Turkish Journal of Agriculture - Food Science and Technology, 12(6): 978-983, 2024
DOI: https://doi.org/10.24925/turjaf.v12i6.978-983.6741

Turkish Journal of Agriculture - Food Science and Technology

Available online, ISSN: 2148-127X | www.agrifoodscience.com | Turkish Science and Technology Publishing (TURSTEP)

Can Biochar Made from Rice Husk Affect Savanna Soils' pH, Electrical Conductivity, and Soil Respiration?

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A R T I C L E I N F O

Research Article

Received : 27.02.2024
Accepted : 25.04.2024

Keywords:
Rice husk biochar
pH
CO_2 evolution
EC
Biochar rates

A B S T R A C T

Biochar is now gaining awareness as a sustainable tool for soil health improvement, boosting carbon (C) storage and the enhancement of nutrient cycling in agricultural soils. This study assesses the effects of biochar on soil respiration, pH, and electrical conductivity (EC) in savanna soils over a 45-day incubation trail in the laboratory. Four different biochar treatments (0, 2, 4, and 6 t/ha) were used in the study. The treatments were established at 26°C, and after 2, 5, and 10 days, the CO_2 levels were recorded. After incubation for 0, 5, 10, and 45 days, the EC and pH were assessed. As the rate of application of biochar increased, the rate of CO_2 evolution increased as well. During the first two days of incubation, the CO_2 evolution rate rose by a value of 129 at 2 t/ha biochar, 146 at 4 t/ha biochar, and 168 ug CO_2/g soil/d at 6 t/ha biochar above the 0 t/ha biochar. Following five days of incubation, the amounts of CO_2 evolution that were higher than the control were 99 with 2 t/ha, 116 with 4 t/ha, and 120 ug CO_2/g soil/d with 6 t/ha of biochar. The increase in CO_2 evolution above the control treatment at 10 days of incubation was 61 with 2 t/ha, 79 with 4 t/ha, and 87 ug CO_2/g soil/d with 6 t/ha of biochar. Analogously, rising patterns in CO_2 emissions were noted. Throughout the whole incubation period, the biochar treatments' soil EC and pH were greater than those of the control treatment. After applying biochar, there were increases in the evolution of CO_2, however after 10 days of incubation, the percentage of C evolved from the addition of biochar decreased as the rates of biochar increased. At two t/ha, four t/ha, and six t/ha, the percentage C developed was 1.74 %, 1.66%, and 0.82% of the applied biochar C, respectively. Although the CO_2 evolved ratio to the total amount of biochar C typically reduced with increasing biochar rates, this study shows that the addition of biochar increases soil respiration, EC, and pH.

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Introduction

Biochar application in agricultural soils does not solely advance soil health and the cycling of nutrients but also surges the sequestration of carbon. They are C-rich organic sources and are resistant to microbial decay. Biochar is generated from the pyrolysis process of different feedstocks/biomass such as agricultural, forest and industrial wastes. Biochar utilization in agricultural lands is critical for boosting the soil properties of degraded thus enhancing crop productivity (Abukari et al., 2022). Biochar addition to agricultural soils can stay in the soil for a longer period and be resistant to microbial degradation thus providing a long-term advantage to the fertility of the soil (Pathy et al., 2020). They also can reduce the leaching of nutrients from the soil and also improve the cycling of nutrients. The use of biochar benefits the crop via its ability to modify the soil chemistry thereby supplying active surface soil nutrients, acting as a catalyst to speed up soil reactions and also improving the physical parameters of the soil.

Soil fertility and crop productivity are primarily influenced by the addition of biochar via their positive effects on soil microbial activity thus influencing nutrient alterations in soil (Hossain et al., 2020). Soil N mineralization in agricultural soils has been found to increase following the addition of biochar (Hu et al., 2014). The report by Zhou et al. (2017) illustrates that the addition of biochar surges nitrification however the report by Cayuela et al. (2014) shows increase in denitrification in the soil through biochar addition.

Furthermore, biochar used as soil amendment influences biological N_2 fixation (Güereña et al., 2015). Yet, little information is known about biochar's effects on soil microbiological processes (Ameloot et al., 2013) and how soil microbial biomass and activity respond differently (Irfan et al., 2019). The use of biochar can also surge, decrease soil microbial biomass and activity, or show no effect (He et al., 2020; Zhao et al., 2020; Hewage et al., 2016). These disparities in biochar effects could be linked to the characteristics of biochar characteristics, soil and the environment. The variation in soil microbial biomass levels after application, which positively influences soil microbial activity, may be explained by an increase in soil nutrients, a suitable pH for the soil, the adsorption of toxic compounds, and an increase in soil-water holding capacity (Azeem et al., 2019).

Jomao-as et al. (2023) suggested that an increase in soil microbial biomass increases soil pH in the corresponding environment. Therefore, biochar pH significantly influences the total microbial abundance and biomass in the soil.

The application of biochar revealed to boost soil quality (Abukari & Duwiejuah, 2019), increase water and nutrient retention capacity (Abukari 2019; Ziblila et al. 2021) enhance nutrient use efficiency (Abukari et al., 2018) and surge soil biological activity (Güereña et al., 2015).

Biochar additions also increase soil EC and pH but the salt-containing biochar vary in their effects (Nain et al., 2022). For instance, Bakshi et al. (2020) produced biochars from switchgrass and corn stover at the same temperatures resulting in lower aromatic C content and higher ash content than the red oak biochar and the wood waste biochar. This study therefore reports the outcome of rice husk biochar on soil respiration, pH and EC in savanna soil in a laboratory incubation study.

Materials and Methods

The study was conducted in the Agricultural Sub-sector Improvement Programme (AgSsIp) laboratory at Nyankpala, University for Development Studies to assess the effect of different rates of biochar (0, 2, 4 and 6 t/ha) on CO_2 evolution, soil pH and EC in fine-textured silty loam soils. Soil samples were collected at a depth of 0-20 cm from maize farmland that has continuously cropped maize for several years. The soil samples were cracked and sieved using a 2 mm sieve and a composite soil sample was collected and analyzed for essential soil characteristics (Table 1).

The rice husk feedstock was used to produce biochar at 550°C and its chemical parameters are presented in Table 2.

The effect of biochar on CO_2 evolution was evaluated by applying biochar at 0, 2, 4 and 6t/ha with fifty-gram of moist soil samples in three folds from each treatment and 5 ml of 0.3 N NaOH in a container collected in a conical flask and incubated at 28 °C for 2, 5 and 10 days. At the end of each incubation time, the container was removed and titrated using 0.1 N HCl and 10 ml 1 M $BaCl_2$ solution. Phenolphthalein was used as an indicator. The quantity of CO_2 in each flask was determined using the amount of HCl employed in the titration. Each pair of incubation was done simultaneously with a blank.

The soil sample was separated into four treatments to evaluate biochar's impact on soil pH and EC. A five-hundred-gram soil sample from each treatment was collected in three copies and amended with biochar at a rate of 0, 2, 4, and 6 t/ha in incubation pots. The pots were incubated at 28 °C for 0, 5, 10, and 45 days before being removed for pH and EC analyses.

The rate of CO_2 evolution throughout each incubation time was used to assess microbial activity (Shah et al., 2016). When microbes are active, they break down organic compounds and release CO_2.

Table 1. Physico-chemical parameters of soil (0-20 cm) used for the study

Parameter	Unit	Value
pH	-	5.8
EC	(dS/m)	0.45
Total N	(%)	0.46
Total mineral N	(ug/g soil)	40.34
Organic matter	(%)	1.22
AB-DTPA extractable P	(ug/g soil)	6.45
AB-DTPA extractable K	(ug/g soil)	5.53
Sand	(%)	61.7
Silt	(%)	30.0
Clay	(%)	8.3
Texture class	-	Sandy loam

Table 2. Chemical parameters of rice husk biochar

Rice husk biochar	Unit	Value
pH		7.32
EC	dS/m	1.67
Total C	g/kg	658
Ca	g/kg	2.36
Mg	mg/kg	5.43

Saturated soil paste was made, left overnight, and then removed with a vacuum pump to assess soil pH and EC (US Lab Staff, 1954). A pH and EC meter were used to measure the extract's pH and EC.

The total N in the soil was determined using Bremner's (1996) Kjeldhal method, whereas mineral N in the soil was measured using Mulvaney's (1994) steam distillation methodology. Available P and K in AB-DTPA soil extract were measured (Soltanpur and Shwab, 1977). Using a Spectrophotometer and a Flame photometer (both from Jenway, UK), the soil extract was analyzed for P and K. $K_2Cr_2O_7$ was employed as an oxidizing agent in the presence of H_2SO_4 to evaluate soil organic matter using the Walkley and Black approach (Shafer et al., 2021). The Bouyoucos hydrometer method, as described by Abdulwahhab and Seker (2021), was utilized to figure out the texture of the soil.

Data Analysis

Statistical analysis of the data was done using a completely randomized design in GenStat 18th Edition, with means being compared through the least significant difference (LSD) test at a significance level of $p<0.05$.

Results and Discussion

Table 3 presents the data on the rate of CO_2 evolution as impacted by varying dosages of biochar. During the 10-day incubation period, the rate of CO_2 evolution in the biochar-supplemented soil was consistently higher than in the unamended soil. The findings also indicated that the rate of CO_2 evolution increased in correlation with an increasing amount of biochar applied. In the initial 48 hours of the incubation period, applying rice husk biochar at 2 t/ha enhanced the rate of CO_2 evolution to 129, in contrast to 98 observed in the control treatment (Table 3). During the incubation period of two days, the equivalent increases in 4 and 6 t/ha biochar application over the 0t/ha treatment were found. Compared to the control, the increases in CO_2 evolution were 99 by 2t/ha, 116 by 4t/ha, and 120 ug CO_2/g soil/d with 6t/ha of biochar after 5 days of incubation. Furthermore, the increases in CO_2 evolution above the control treatment were 61 by 2 t/ha, 79 by 4 t/ha, and 87 ug CO_2/g soil/d by 6 t/ha of biochar. These findings showed that using biochar boosted the rate of CO_2 evolution in soil significantly. With higher amounts of biochar application, the rate of CO_2 increased in general.

The overall CO_2 generation responded to biochar application similarly to the rate of CO_2 evolution (Fig 1). Throughout all incubation periods, cumulative CO_2 generation was consistently higher in the biochar treatment than in the control treatment. The findings also revealed that the amount of CO_2 generated was proportional to the amount of biochar used. During the two days of incubation, the greatest quantity of 389 ug CO_2/g was created by applying biochar at a rate of 6 t/ha. The next largest levels of 261 ug CO_2/g were generated by 4 t/ha and 242 ug CO_2/g by 2 t/ha of biochar over two days. During two days, biochar at 6 t/ha boosted CO_2 generation by 35% over control.

On days 5 and 10, the process of increasing the emission of CO_2 with biochar at 2, 4, and 6 t/ha was remarkably similar to that on day 2. Conversely, the percentage of increase in CO2 production with 4 t/ha biochar decreased over time, peaking at 35% on day 2, 28% on day 5, and 25% on day 10.

These findings indicated that biochar application significantly boosted CO_2 generation throughout the 10-day incubation period, while the increase was comparable to the quantity of biochar administered. Although CO_2 generation is linked to microbial activity, it is reasonable to argue that biochar application significantly boosts soil microbial activity which is in line with some of the published literature. In one instance, Ehsani et al. (2022) discovered that biochar treatment increased urease activity, microbial biomass-C and N, total organic C, and CEC significantly. According to Kamal (2014), using biochar alone or in conjunction with phosphorus enhanced microbial population, microbial biomass-C, microbial biomass-N, and microbial biomass-P, as well as enzymatic activities including urease and phosphatase activity. Wu et al. (2022) found that modifications in soil characteristics caused by biochar impacted microbial activity and community structure differently.

Yan et al. (2022) have shown that changes in soil microbial populations cause variations in nutrient conversions, which can affect crop development. These results contradict the widely held idea that using biochar as soil amendments might improve C storage and hence reduce CO_2 emissions (Bolan et al., 2022). This may be conceivable in the long run, however, we tested CO_2 levels just 10 days after adding charcoal. Furthermore, CO_2 evolution is affected by the temperature at which biochar is produced. Several earlier investigations have revealed very varied CO_2 generation from soils modified with biochars generated at temperatures ranging from 350 to 850°C (Premchand et al., 2023; Ghorbani et al., 2022).

The evolution of C into CO_2 following the application of biochar C is shown in Table 4. During 10 days of incubation, the results indicated that, while overall CO_2 evolution rose with increasing amounts of biochar, the percentage of C evolved as CO_2 of the additional biochar C declined with increasing levels of biochar C.

Table 3. Effect of biochar on the rate of CO_2 evolution during 10 days of the incubation period

Biochar rates	Day 2	Day 5	Day 10
	ug CO_2/g soil/d		
0 t/ha	98a	72c	58c
2 t/ha	129c	99b	61b
4 t/ha	146b	116t	79a
6 t/ha	168d	120t	87ab

Means with different letter(s) within columns are significantly different (p<0.05)

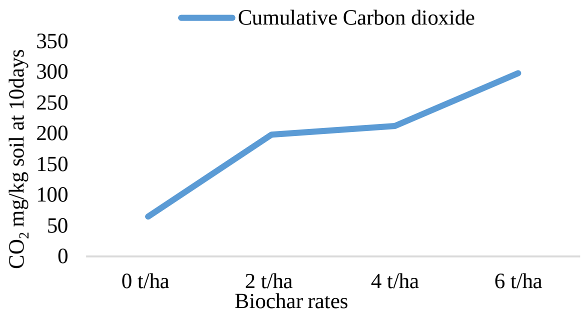

Figure 1. Cumulative CO_2 production (mg/kg soil) from the soil during 10 days of incubation as influenced by biochar

The findings revealed that the %C of biochar developed as CO_2 in 10 days was 1.78% with 2 t/ha of biochar application, 1.56% with 4 t/ha of biochar application, and 0.97% with 6 t/ha of biochar application, indicating that the contribution of C to the atmosphere usually decreased with increasing levels of biochar application. These findings are consistent with previous research that found reduced CO_2 evolution from soil with biochar application (Yadav et al., 2023; Rittl et al., 2020).

The results obtained on soil EC as influenced by different levels of biochar are presented in Table 5. They are affected by the temperature at which biochar pyrolyzes. Several earlier investigations have found extremely varied CO_2 generation from soils modified with biochars generated at temperatures ranging from 350 to 850 ºC (Premchand et al., 2023; Ghorbani et al., 2022).

Throughout all incubation periods, the effect of rice husk biochar on soil EC was significant (p<0.05). At days 0, 5, 10, and 45 days of incubation, the results were significant (p<0.05). The soil EC rose in general, as the dose of biochar applied increased. At day 0, the soil EC varied from 1.26 dS/m in 0t/ha biochar to 1.86 dS/m in 6t/ha rice husk biochar. At day 5, the soil EC values ranged from 1.10 dS/m in the 0t/ha treatment to 1.96 dS/m in the 6t/ha rice husk biochar treatment. The soil EC values observed at 0t/ha rice husk biochar varied from 1.12 dS/m to 1.61 dS/m in the soil receiving 6t/ha biochar at day 10. Additionally, the soil EC ranged from 0.79 to 1.85 dS/m in the 0t/ha and 6t/ha of rice husk at 45 days of incubation respectively.

The findings from this study reveal that increasing the quantities of rice husk biochar significantly influenced soil EC in all the incubation stages. The possible explanation for the increase in soil EC following the addition of rice husk biochar could be due to the existence of salt in rice husk biochar. Many studies have also shown that rice husk biochar improves soil EC and pH (Nain et al., 2022).

Table 4. Percent C of added biochar evolved as CO_2 at 10 days of incubation

Biochar dosage	Biochar C kg/ha	CO_2 evolved in 10days mg/kg	C evolved as CO_2 from biochar mg/kg	C evolved as CO_2 from biochar kg/ha	%C of biochar evolved in 10 days
0t/ha	-	649d	-	-	-
2t/ha	2930a	857a	37f	58y	1.78e
4t/ha	5889f	892s	50y	98x	1.56g
6t/ha	11664g	945t	49j	95w	0.97j

Means with different letter(s) within columns are significantly different ($p<0.05$)

Table 5. Influence of biochar on soil electrical conductivity at 45 days of the incubation period

Biochar dosage	The incubation period (days) Soil EC (dS/m)			
	0	5	10	45
0t/ha	1.26b	1.10b	1.12b	0.79a
2t/ha	1.29b	1.62c	1.34d	1.81ab
4t/ha	1.88a	1.98d	1.63d	1.83ab
6t/ha	1.86a	1.96d	1.61d	1.85ab

Means followed by different letter(s) within columns are significantly different ($p<0.05$)

Table 6. Influence of biochar on soil pH at 45 days of the incubation period

Biochar dosage	The incubation period (days)			
	0	5	10	45
0t/ha	6.77w	6.93e	7.38b	7.49y
2t/ha	7.17b	7.25b	7.61d	7.53y
4t/ha	7.50c	7.38eb	7.69d	7.89d
6t/ha	7.56c	7.56d	7.72d	8.24e

Means followed by different letter(s) within columns are significantly different ($p<0.05$)

Though, the properties of biochar extensively vary, their influence changes with the amount of salt present in biochar (Yao et al., 2022). Singh et al. (2022) observed that the biochars generated from switchgrass and maize stover had lower aromatic C and higher ash levels than biochars generated from red oak and wood waste.

Table 6 demonstrates the effects of different rice husk biochar rates on soil pH over 45 days. The results revealed that biochar treatment resulted in a significant elevation in soil pH soon after application at 0 days. At day 0, the soil pH rose as biochar levels increased. During subsequent incubation periods, the impact of biochar on soil pH is sustained. Furthermore, the rise in soil pH was often related to the amount of biochar used, with higher values observed with greater quantities of biochar. During the 0-day incubation period, a maximum rise of 10% in soil pH was seen with biochar at 6 t/ha, compared to a 7% increase with 4 t/ha and a 5% increase with 2 t/ha biochar. On day 5, a biochar level of 6 t/ha resulted in the greatest improvement in soil pH of 6%. Similarly, a 4% rise in soil pH was seen in the condition that received biochar at 4 t/ha for 10 days. Whereas biochar at 6 t/ha resulted in a 5% improvement in soil pH after 45 days.

In all treatments, the data also showed an indication for the pH of the soil to decrease with longer incubation times. The results also showed that the pH of the soil decreased significantly in the early stages of incubation than in the later stages. Additionally, the results demonstrated that although the addition of biochar immediately raised the pH of the soil, these increases did not last for the duration of the incubation periods. On the other hand, increased soil pH was noted at biochar treatments, and this increase was correlated with the amount of biochar applied. The addition of biochar can increase or decrease soil pH due to the salt content of salt present in the biochar. Sun et al. (2021) observed that the biochar pH varies depending on the source, pyrolysis temperature, and degree of oxidation. Haider et al. (2022) and Da Silva Mendes et al. (2021), stated that biochar influences the physical and chemical properties of soils such as the soil pH, soil structure, and micronutrient availability. Rashmi and Biswas (2020) observed that legume-derived biochar boosted soil pH more positively than non-legume-derived biochar.

Conclusion

The study showed that the addition of biochar positively surged microbial activity leading to the release of a higher amount of CO_2 in a short incubation period. Besides, biochar additions increased soil EC and pH at short-term incubation. The %C of biochar developed as CO_2 at 10 days of incubation declined with increasing amount of biochar carbon.

Competing interest

The authors declare no conflict of interest in this paper.

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