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EFFECT OF BIOCHAR ON THE AGRONOMIC AND ENVIRONMENTAL PROPERTIES OF BOKASHI AND COMPOST

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Abstract: It is essential to incorporate organic amendments such as compost and bokashi in sustainable agricultural systems at the farm level. However, the potential benefits of using biochar as an additive in bokashi have not been previously studied. Therefore, this research aimed to explore the effects of biochar on the agronomic and environmental aspects of bokashi and compost production. To achieve this, a field experiment was conducted, comparing bokashi and compost piles with and without biochar. During the maturation process, various parameters including temperature, chemical composition, and biological changes were monitored. The findings demonstrated that the inclusion of biochar in both types of amendments helped regulate the maximum temperatures reached during the process. Moreover, bokashi and compost piles with biochar exhibited higher pH levels and lower CO_2 emissions during maturation; and bokashi with biochar showed increased forage productivity. In conclusion, the use of biochar had a positive impact on the maturation process and overall quality of bokashi and compost. This has significant advantages for agriculture and organic waste management, as it enhances performance for crops and offers practical applications.
Keywords: nutrients, CO_2 emissions, N cycle, organic waste, organic amendments.

INTRODUCTION

In today's agriculture, there is a need to increase productivity to meet the global demand for food. In response to these challenges, various initiatives have been proposed to promote sustainable agricultural systems. Implementing good practices is crucial for achieving sustainable agricultural systems. For instance, effective management of soil fertility is essential to improve its physical, chemical, and biological properties. Currently, the application of different residues stabilized by biological or other methods help to increase the quality of soil (Medina et al., 2015).

An alternative use of agricultural waste is the production of Bokashi, a stabilized product with high organic matter and nutrient content, porosity, and water retention capacity, has gained attention as a promising alternative to compost due to its ability to introduce beneficial microorganisms that improve soil health and properties (Quiroz y Céspedes 2019). The compost, on the other hand, is an organic material produced through the recycling of organic waste. It serves as a natural fertilizer due to microbial activity and offers benefits such as improving soil structure and enhancing crop development. Compost is a cost-effective option that utilizes organic waste and different additives (Chen et al., 2023). Additionaly, the biochar production is another alternative to re-utilizate the residues, that involves thermally stabilizing organic materials rich in carbon. Biochar has favorable physical, chemical, and biological properties, including high porosity and surface area, cation exchange capacity, water retention capacity, and improved nutrient availability, leading to increased crop production (Muñoz et al., 2019; Ginebra et al., 2022).

Considering the limited scientific research available on the maturation process and characterization of Bokashi, this research aims to provide scientific information on the maturation process of stabilized materials such as compost and Bokashi, with the addition of biochar as a technological innovation. The objective is to evaluate the impact of biochar on agronomic and environmental parameters in the production of Bokashi and compost.

MATERIALS AND METHODS

EXPERIMENTAL FIELD

This research was carried out in a rural area in Los Avellanos farm (36º42'38.2"S latitude and 71º50'19.5"W longitude), located at Central-South of Chile, with Mediterranean climate.

COLLECTION OF RAW MATERIALS

Sheep manure was collected in the farm's barn and stored in solid form. The biochar was previously produced in a pyrolysis oven type Kon-Tiki (Schmidt and Taylor, 2014) using cherry pruning wastes. Pyrolysis was carried out reaching a maximum temperature of approximately 500°C and a material with the following chemical characterization was obtained: pH 10.34, electrical conductivity 2.73 dS m^{-1}, organic C 81.1%, total N 1.48 %, P available 0.1% and K available 0.79%.

PREPARATION OF BOKASHI

In the preparation of bokashi, the inputs indicated in Table 1 were incorporated. The inoculum solution was prepared in a 200 L container that contained: 20 L of microorganism inoculum with phosphorus-solubilizing bacteria (obtained from ponds with anaerobic fermentation), 10 L of cow's milk whey, 4 L of molasses, 250 g of yeast and water to complete 200 L. All the previously mentioned inputs were acquired through purchase except the microorganism inoculum that was prepared on the anaerobic ponds enabled for this purpose.

Supplies	Amount (Kg)
Sheep manure	300 (38.7%)
Substrate*	300 (38.7%)
Biochar**	50 (6.5%)
Wheat bran	125 (16.1%)
Yeast	0,25 kg (0.03%)
Microbial innoculum***	20 L
Serum	10 L
Molasses	4 L
Water	170 L

Table 1. Supplies for the production of bokashi.

* Mature bokashi; ** Used only in treatments B+BC; *** phosphorus-solubilizing bacteria.

In the field, two bokashi piles were set up with identical elements and proportions as specified for their implementation. The only distinction between the two piles was the presence or absence of biochar during preparation. The solid materials (refer to Table 1) were thoroughly mixed using a tractor with a shovel, while the liquid supplies were first mixed in a jar before being applied and mixed with the solid materials. Subsequently, a generous amount of water was added to initiate microbiological activity.

Temperature was observed over a period of 18 consecutive days. Whenever the temperature reached 50 ºC, the bokashi piles were rotated using a tractor to lower their temperature. Throughout this time, samples were collected every other day in order to conduct chemical and biological analysis in the laboratory.

COMPOST PRODUCTION

The production of compost involved the implementation of two compost piles in the field. Both piles consisted of the same elements and proportions as indicated in Table 2, with one pile containing biochar and the other without. The materials were layered vertically in the compost piles. After evenly applying water to initiate microbial activity, the temperature was monitored. Once the temperature of the piles dropped below 50 ºC, mechanical action was used to turn each pile and facilitate microbial processes.

Supplies	Amounts (Kg)
Sheep manure	90 (32.7%)
Fresh residues (leaves and steams of vegetables)	90 (32.7%)
Cereal straw	75 (27.2%)
Biochar*	16.5 (6.0%)

Table 2. Supplies for the production of compost.

* Only was used in the treatment C + BC

To replicate the variations in substrate maturation due to climatic differences, two sets of experiments were conducted for both assays. The first set took place in the spring season (November 2021), while the second set was carried out in the autumn season (March 2022). Each set consisted of two repetitions.

The treatments included Bokashi (B), Bokashi with biochar (B+BC), Compost (C), and Compost with biochar (C+BC).

TEMPERATURE

Temperature measurements were taken during the maturation period of 18 days for both the bokashi and compost piles in both the spring and autumn stages. A thermometer (Generic brand, model 5AC402539, 40 cm long) was used to periodically record temperatures. The measurements were taken from the four cardinal points (north, south, east, and west exposures) of each pile to ensure a representative sample. It is important to note that the temperatures were taken simultaneously to ensure similar environmental conditions throughout the duration of the experiment.

CHEMICAL CHARACTERIZATION

Samples were extracted from each pile of bokashi on days 2, 4, 6, 8, 10, 12, 14, 16 and 18 and in the case of compost, sampling was carried out at the end of four months of maturation for subsequent chemical analysis at the Soil Analysis Laboratory of the University of Concepción.

The pH, electrical conductivity, nitrates and ammonium, available phosphorus, available calcium and magnesium were evaluated, according to the standardized methodology for compost (Sadzawka et al., 2005). The carbon and total nitrogen content was determined by dry combustion in a CN elemental analyzer (LECO, TruSpec CN, USA) with which the carbon/nitrogen ratio of the residue was obtained.

CO_2 EMISSION ANALYSIS

To assess environmental conditions, a respirometry test was conducted in a controlled laboratory setting, where temperature and humidity were regulated. The samples were incubated in a chamber at a consistent temperature of 22 ºC and humidity levels. The CO_2 emissions were then analyzed using infrared spectroscopy, specifically the Licor model 820. To determine the CO_2 emissions resulting from the use of bokashi, samples were incubated every other day for 18 days. As for the compost, the sample was evaluated at the end of the maturation period, which lasted for 4 months.

PRODUCTIVITY DETERMINATION

The perennial forage species *Lolium perenne* L. of the Nui cultivar was used for this essay. A substrate of 600 grams of a pre-washed sand mixture was used, along with perlite (amorphous aluminum sodium potassium silicate) to enhance moisture retention capacity. The sand and perlite were mixed in a ratio of 2:1 v/v, respectively. The amendments (B, B+BC, C, and C+BC) were added to the sand-perlite mixture at a rate of 2% (w/w) or 12 g per pot, and the mixture was homogenized. A seed weight of 1 g per pot (equivalent to 25 kg ha^{-1}) was sown, with a germination rate of 94%. The pots were placed in a growth chamber (Biobase TCL, model BJPX-L450) with a constant temperature of 18-22°C and a day-night light variation of 14 h day and 10 h night. The pots were randomly rotated every 3 days within the chamber. Periodic watering of 20 mL of distilled water (pH 6) was done every 3 days.

STATISTICAL ANALYSIS

Two independent assays were considered. The normality was evaluated with the Shapiro-Wilks test, and the results were subjected to parametric tests of comparison of means for independent data, using T-Student and LSD Fisher tests with the statistical software INFOSTAT, version 2018.

RESULTS AND DISCUSSION

TEMPERATURE ANALYSIS

In the bokashi prepared during the spring season (Figure 1A), there was an initial increase in temperature in the first 13 days. The temperature fluctuated between 25°C and 59°C for treatment B, while treatment B + BC had a slightly lower temperature ranging from 2 to 5°C. After day 13, both treatments experienced a significant decrease in temperature and stabilized at 42-44°C without any significant differences. n various ecosystems, the maximum temperature suitable for heterotrophic microorganisms plays a crucial role. According to a study conducted by Simbolon et al. (2023), the highest cellulolytic activity was observed at 40°C for both actinobacteria and heterotrophic bacteria isolates. This suggests that temperatures exceeding this level may not be favorable for their activity. Additionally, Strom (1985) found that a temperature threshold of approximately 60°C leads to a significant reduction in bacterial species diversity during thermophilic solid-waste composting. To ensure microbial activity, we consider 50°C as the maximum temperature. Notably, in treatment B, temperatures above 50°C were more frequent (8 times) compared to treatment B+BC (6 times).

Throughout the autumn season (Figure 1B), there was a consistent rise in temperatures from the start of establishment to the 13th day of maturation. In the control group (B), temperatures ranged between 24 °C and 58 °C, while in the treatment group with biochar (B + BC), temperatures ranged between 23 °C and 53 °C. However, the temperatures in the control group (B) were slightly higher, with a difference of 2 – 7 °C compared to the treatment group (B + BC). It is worth noting that the control group had eight instances where the temperature reached or exceeded 50°C, whereas the treatment group (B + BC) only had four instances. This observation is significant as excessively high temperatures can have a detrimental effect on microbial activity.

During the spring compost maturation process (Figure 2A), the compost piles experienced a significant temperature increase in the initial four days after being prepared, with both treatments starting at 26 °C. In this initial phase, treatment C+BC reached its peak temperature at 63 °C, while treatment C reached a maximum of 65 °C.

Between day 5 and day 10, the temperature gradually decreased in both treatments, reaching 43 °C in treatment C+BC and 48 °C in treatment C. However, there was a slight increase in temperature between day 10 and day 12, with treatment C+BC reaching 53 °C and treatment C reaching 57 °C.

Finally, from day 13 to day 18, the

temperature declined to 43 ºC in treatment C+BC and 47 ºC in treatment C.

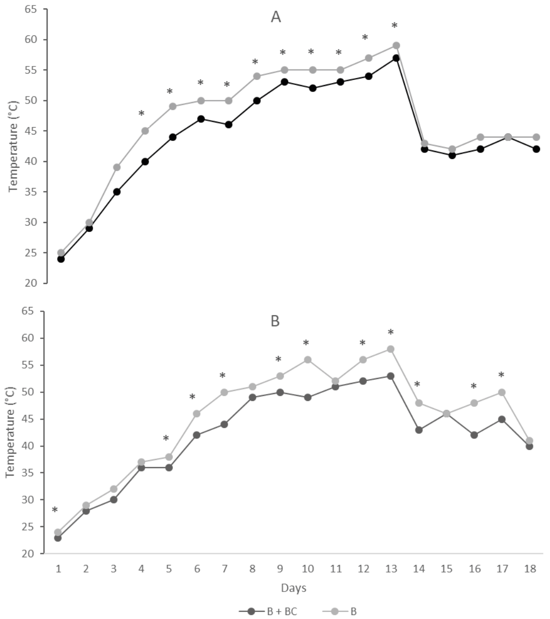


Figure 1. Recorded temperatures during the bokashi maturation process. A) spring, B) autumn. Statistical differences were observed between the treatments on each day of evaluation, as indicated by the asterisk (*).

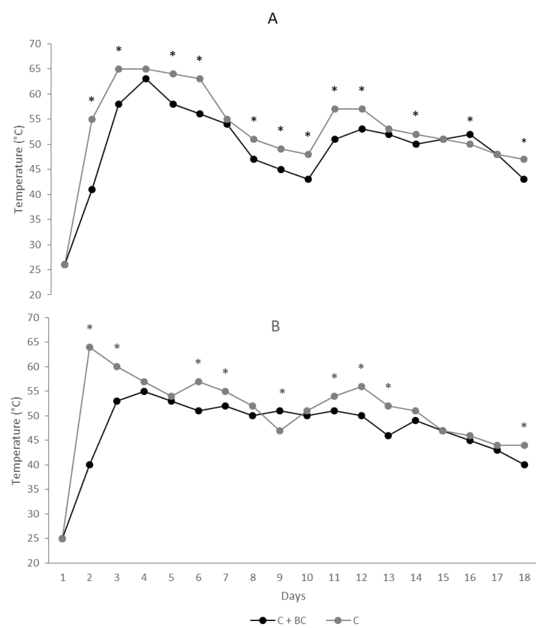


Figure 2. Recorded temperatures during the composting maturation process. A) spring, B) autumn. Statistical differences were observed between the treatments on each day of evaluation, as indicated by the asterisk (*).

Significant differences in temperature variations of the compost piles were observed on days 2, 3, 5, 6, 8, 9, 10, 11, 12, 14, 16, and 18. The statistical analysis revealed that treatment C had higher temperatures compared to treatment C+BC, with a temperature difference ranging from 1 to 7 °C.

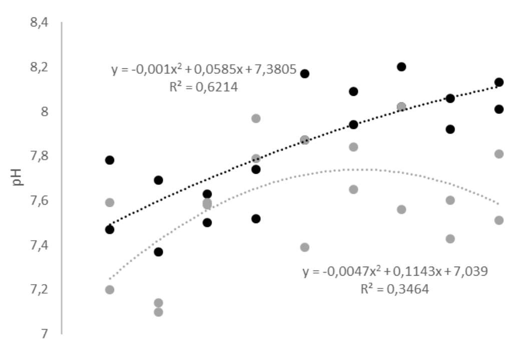
Furthermore, when considering a maximum limit of 50 ºC, it was found that treatment C had a higher frequency of temperatures exceeding this threshold compared to treatment C+BC. On the other hand, treatment C+BC was able to maintain the temperature of the pile at more moderate levels.

In the case of the compost piles prepared during the autumn stage (Figure 2B), the control treatment reached its peak temperature of 64 ºC on day 2. However, treatment C + BC did not reach its maximum temperature until day 4 of maturation, with a peak temperature of 55 ºC. Following its peak temperature, treatment C experienced fluctuations in temperature until day 12, ranging between 64 ºC and 56 ºC, before gradually decreasing to 44 ºC by day 18. On the other hand, treatment C + BC showed a gradual decrease in temperature, with a lower temperature of 41 ºC reached by day 18. The temperature variations between the compost piles in treatments were statistically different on days 2, 3, 6, 7, 9, 11, 12, 13, and 18. Specifically, treatment C recorded higher temperatures, showing a difference of 1 – 24 °C compared to treatment C+BC.

When considering an upper limit of 50 ºC, it was observed that treatment C had a frequency of temperatures exceeding this threshold 12 times higher than treatment C+BC. In contrast, treatment C+BC managed to maintain the temperature of the compost pile at more moderate levels.

NUTRITION PARAMETERS

Regarding the different chemical parameters obtained from the assay in different seasons, no differences were obtained in pH, electric conductivity, P, Ca and Mg available. For pH and electric conductivity were obtained difference between treatments (Figure 2). At the end of the evaluated period, the pH of the bokashi was 7.7 to B and 8.1 to B+BC. The electric conductivity was higher in treatment with BC (2.5 DS cm^{-1}) compared without biochar (B=1.5 DS cm^{-1}), but is necessary to consider that in NCh2880 for compost or similar materials the maximum allowed is 3 DS cm^{-1}. No significant differences were observed in the pH, electric conductivity, available P, Ca, and Mg levels between the different seasons. However, there were variations in pH and electric conductivity among the different treatments (Figure 2). The pH of the bokashi was found to be 7.7 for treatment B and 8.1 for treatment B+BC at the end of the evaluation period. The electric conductivity was higher in the treatment with biochar (2.5 DS cm^{-1}) compared to the treatment without biochar (B=1.5 DS cm^{-1}). It should be noted that the maximum allowed electric conductivity for compost or similar materials, according to NCh2880 (INN, 2015), is 3 DS cm^{-1}. There were no significant differences in the availability of nutrients such as P, Ca, and Mg between the treatments, with average levels of 0.3%, 0.5%, and 0.3% respectively at the end of the evaluation period (Tables 3 and 4).



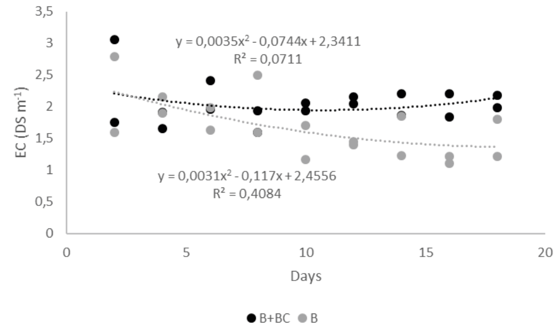


Figure 2. Variation in pH and electric conductivity during the bokashi maturation process.

In our research, biochar has not been shown to have a significant effect on nutritional parameters (Tables 3 and 4) of bokashi and compost produced (Table 5); not allowing demonstration of the ability of biochar to retain nutrients produced during the maturation process. The pH in all cases was higher than the level allowed by NCh2880 for compost. This probable is due pH initial of the mixture of feedstock used.

However, several studies have provided scientific evidence of biochar's ability to retain nutrients on its surface during composting. For instance, Joseph et al. (2018) demonstrated that during composting, dissolved nutrients are absorbed into the pores of biochar, leading to the formation of a nutrient-rich organo-mineral layer. This process results in the retention and release of nutrients, which contributes to improving the nutrient content in the compost. Additionally, Jílková (2023) conducted a microcosm experiment and observed that biochar affected nutrient availability and retention in agricultural soil, demonstrating the potential of biochar to retain nutrients during composting. Furthermore, Sánchez-Monedero et al. (2019) reported that the application of a mixture of biochar and compost benefited crops, indicating the nutrient retention capacity of biochar during composting.

Days	Total N (%)	$N\text{-}NH_4^+$ (mg kg^{-1})	P av. (%)	Ca av. (%)	Mg av.(%)	Humidity (%)
2	0.96	272.3	0.35	0.48	0.24	52.4
4	0.93	447.1	0.37	0.47	0.25	47.5
6	1.00	638.0	0.31	0.44	0.26	42.7
8	1.01	814.6	0.33	0.45	0.24	43.6
10	0.95	730.9	0.33	0.44	0.23	38.2
12	0.89	917.4	0.35	0.45	0.24	34.3
14	0.90	940.8	0.35	0.47	0.23	35.3
16	0.91	671.7	0.31	0.44	0.26	35.2
18	0.92	859.3	0.33	0.47	0.26	35.6

Table 3. Chemical composition in bokashi (B) during the maturation process.

Av. = available

Days	Total N (%)	$N\text{-}NH_4^+$ (mg kg^{-1})	P av. (%)	Ca av. (%)	Mg av.(%)	Humidity (%)
2	0.91	375.9	0.41	0.60	0.29	47.6
4	0.88	555.8	0.35	0.50	0.24	44.7
6	1.12	453.7	0.35	0.44	0.24	43.1
8	0.99	667.0	0.33	0.41	0.25	45.2
10	0.96	800.7	0.35	0.54	0.27	41.1
12	0.94	828.6	0.37	0.54	0.28	38.2
14	1.00	856.2	0.37	0.54	0.28	39.4
16	0.97	809.5	0.37	0.53	0.28	40.1
18	1.01	802.6	0.37	0.55	0.29	38.3

Table 4. Chemical composition in bokashi with biochar (B+BC) during the maturation process.

Av. = available

Parameters	Units	Reference Range NCh2880*	C	C + BC
pH	--	5.0 - 7.5	8.04	8.01
Cond. Eléctrica	dS m^{-1}	< 3	1.45	1.73
M O	%	> 20	31.19	33.63
Nitrógeno Total	%	≥ 0.5	1.03	1.18
Ratio C/N	--	≤ 30	17.57	16.53
$N\text{-}NO_3$	mg kg^{-1}	--	163.6	368.8
$N\text{-}NH_4$	mg kg^{-1}	< 500	85.4	62.4
P available	%	≤ 0.1	0.87	0.52
K available	%	--	1.30	1.05
Ca available	%	--	2.35	1.8
Mg available	%	--	0.55	0.50
Humidity	%	30 - 45	44.5	41.3

Table 5. Chemical characterization of compost after 4 months of maturation.

* Source: INN (2015)

TOTAL C

For the total C concentration in bokashi produced in autumn (Figure 3) and compost (Table 5), no differences were found with the addition of biochar in 6% in a pile of compost. Probably, the applicate doses might be higher to produce relevant differences. However, in the case of bokashi produced in the spring season, it was possible to observe the difference between treatments; with a difference of 0.95% of total C in the organic substrate. This is related to the contribution from the structural C contained in the biochar, having 81.1% total C highly stable and recalcitrant, which reduces its decomposition compared to the decomposition of organic components present in fresh organic matter or stabilized as a microbial process as hummus. This increase benefits the quality of the amendment when is used in soils with low organic matter content.

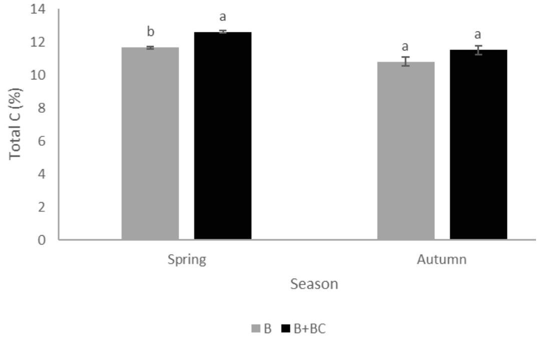


Figure 3. Total carbon (%) in bokashi at the end of the maturation period. Bars showed standard error. LSD Fisher Test ($p \leq 0.05$).

MICROBIAL RESPIRATION

During the period (Figure 4), variations in microbial respiration were observed, with no notable differences between treatments in the spring season. However, in the fall season, the respiration rate was higher in bokashi without biochar (B) at 274.7 mg CO_2 kg^{-1} h^{-1}, while the addition of biochar reduced this value by 15%. This contrast is depicted in Figure 5, which illustrates that bokashi with biochar (B + BC) initially produces less CO_2 compared to bokashi alone. Interestingly, a peak in CO_2 production is observed at day 10 of the maturation process, after which it gradually decreases. In contrast, bokashi without biochar exhibits a high CO_2 production from days 4 to 14 of incubation, displaying a different pattern of behavior.

In the case of compost microbial respiration (Figure 6), there were no significant differences in the CO_2 emission rate among the treatments. However, it is important to note that the sample was only taken once at the end of the 4-month maturation process when the material had stabilized in terms of chemical properties (Table 3).

In terms of the CO_2 emission rate in the compost trials, treatment C+BC showed a lower rate of 23 mg kg^{-1} h^{-1}, while treatment C had a higher rate of 35 mg kg^{-1} h^{-1}. The presence of biochar in treatment C+BC is believed to contribute to the decrease in the CO_2 emission rate compared to treatment C. This could be due to biochar's ability to retain carbon and reduce microbial decomposition. Aboagye et al. (2022) found that the addition of rice husk biochar to compost helped stabilize carbon by forming organic complexes. Similarly, Barthod et al. (2016) suggest that the adsorption of organic components onto the biochar's surface could be responsible. On the other hand, a different study by Jia et al. (2016) showed that the addition of biochar accelerated the composting process, leading to increased CO_2 emissions.

For instance, Gao et al. (2023) demonstrated that biochar co-compost improved nitrogen retention and reduced carbon emissions in a winter wheat cropping system, indicating the potential of biochar to influence the carbon dynamics of the substrate. However, Biederman and Harpole (2012) conducted a meta-analysis on the effects of biochar on plant productivity and nutrient cycling, highlighting the variable effects of biochar and the need for further research to justify its widespread application. Additionally, Dařenová et al. (2022) investigated the response of soil CO_2 efflux to the combined application of adaptation technologies, nitrogen fertilization, and external carbon amendment in wheat and barley fields, emphasizing the potential negative environmental impact of agricultural practices and the need for sustainable soil management strategies.

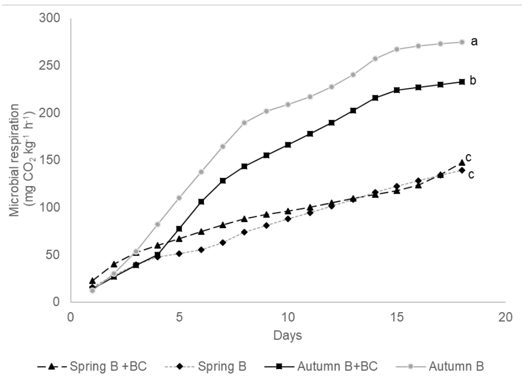


Figure 4. Microbial respiration accumulated from bokashi during the period evaluated. Different letters indicate statistical differences between treatments at the end of the period. LSD Fisher Test ($p \leq 0.05$).

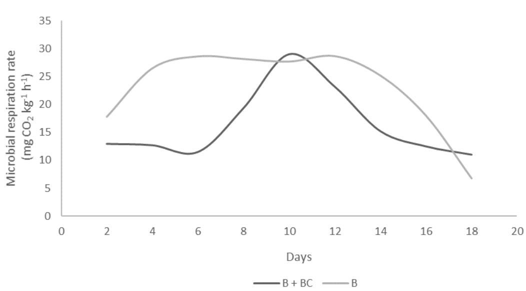


Figure 5. Microbial respiration rate of bokashi produced in the autumn season.

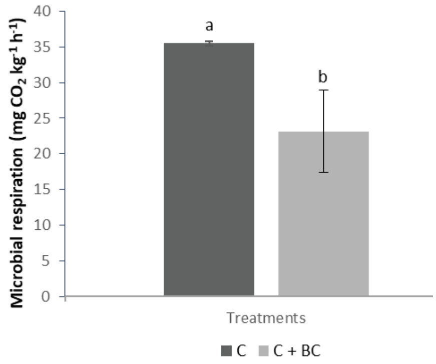


Figure 6. Microbial respiration in compost without (C) and with biochar (C + BC). Bars show standard deviation.

PRODUCTIVITY USING THE ORGANIC AMENDMENTS

The different treatments (Figure 7) showed notable variations in forage productivity. In comparison to the other treatments (B, C, and C+BC), the treatment B + BC resulted in a 37% higher yield. All treatments performed better than the control, which only used an inert substrate. This suggests that the addition of a 2% p/p dose enhances the nutrient content of the substrate. Despite the similar nutritional content of the amendments, the combination of bokashi with biochar increased forage production. This could be due to the release of nutrients from the biochar surface facilitated by organic substances from the roots. Similarly, Gao et al., (2023) indicate that the addition of biochar to compost led to an increase in the overall biomass of winter wheat, ultimately resulting in a reduction in nutrient leaching.

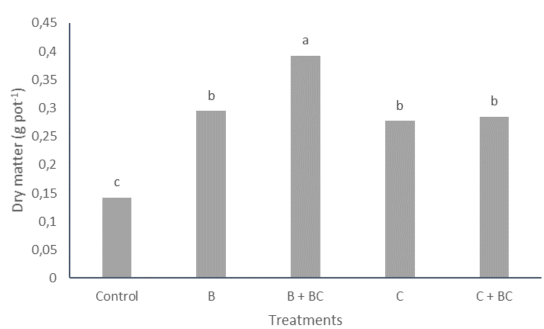


Figure 7. Productivity of *Lolium perenne* cv Nui using different organic amendments.

CONCLUSIONS

Introducing biochar into the production of bokashi and compost has a positive impact on both agronomic and environmental aspects. This can be seen in the lower temperatures observed during the maturation phase of the piles. Furthermore, the inclusion of biochar results in significant alterations in pH levels and electric conductivity. Moreover, the addition of biochar aids in reducing the release of CO_2 during the maturation and stabilization of compost and bokashi. A controlled study demonstrated that bokashi containing biochar increased forage productivity.

Based on these discoveries, integrating biochar into the production process of bokashi and compost offers multiple advantages for agriculture, the environment, and waste management. This approach is practical and enhances the agronomic performance for cultivating forage.

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