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Research Article

Impact of Biochar Application on Chemical and Microbial Properties of Soil

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ABSTRACT

Biochar is a carbonaceous solid compound formed by high-temperature of organic waste. The quality of biochar produced is determined by pyrolysis conditions and the type of raw materials. This study focused on the evaluation of the impact of biochar application on soil chemical and microbial properties. Four types of biochar from corn cobs, sawdust, mud press, and rice hull were produced and their chemical composition (pH, Organic Matter, Organic Carbon, Total Nitrogen, Carbon: Nitrogen Ratio, Available Phosphorus, and Exchangeable Potassium) was analyzed. A pot experiment with five treatments [T_1 - Pure Soil; T_2 – Soil + corn cob biochar; T_3 – soil + sawdust biochar; T_4 – soil + mud press biochar; T_5 – soil + rice hull biochar] replicated three times was arranged in a completely randomized design (CRD). An equal amount of soil was placed in pots and mixed with biochar at a ratio of fifty grams (50g) per one-thousand grams (1000g) of soil. A total of fifteen experimental pots were used in the study where each pot contains a soil-biochar mixture of one-thousand five-hundred grams (1500g). Pearson's correlation coefficients were used to determine how the soils applied with biochar are affected after sixty days of incubation and determine how biochar sources were related. All four biochar from rice hull, corn cobs, mud press, and sawdust are all alkaline and contain comparable amounts of organic matter, organic carbon, pH, soil nitrogen, available phosphorus, and exchangeable potassium. The result of the study showed that biochar application significantly improved soil pH, soil organic matter content, soil organic carbon, and soil nitrogen content. Soils amended with biochar showed comparable amounts of available phosphorus and exchangeable potassium. The application of biochar in soils therefore can be considered a potential solution to enhance soil fertility for sustainable crop production.

Keywords: *Biochar, Feedstock, Incubation, Pyrolysis, Soil amendment*

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Introduction

The health of the soil is critical to successful crop production. Low soil organic matter, acidity, alkalinity, nutrient depletion, and poor microbial diversity are just a few of the major soil problems worldwide that impact soil health and food production (Das et al., 2022). With these scenarios, there is a need to reset and rethink strategies on how to enhance soil fertility and increase crop yield to attain food sufficiency (Singh R. et al., 2022). The need to adopt sustainable farming practices like amending the soil with biochar can be a promising strategy to improve soil health. Biochar is a stable carbon compound produced through the heating of biomass in the absence of oxygen which can be used as a soil amendment to restore soil's physical, chemical, and microbial properties (Ding et al., 2016). The promising benefits of using biochar in enhancing the fertility of degraded soils are a potential option (Abhishek et al., 2022). Biochar application enhances the mineralization of carbon and the transformation of nutrients.

In the past years, the widespread application of biochar in agricultural land has significant contribution to the development of a sustainable food production system (Tan et al., 2022). However, there is a need to evaluate the biochar-soil interactions considering the type of feedstock or organic materials to be used. Thus, this study was conducted purposely to evaluate the effect of biochar application on soil qualities specifically on soil chemical and microbial attributes.

Methods

Biochar Production and Composition Analysis

Different industrial wastes such as rice hulls, corn cobs, mud presses, and sawdust collected within the locality were made into biochar via pyrolysis with the use of a fabricated biochar kiln. The biochar retort was made from galvanized iron sheets and metal bars. It took 30-40 minutes prior to complete the pyrolysis of the biomass inside the kiln. The kiln was cooled down before collecting the biochar. The pH, Organic Matter (%), Organic Carbon (%), Total Nitrogen (%), Carbon: Nitrogen Ratio, Available Phosphorus (%), and Exchangeable Potassium (%) composition of the four biochar products were analyzed.

Research Design and Procedure

The experiment was arranged in a Completely Randomized Design with four treatments replicated three times having a total of twelve experimental units or pots. Each pot contains a 10.5-kilogram mixture of soil and biochar with a ratio of fifty grams of biochar per kilogram of soil. Experimental pots were randomly arranged inside a chamber. Pots were maintained at room temperature and were watered once a week with distilled water to maintain field capacity and were incubated for 60 days.

Results and Discussion

Chemical Composition of Biochar Products

The formulated biochar products were analyzed for pH, Organic Matter (%), Organic Carbon (%), Total Nitrogen (%), Carbon: Nitrogen Ratio, Available Phosphorus (%), and Exchangeable Potassium (%). Table 2 presents the comparison of biochar derived from four different feedstocks – corn cobs, sawdust, rice hull, and mud press. The pH of the four biochar was significantly different ($P < 0.05$) which ranged from 8.91 (strongly alkaline) to 9.96 (very strongly alkaline). Biochar from corncobs and sawdust indicated the same highest pH of 9.84, followed by biochar-rice hull with 9.14, and biochar-mud press with 8.91. The results implied that all four biochar are alkaline.

The biochar derived from corn cobs, rice hull, mud press, and sawdust showed comparable amounts of organic matter and organic carbon which ranged from 21.80 to 39.40 and 12.64 to 22.85 percent, respectively. The presence of organic carbon in compost helped improve the physical and chemical properties of soils. Total nitrogen among biochar significantly varied from each other with biochar-rice hull having the highest Nitrogen with a value of 1.97 percent, followed by biochar-corn cobs with 1.75 percent, biochar-mud press with N contents of 1.53 and 1.09 for biochar-sawdust. The total NPK of the four-biochar ranged from 2.05 (sawdust) to 3.34 (corn cobs) lower than the 5% required for a material to be considered organic (PNS for Organic Fertilizer). The C/N ratios of the products were 11A. A ratio below 20 is an indication of acceptable maturity of the final products, a ratio of 15 or even less is preferable (Inbar et al., 1990). Organic amendments with a low C: N ratio will decompose much faster than residue with a high C: N ratio.

Table 1. Chemical Composition of Biochar Derived from four Agricultural Waste Materials

PARAMETER	BIOCHAR FEEDSTOCK				SD	$t_{0.05}$	P_{value}
	Corn Cobs	Sawdust	Mud press	Rice hull			
pH	9.84	9.84	8.91	9.14	0.88	20.21**	0.00
Organic matter (%)	35.00	21.80	30.60	39.40	2.54	4.09*	0.02
Organic carbon (%)	20.30	12.64	17.75	22.85	1.32	4.08*	0.02
Total Nitrogen (%)	1.75	1.09	1.53	1.97	0.12	4.09*	0.02
C: N Ratio	11.60	11.60	11.60	11.60	0.02	---	
Available P (%)	0.125	0.05	0.05	0.162	0.07	24.43**	0.00
Exchangeable K (%)	1.46	0.91	0.55	0.66	0.60	3.28*	0.04
NPK (%)	3.34	2.05	2.13	2.79	0.87	20.21**	0.00

Soil Properties Before Biochar Application

The chemical composition of the soil before the addition of biochar and incubation for 60 days is presented in Table 2. The pH of the soil used in the experiment was 5.66 described as moderately acidic. Soil pH is a measure of the acidity or basicity of soil. Soil pH is considered a master variable in soils as it affects many chemical processes. It specifically affects plant nutrient availability by controlling the chemical forms of the different nutrients and influencing the chemical reactions. The optimum pH range for most plants is between 5.5 and 7.5; however, many plants have adapted to thrive at pH values outside this range. Plants grown in acid soils can experience a variety of stresses including aluminum (Al), hydrogen (H), and/or manganese (Mn) toxicity, as well as nutrient deficiencies of calcium (Ca) and magnesium (Mg).

Organic matter content was considered high at 4.27 percent, consequently, organic carbon was 2.47 percent and nitrogen was very high at 2.24 percent, respectively. According to Sullivan et al. (2019), sustainable crop production can only be attained when soils contained 3.44 percent organic matter. The sustainability is achieved because SOM above 3.44 percent stabilizes the soil structure, decreases bulk density, and promotes heightened nutrient cycling. Sullivan et al. (2019) later reported that soils with SOM content of 2.06 percent were susceptible to degradation.

Soil organic matter is the sole source of nitrogen in the soil. The lower organic matter content of the soil limits the presence of nitrogen. According to Wang et al. (2008), a total N of less than 0.1 percent is marginally suitable for crop production. The soil had 2.24.24 percent nitrogen; therefore, the soils were rated as containing very high total N.

The critical limit of the soil available P for crop production is 10 ppm. This means that the soil (3.20 ppm) contained P below the critical limit. Potassium aids the plant in using water efficiently, preventing many diseases and heat damage. Potassium helps cycle nutrients through leaves, roots, and stems. The soil in the study contained a very high amount of potassium at 350 ppm.

Table 2. Chemical Composition of Soil before Incubation

Chemical Properties	Level	Qualitative Description
Soil pH	5.66	Moderately acidic
Organic Matter (%)	4.27	High
Organic Carbon (%)	2.47	Medium
Nitrogen (%)	2.24	Very High
Available P (ppm)	3.20	High
Exchangeable K (ppm)	350	Very high

Chemical Properties of Soils after Biochar Application

<u>*Soil pH*</u>

The pH level of the amended soils after incubation for 2 months is presented in Table 2. After applying biochar to the soils and incubating for 60 days, the amended soils had a significantly higher soil pH (at least 0.111 units) than the control sample. From the original soil pH of 5.66, there is strong evidence (p = 0.016) that the biochar application intervention improves the soil pH. The result of the study conforms with the findings of Pandian et al. (2016) who found that biochar raised soil pH from 5.7 to 6.3. This study showed that the addition of biochar improved the soil pH of the acid soil. This property of biochar is important to increase the soil CEC (cation exchange capacity) when biochar is added to the soil. The liming power of biochar depends basically on its ashes content which is not really biochar but one of its fractions. The ash content of biochar is very variable and depends on the substrates.

The liming effect of the biochar ashes was dependent on its feedstock (P = 0.042) which has an SD of 0.42. This means that some biochar had higher ash content like sawdust which increased pH level by 6.75 percent, corn cobs by 6.64 percent, and rice hull by 6.24 and the least increment is observed in mud press with 5.83 percent. Biochar can increase pH by 0.5–1.0 unit in most cases for the application of biochar, nutrients are directly available through the solubilization of ash in the solid biochar residue and other nutrients may become available through microbial utilization of a small labile carbon component of biochar (Shackley et.al., 2012).

Table 2. Soil pH of Incubated Soils with Biochar

	TREATMENTS	Soil pH
T_1	Control - soil only, no biochar	5.59
T_2	50 g of biochar per kg of soil (Corn cobs)	6.64
T_3	50 g biochar per kg of soil (Sawdust)	6.75
T_4	50 g of biochar per kg of soil (Mudpress)	5.83
T_5	50 g of biochar per kg of soil (Rice hull)	6.24
P value (Biochar vs Control)		3.70*
Standard Deviation		0.42
P value (Biochar source)		30.41**
Standard Deviation		0.42

Means with common letters are not significantly different at 5% level by DMRT
** Highly significant
* Significant at 5% level

<u>*Soil Organic Matter*</u>

The change in organic matter content of soils amended with four types of biochar after 2 months is presented in Table 3. The biochar application significantly improved the organic matter of the soils (P = 3.40) approximately by 0.24 units.

Many studies have shown that biochar improves the physic-chemical properties of soil, particularly in maintaining the soil organic matter levels (Chan et al., 2007). Furthermore, the application of biochar to soils is a practical method to aid in the long-term maintenance of the soil's organic carbon contents and soil fertility. The application of biochar to soils can maintain SOM levels and soil aggregation stability (Kimetu and Lehmann, 2010) because biochar contains recalcitrant C from microbial degradation and by a charged surface with organic functional groups.

There were highly statistically significant differences (P < 3.40) between biochar feedstock types which could have a profound effect on soil organic matter content.

Table 3. Organic Matter Content (%) of Incubated Soils with Biochar

	TREATMENTS	SOM (%)
T_1	Control - soil only, no biochar	4.60
T_2	50 g of biochar per kg of soil (Corn cobs)	3.98
T_3	50 g biochar per kg of soil (Sawdust)	4.43
T_4	50 g of biochar per kg of soil (Mud press)	4.36
T_5	50 g of biochar per kg of soil (Rice hull)	3.97
P value (Biochar vs Control)		3.40*
Standard Deviation		0.24
P value (Biochar source)		34.28**
Standard Deviation		0.24

Means with common letters are not significantly different at 5% level by DMRT
** Highly significant
* Significant at 5% level

Soil Organic Carbon

The organic carbon contents of soils amended with biochar from different feedstock sources after 60 days are presented in Table 4. The biochar application significantly improved the organic carbon of the soils (p = 5.97) approximately by 0.09 units. High significant differences (p< 50.95) were observed between biochar feedstock types, which could have a profound effect on soil organic matter content.

Table 4. Organic Carbon (%) Content of Incubated Soils with Biochar

	TREATMENTS	SOC (%)
T_1	Control - soil only, no biochar	2.67
T_2	50 g of biochar per kg of soil (Corn cobs)	2.31
T_3	50 g biochar per kg of soil (Sawdust)	2.49
T_4	50 g of biochar per kg of soil (Mud press)	2.45
T_5	50 g of biochar per kg of soil (Rice hull)	2.31
P value (Biochar vs Control)		5.97*
Standard Deviation		0.09
P value (Biochar source)		50.95**
Standard Deviation		0.09

Means with common letters are not significantly different at 5% level by DMRT
** Highly significant
* Significant at 5% level

Total Nitrogen

The nitrogen contents of soils amended with biochar from four feedstock sources after 2 months are presented in Table 6. The biochar application significantly improved the nitrogen contents of the soils (P = 15.38) approximately by 0.06 units.

According to Mukherjee and Zimmerman (2013) and Zheng et al. (2017), biochar has great potential as a source of available nutrients and could release large amounts of nitrogen and phosphorus. Table 6 further indicated that there were highly significant differences (p< 80.84) between biochar feedstock types suggesting that the biochar of the feedstock types a had profound effect on the nitrogen availability of the soil. Biochar from rice hull showed the highest percentage increase of N (2.30%), followed by corn cobs and sawdust with 2.27 and 2.25 percent, while the least was observed on mud press with 2.17 percent.

Table 5. Nitrogen Content (%) Content of Incubated Soils with Biochar

	TREATMENTS	Soil Nitrogen (%)
T_1	Control - soil only, no biochar	1.82
T_2	50 g of biochar per kg of soil (Corn cobs)	2.27
T_3	50 g biochar per kg of soil (Sawdust)	2.25
T_4	50 g of biochar per kg of soil (Mud press)	2.17
T_5	50 g of biochar per kg of soil (Rice hull)	2.30
P value (Biochar vs Control)		15.38**
Standard Deviation		0.06
P value (Biochar source)		80.84**
Standard Deviation		0.06

Means with common letters are not significantly different at 5% level by DMRT
** Highly significant
* Significant at 5% level

<u>*Available Phosphorus*</u>

The change in phosphorus contents of soils amended with biochar from various feedstock sources after 2-month-incubation is presented in Table 6. The result revealed that biochar application has the potential to improve the availability of phosphorus in the soil.

Biochar applications do not significantly contribute to enhancing the availability of phosphorus in the amended soils (p = 1.43). The function of phosphorus in plants is very important. It plays key roles in many plant processes such as energy metabolism, the synthesis of nucleic acids and membranes, photosynthesis, respiration, nitrogen fixation, and enzyme regulation (Vance et al. 2003). Adequate phosphorus nutrition enhances many aspects of plant development including flowering, fruiting, and root growth.

According to Zhang et al. (2016), phosphorus inputs from biochar vary with the type of biochar. This jives with the result of the study where feedstock types significantly vary in terms of P increase in the incubated soils (P = 29.24). Corn cobs biochar contributed the highest amount of available phosphorus to soils with 11.20 ppm, while the least was observed on rice hull with 9.96 ppm. Results indicated that biochar was able to bring available P into soils, but the amount and form of available P were dependent on biochar types.

Table 6. Available Phosphorus (ppm) Content of Incubated Soils with Biochar

	TREATMENTS	Available Phosphorus (ppm)
T_1	Control - soil only, no biochar	9.70
T_3	50 g of biochar per kg of soil (Corn cobs)	11.20
T_4	50 g biochar per kg of soil (Sawdust)	10.10
T_5	50 g of biochar per kg of soil (Mud press)	9.90
T_9	50 g of biochar per kg of soil (Rice hull)	9.60
P value (Biochar vs Control)		1.43^{ns}
Standard Deviation		0.70
P value (Biochar source)		29.24**
Standard Deviation		0.70

Means with common letter are not significantly different at 5% level by DMRT
** Highly Significant
ns – not significant

Exchangeable Potassium

The potassium contents of the amended soils after incubation are presented in Table 7. After applying biochar to the soils and incubating for 60 days, there was no significant increase in the potassium contents of the soil. From the original K level of 350 ppm, there was low evidence (p = 2.10) that the biochar application intervention improves the potassium availability in the soils. The biochar-amended soils had comparable amounts of potassium to the control sample.

The result of the study however showed that the soils mixed with various biochar were significantly different in terms of K contents after 60 day-incubation periods. Biochar derived from rice hull and sawdust increased the potassium content of the soil to 510 and 350 ppm, respectively. Zheng et al. (2017) found out that biochar is a good source of available nutrients including potassium. Biochar contains available P, available K, available Na, available Ca, and available Mg (Masto et al.,2013).

Table 7. Exchangeable Potassium (ppm) Content of Incubated Soils with Biochar

	TREATMENTS	Potassium (ppm)
T_1	Control - soil only, no biochar	180
T_2	50 g of biochar per kg of soil (Corn cobs)	300
T_3	50 g biochar per kg of soil (Sawdust)	360
T_4	50 g of biochar per kg of soil (Mud press)	160
T_5	50 g of biochar per kg of soil (Rice hull)	510
P value (Biochar vs Control)		2.10^{ns}
Standard Deviation		145.00
P value (Biochar source)		4.59*
Standard Deviation		145.00

Means with common letters are not significantly different at 5% level by DMRT
* – Significant at 5% level
ns – not significant

Conclusion

Based on the result of the study, biochar application improves soil pH and organic matter of moderately acidic soil after incubation for two months. Biochar from rice hull and corn cobs as feedstock sources enhanced the NPK contents of the soils better than the biochar feedstock derived from mud press and sawdust. The application of rice hull and corn cobs biochar is a good soil amendment since it provided a good chemical and microbial soil environment favorable for crop production.

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