - Double fertilization with biochar and T8 - Control

Table 5. Contents of iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn) after 28 months, under different fertilization strategies in area under *U. decumbens*, using ash from the burning of sugarcane bagasse and conventional mineral fertilizers

Treatments	Fe	Mn	Cu	Zn
	(mg dm^{-3})			
T1	119 a	8.5 a	0.47 a	0.80 a
T2	115 a	9.4 a	0.36 a	0.82 a
T3	118 a	9.6 a	0.36 a	1.20 a
T4	112 a	9.7 a	0.41 a	0.81 a
T5	123 a	9.2 a	0.36 a	0.83 a
T6	129 a	8.0 a	0.32 a	1.20 a
T7	125 a	8.8 a	0.44 a	1.10 a
T8	116 a	9.7 a	0.40 a	0.87 a

Means followed by the same letter in the columns do not differ by Tukey test ($p \leq 0.05$). T1 - Mineral fertilization; T2 - Fertilization with limestone plus mineral fertilizer; T3 - Liming; T4 - Biochar; T5 - Biochar plus mineral fertilizer; T6 - Liming plus biochar; T7 - Double fertilization with biochar and T8 - Control

forage sorghum panicle mass, soil pH, and Ca and P contents, results that differ from those found in this study.

On the other hand, even after the accumulated application in the two years of experiment in the area with 47.68 Mg ha^{-1} of biochar, the contents of macro and micronutrients in the soil did not change, except for S. The non-significance of nutrient contents between treatments after 28 months of experiment in the area may be related to the low rate of mineralization of biochar, as described by Bruun & El-Zehery (2015). The mean residence time (MRT) of biochar in the soil is 108 days for labile fractions and 556 years for recalcitrant fractions, and biochars are composed of 3% of labile fractions and 97% of recalcitrant fractions (Wang et al., 2016). Therefore, even after applications of large amounts in the treatment T7, the release of nutrients is only 3% of the total biochar. Another factor that may have contributed to the absence of difference between the treatments is that the material used in the biochar comes from a grass. Biochars from grasses, as reported by Wang et al. (2016), have an average decomposition rate of 0.007% per day, and the average decomposition of annual crops is 0.025% per day, thus supplying low amounts of nutrients to the soil and plants.

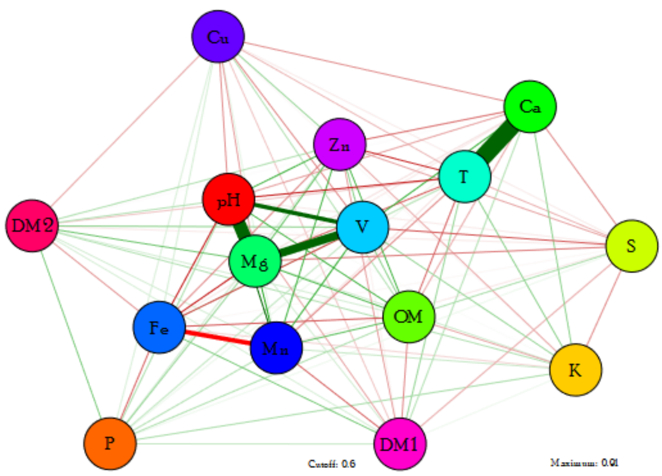
The increase in soil pH, resulting from the application of biochar, may be related to the pyrolysis process, which involves the decomposition of acidic groups of the residues that are volatilized during burning (Zhang et al., 2021). The absence of statistical difference in the soil nutrient contents as a function of the treatments adopted possibly occurred because the amount of biochar used and the mineral fertilizers were recommended based on equivalent amounts of nutrients present in the treatments adopted.

As for the organic matter content, no influence was observed when the ash was added. Organic matter (OM) contents were not influenced by the addition of ash (Table 3). In the study conducted by Li et al. (2021) with biochar produced from rice husk, the increase in the proportion, relative to the mass of soil, increased the organic carbon contents, differing from the results found here. In this study, as the soil is sandy, with 56 g kg^{-1} of clay, the physical and chemical protection of carbon for the formation of organo-mineral complexes is a limited process. Above all, the accumulation of carbon in sandy soils, even after a period of two years of experiment in the area, is a complex process, especially in the case of a tropical region that has high temperature associated with constant humidity, as found during the monitoring in this study. Despite the low mineralization of biochar, the positive effect is its persistence in the soil on a hundred-year scale. Thus, its recalcitrance may play an important role in the carbon sequestration to the soil (Wang et al., 2016). In a study evaluating the effect of biochar from barley straw burning after 451 days, it was observed that only 1.8 to 1.9% of the carbon contained in the biochar was mineralized. As for the carbon from the organic matter of the non-incubated soil, there was decomposition of 6.6% (Bruun & El-Zehery, 2015). Therefore, increments in carbon contents with the use of biochar are complex, especially in soils with low clay contents.

A network of comparisons was created using Pearson's correlation to visualize all the characteristics measured in this study simultaneously (Figure 3). Positive correlations were expressed by green lines, negative correlations were expressed by red lines, and the intensity of the correlation is proportional to the thickness of the lines.

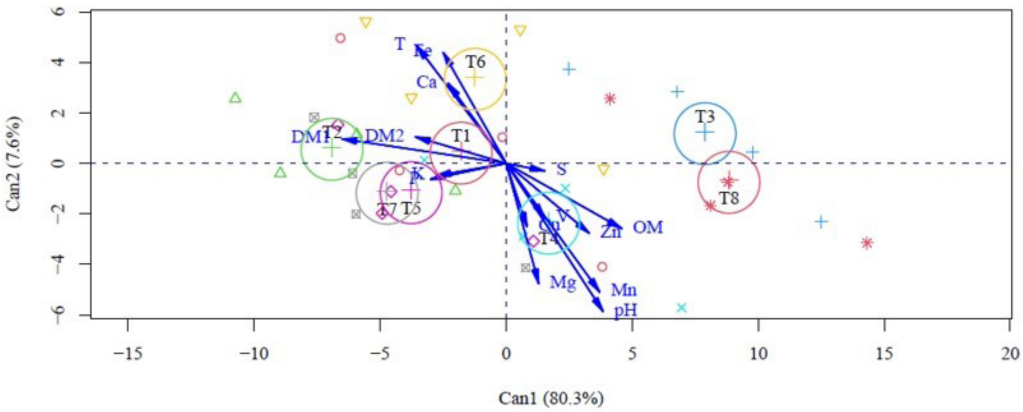
There are groups of positive values, showing a high correlation between the variables analyzed (Figure 3). A high positive correlation was observed between calcium (Ca) and cation exchange capacity (T), indicating that the higher the Ca contents, the higher the T value. Similarly, a positive correlation was found between pH, magnesium (Mg) and base saturation (V%), indicating that the higher the Mg contents and the higher the V%, the higher the pH values, which may be related to the presence of Ca and Mg in the residue used. The negative correlation between pH and iron (Fe) indicates that the increase in pH leads to lower Fe contents. Fe content was negatively correlated with Mg and manganese (Mn), indicating that higher Fe values resulted in lower Mg and Mn contents.

To assess the contribution of each variable, analyses of canonical variables were performed (Figure 4). This method



T1 - Mineral fertilization; T2 - Fertilization with limestone plus mineral fertilizer; T3 - Liming; T4 - Biochar; T5 - Biochar plus mineral fertilizer; T6 - Liming plus biochar; T7 - Double fertilization with biochar and T8 - Control

Figure 3. Correlation between the variables pH, phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), soil organic matter (OM), cation exchange capacity (T), iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn), and dry matter yield in the first year (DM1) and second year (DM2), after the use of ash from the burning of sugarcane bagasse as a fertilizer source between the 2020/21 and 2021/22 seasons



T1 - Mineral fertilization; T2 - Fertilization with limestone plus mineral fertilizer; T3 - Liming; T4 - Biochar; T5 - Biochar plus mineral fertilizer; T6 - Liming plus biochar; T7 - Double fertilization with biochar and T8 - Control

Figure 4. Analysis of canonical variables of pH, phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), soil organic matter (OM), cation exchange capacity (T), iron (Fe), manganese (Mn), copper (Cu) and zinc (Zn), and dry matter yield in the first year (DM1) and second year (DM2) as a function of the treatments

is similar to the principal component analysis; however, it should be used when the study is composed of an experimental design with replications (Baio et al., 2018). The accumulation of variances in the first two variables corresponded to 88%, being higher than the recommended one, which is at least 80%.

The eigenvectors plotted in Figure 4 show that the dry matter yields of the 2020/21 and 2021/22 seasons were close. The treatments T5 and T7 were close to P and K contents. The treatments T6 and T1 were close to each other and close to Ca, Fe and T contents. The treatment T4 was close to Cu, Mg and V% contents. The treatments T3 and T8 were close to each other.

Conclusions

1. Effects of biochar application on *U. decumbens* dry matter yield were limited only to the first year of cultivation.

2. Association of mineral fertilizer and biochar was able to increase dry matter yield by up to 131% when compared to the control treatment during the first year.

3. Association of biochar with mineral fertilizer in degraded pasture area during the first year becomes a promising alternative to improve dry matter yield.

4. Management strategies to restore degraded pasture of *U. decumbens* do not affect soil chemical attributes, except for sulfur.

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