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TEMPORAL DYNAMICS OF SOIL CHEMICAL PROPERTIES DURING INCUBATION WITH BIOCHAR FROM DIVERSE BIOMASS SOURCES

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ABSTRACT: *Soil chemical properties degradation is a very serious challenge facing food production in the tropics. To ensure sustainability, there is need for soil improvement. This study aimed at investigating the temporal dynamics of soil chemical properties during incubation with biochar from diverse biomass sources. An incubation experiment was carried out at the Soil Science Laboratory Faculty of Agriculture, Imo State University. The soil used was for the experiment was taken at the depth from 0 - 20 cm from Imo State Teaching and Research farm Owerri. The collected soil was air-dried, crushed, and sieved using 2 mm sieve and characterized before treatments application. Three types of biomass used for biochar production were saw dust, poultry manure and pig dung. The biomasses selected were air-dried before pyrolysis. Prior to the insertion of the biomasses, the biochar machine was first be heated for 10 minutes. 1kg of each agricultural wastes residue was inserted into the modified gas biochar kiln and charred at 300°C for 60 minutes. 500g soil each was placed in plastic container with a lid. The soil was mixed with 5g of the produced biochar each at the rate of 20t ha^{-1}. The detailed treatments used for this experiment were as follows: T1: Saw dust biochar (20 t ha^{-1}), T2: Poultry manure biochar (20 t ha^{-1}), T3: Pig dung biochar (20 t ha^{-1}), T4: 10 t ha^{-1} of Saw dust biochar + 10 t ha^{-1} of Poultry manure biochar, T5: 10 t ha^{-1} of Saw dust biochar + 10 t ha^{-1} of Pig dung biochar, T6: Control (No biochar amendment). 200ml of deionized water was added for three consecutive days to ensure field capacity is obtained. The containers were cover with lids and strongly tied with black waterproof to maintain dark condition. The incubation experiment was arranged in completely randomized design. Soil samples were collected on days 30, 45, 60 and 75 to analyze its chemical properties The result of the chemical composition of the produced biochar showed that all the produced biochars had an elevated pH and high exchangeable cations with its highest on PMB. The carbon content of the animal based biochars (PMB and PDB) was higher than that found on the plant based biochar (SDB). The nitrogen content followed a reverse trend as seen in carbon content. The results of the biochar application on the chemical properties of the soil showed increase in pH, SOM, TN, Avail P, Exch. Cations and Exch. H with a reduction in Exch. Al. The highest impact on pH, Avail P, Ca, Mg, K and CEC were on soils treated with PMB @ 20t/ha. Soils with SDB @ 20t/ha gave the highest SOM but its combination with PMB (SDB @10t/ha and PMB @10t/ha) gave the highest TN with control exhibiting higher Exch. Al. Despite the increase observed, dynamic changes were observed across the incubation intervals in all the evaluated soil chemical properties. The interaction between biochar from different biomass sources and incubation time underscore the importance of tailoring biochar use to specific biomass and environmental conditions. PMB@20t/ha stand out as the only produced biochar in this study, which not just impact positively on almost all the soil chemical properties evaluated but also maintain a long-lasting effect on the soil. Although, the results from the study showed a clear effect of biochar on soil chemical properties, conducting comprehensive field trials is recommended to ensure that local farmers benefit from this research finding.*

KEYWORDS: Biochar, Biomass, Soil chemical properties, Incubation, Temporal dynamics.

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INTRODUCTION

The decline in soil quality caused by intensive farming and climate change present a major challenge to ensuring food supply globally (Al-wabel et al., 2015). The exponential increase of greenhouse gas (GHGs) emissions from human activities is harming the environment and threatening sustainable farming systems (Kumar et al., 2018). Additionally, the growing population, projected to reach 9.8 billion by 2050, will place significant strain on agricultural systems worldwide (Ayaz et al., 2021). Hence to sustain the growing population and address rising food demands while mitigating climate change, a practical and cost effective approach is essential for improving soil health, boosting crop productivity and promoting sustainable farming system and environmental stability (Singh et al., 2022). Biochar, with its distinct features like a large surface area, abundant functional groups, porous structure, high cation exchange capacity, embedded minerals, and strong adsorption abilities, has emerged as a valuable tool for reducing greenhouse gases, managing the environment, and enhancing soil fertility (Abhishek et al., 2022).

Biochar a material rich in carbon serves not only as a renewable fuel but also as an additive for soil quality improvement (Lehmann and Joseph, 2009). Biochar has recently gained recognition as an organic amendment rich in mineral nutrients, capable of enhancing soil quality and boosting crop yields. As an organic amendment, biochar enhances soil fertility, indirectly boosting crop yields while posing no harm to the soil, especially in subtropical and tropical regions (Meier et al., 2021).This is because the applications of biochar can be help in the development of good pore structure, large specific surface area, abundant surface functional groups, and stable carbon structure skeleton in the soil (Guo et al. 2014; Scislowska et al. 2015). However, the properties possessed by biochar are influenced by the type of biomass and the manufacturing process (Ferrella et al., 2014). Biochar whose raw material has high lignin content will produce biochar of about 65% and has higher carbon content which is difficult to decompose in the soil (Yashika et al. 2019). Stability of biochar's properties does not insinuate that the biochar properties remain unchanged. Nevertheless, the stability of biochar is shaped by its own properties, the type of soil it interacts with, management practices and the presence of soil organism (Rechberger et al. 2017).

Many researches have explained that biochar properties influence differs from one soil types to another (El-Naggar et al., 2019). According to them, there is variation in the trends of increase in pH, carbon content, nitrogen content, available P with a decrease in exchangeable Al among various soil types. According to Yuan and Xu, 2011, the impact of biochar on nutrient retention, soil pH and organic matter dynamics can vary depending on the length of time biochar has been in contact with the soil. In this context, we hypothesized that biochar produced from different biomass when incubated will show a varying change in its chemical properties, nutrient availability and enhancement with time. Hence, the purpose of this study was to evaluate the temporal dynamics of applied biochar derived from saw dust, poultry manure and pig dung at different incubation time on soil chemical properties.

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MATERIALS AND METHOD

Study Area Description

The study was conducted at the Soil Science Laboratory Faculty of Agriculture, Imo State University. The location of the study fall within latitude 5º30'29.09" N and longitude 7º2'32.35" E. The study area experiences bimodal pattern of rainfall (April- July) and (September - November), with short spell in August normally called "august break". the mean annual maximum rainfall is 2238mm and maximum and minimum temperature of 32ºC and 23ºC respectively, while relative humidity is in the range of 63- 80%.

Collection and preparation of soil

The soil used for the study was taken at the depth from 0 - 20 cm from Imo State Teaching and Research farm Owerri. The soil sample was exposed to air-drying, followed by crushing and sieving using 2 mm sieve. Prior to treatments application the physical and chemical properties of the initial soil were analyzed.

Biochar preparation and characterization

Three types of biomass (saw dust, poultry manure and pig dung) obtained locally in Owerri, Nigeria, were selected for the production of biochar. This biomass selection reflects a range of organic waste materials abundant in the area, making them suitable for biochar production. The biomasses selected were air-dried before pyrolysis. Before adding the biomasses, the biochar machine was preheated for 10 minutes. 1kg of each agricultural wastes residue was inserted into the modified gas biochar kiln and charred at 300ºC for 60 minutes. The produced biochar was analyzed for its chemical composition before its application to the soil. The biochar yield was calculated as the mass difference between the initial biomass and the produced biochar express in percent.

Laboratory incubation study

The incubation study was carried out for 75-days period to investigate how biochar produced from different biomass (saw dust, poultry manure and pig manure) influences soil chemical properties. 500g soil each was placed in plastic container with a lid. The soil was mixed with 5g of the produced biochar each at the rate of 20t ha^{-1}. 200ml of deionized water was added for three consecutive days to ensure field capacity is obtained. The containers were cover with lids and strongly tied with black waterproof to maintain dark condition. The experiment was maintained at the temperature range of 27ºC to 28ºC (room temperature) while the relative humidity was in the range of 63 - 80%. The incubation experiment was arranged in completely randomized design replicated thrice while following the experimental treatments. Soil samples were collected on days 30, 45, 60 and 75 to analyze its chemical properties (soil pH, organic C, total N, available P exchangeable K, Ca, Mg, Na, H and Al). The detailed treatments used for this experiment were as follows: Saw dust biochar (20t/ha), Poultry manure biochar (20t/ha), Pig dung biochar (20t/ha), Saw dust biochar (10t/ha) + Poultry manure biochar (10t/ha), Saw dust biochar (10t/ha) + Pig dung biochar (10t/ha) and Control (No biochar amendment).

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Soil laboratory Analysis

The soil pH was determined using a pH meter in a 1:2.5 w/v soil-water extract. Available phosphorus was determined using Bray 2 method (Olsen and Sommers, 1982). Total nitrogen was determined by Micro-kjeldahl digestion technique (Bremner, 1996). Organic carbon was determined by wet digestion method (Nelson and Sommers 1982). Exchangeable bases (Ca, Mg, K and Na) were determined by neutral ammonium acetate procedure buffered at pH 7.0 (Thomas, 1982). Exchangeable acidity (Al and H) was gotten by the method described by McLean (1982).

Biochar laboratory Analysis

The pH of the biochars was measured in 1: 20 w/v biochar water extracts using pH meter. The different biomass biochar was each digested by nitric and perchloric acid (Kalra et al. 1988) and then the extract were used to measure total elements (P, Ca, Mg, Na and K) according to the standard methods. Phosphorous content from the biochar extractant was determined calorimetrically using spectrophotometer. The Walkley and Black method based on dichromate oxidation, was employed to determine organic carbon. (Nelson and Sommer, 1982). Total Nitrogen was determined by macro kjeldahl method (Bremner and Mulvaney, 1982).

Statistical Analysis

All data was subjected to the analysis of variance (ANOVA) procedure using SPSS version 25. The means was separated using Duncan Multiple Range Test at $P < 0.05$. The relationship between soil properties at different time interval was evaluated using correlation analysis.

RESULTS AND DISCUSSION

Soil initial properties before the incubation experiment

The Particle size distribution analysis of the soil before incubation experiment showed that the soil was of loamy sand with percentage of sand of 85% with its clay and silt content at 12% and 3% respectively (Table 1). This is typical of soils originating from coarse parent materials as reported by Federal Ministry of Agriculture and Natural Resources (1990). The chemical analysis of the soil used showed that nitrogen, soil organic matter, calcium, potassium are of low range according to Esu, 1991, with its phosphorus content, magnesium and cation exchange capacity at medium range (Table 1). However, the soil was acidic in nature (4.6). The soil chemical composition reflects the generally low inherent soil fertility of tropical soils under continuous cultivation (Major et al., 2010).

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Table 1: Selected physicochemical properties of initial soil prior to incubation study

Soil parameters	Values
Sand (%)	85.0
Silt (%)	3.0
Clay (%)	12.0
Textural class	**Loamy sand**
Soil pH	4.6
Available Phosphorus ($mgkg^{-1}$)	14.7
Total nitrogen (gkg^{-1})	1.26
Organic matter(gkg^{-1})	16.19
Exchangeable cations	
Calcium ($cmolckg^{-1}$)	1.76
Magnesium ($cmolckg^{-1}$)	0.95
Potassium ($cmolckg^{-1}$)	0.37
Sodium ($cmolckg^{-1}$)	0.05
Cation exchange capacity ($cmolck^{g-1}$))	8.0
Exchangeable acidity	
Hydrogen ion ($cmolkg^{-1}$)	0.10
Aluminium ion ($cmolkg^{-1}$)	0.70

Chemical composition of the biochar used for the incubation study

The chemical properties of the three biochars produced from the three different agricultural wastes are presented in Table 2. Among the biochars produced from different biomass, poultry manure gave the highest pH value (9.4). This might be an attribute of biochar ash content (Gaskin et al., 2008). The biochar yield ranges 67.6 – 84 % with the highest value from pig dung (84%) and the lowest from poultry manure (67.6%). The variation found in the biochar yield is a function of type of feedstock used (Downie et al., 2009). Highest total carbon was found on the saw dust ($34.3gkg^{-1}$). The total N of the produced biochar ranges from 11.2 to 25.2 gkg^{-1} with the highest from poultry manure ($25.2gkg^{-1}$) while the lowest was from saw dust ($11.2gkg^{-1}$). Total P, Ca, Mg, K and Na were highest in biochar produced from saw dust (3096.43mg/kg), poultry manure (722.5mg/kg), pig dung (918.0mg/kg), poultry manure (820.6mg/kg) and saw dust (303.6 mg/kg) respectively. Its lowest were found in poultry manure (2424.92mg/kg), saw dust (178.5mg/kg), saw dust (127.5mg/kg), saw dust (429.8mg/kg) and poultry manure (203.3mg/kg) respectively. The variations seen on the nutrient composition among the produced biochars might be due to variations which occur during progressive concentration of minerals and destruction of volatile lignocellulosic matters as heat passes through the different biomass (Tsai et al., 2012).

Table 2: The chemical composition of the biochars used for the incubation study

Biochar	Biochar Yield (%)	pH (H_2O)	Total C	Total N	Total P	Total Ca	Total Mg	Total K	Total Na
			g/kg		$mgkg^{-1}$				
Pig Dung	84.0	6.3	30.7	19.6	3059.13	246.5	918.0	742.4	204.3
Poultry Manure	67.6	9.4	33.5	25.2	2424.92	722.5	782.0	820.6	203.3
Saw Dust	76.0	7.3	34.3	11.2	3096.43	178.5	127.5	429.8	303.6

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The effect of saw dust biochar (SDB), poultry manure biochar (PMB) and pig dung biochar (PDB) on soil chemical properties

Effect of SDB, PMB, and PDB Treatments on soil pH and organic matter of the soil

The analysis of soil pH data using repeated measures showed a significant impact on days of incubation and on the interaction between treatments and days of incubation (Table 3). The simple effect revealed a notable effect on each measurement point (Table 3). The highest pH was observed in SDB @ 10t/ha + PMB @ 10t/ha at 30 and 45 days measurement while PMB @ 20t/ha gave the highest pH at 60 and 75 days. In all, soil pH in the SDB @ 10t/ha + PMB @ 10t/ha at 30 days was significantly highest (6.37), followed by PMB @ 20t/ha (6.33) treatments, although variation was observed both treatments were statistically the same. Although, PMB @ 20t/ha showed slight decrease at 45 days incubation , it maintained the highest pH as the incubation days progresses from 60 to 75 days (Table 4). The control treatment (No biochar amendment) at 45 days interval recorded the lowest pH (5.90).

Numerous studies have previously demonstrated that organic amendments can elevate soil pH (Haque et al., 2021 and Masud et al., 2020). In our study we observed a substantial improvement in soil pH when biochar are applied, as opposed to the control except at 75 days where control showed a reasonable increase. Also, compared to other biochar, poultry manure biochar exhibited a longer-lasting influence on soil pH levels. The rise in soil pH can be linked to increased base saturation from three cations (Ca, K and Mg) (Table 2) and also driven by the high ash content in biochar. The ash generated during the pyrolysis process contributed to the alkaline nature of the resulting biochar. The high concentration of basic cations, primarily calcium found in ash compensates for soil calcium deficiency and enhances pH levels (Ch'Ng et al., 2019 and Norazlina et al., 2014).

Table 3: The repeated measures (ANOVA) analysis results using General Liner Model (GLM) for the P values and significant level of the treatments, days of incubation, and treatments with days of incubation interactions of parameters

Factors	Treatment		Days of incubation		Treatment*Days of incubation	
	P values	Significant Level	P values	Significant Level	P values	Significant Level
pH	<0.0001	***	<0.0001	***	<0.0001	***
OM	<0.0001	***	<0.0001	***	<0.0001	***
TN	<0.0001	***	<0.0001	***	<0.0001	***
Avail. P	<0.0001	***	<0.0001	***	<0.0001	***
Exch. Ca	<0.0001	***	<0.0001	***	<0.0001	***
Exch. Mg	<0.0001	***	<0.0001	***	<0.0001	***
Exch. K	<0.0001	***	<0.0001	***	<0.0001	***
Exch. Na	<0.0001	***	<0.0001	***	<0.0001	***
CEC	<0.0001	***	<0.0001	***	<0.0001	***
Exch. Al	<0.0001	***	<0.0001	***	<0.0001	***
Exch. H	<0.0001	***	<0.0001	***	<0.0001	***

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Table 4 Effect of SDB, PMB, and PDB Treatments on Soil pH

Treatments	Soil pH			
	Day 30	Day 45	Day 60	Day 75
SDB @ 20t/ha	6.07b ± 0.06	5.93c ± 0.06	5.93d ± 0.06	6.23c ±0.07
PMB @ 20t/ha	6.33a ± 0.12	6.47a ± 0.06	6.57a ± 0.06	6.57a ±0.05
PDB @ 20t/ha	6.27a ± 0.07	6.27b ± 0.06	6.40ab ± 0.00	6.27bc ±0.06
SDB @ 10t/ha + PMB @ 10t/ha	6.37a ± 0.06	6.50a ± 0.10	6.47ab ± 0.07	6.37bc ±0.06
SDB @ 10t/ha + PDB @ 10t/ha	6.23a ± 0.07	6.50a ± 0.10	6.20c ± 0.10	6.30bc ±0.10
Control	6.00b ± 0.10	5.90c ± 0.10	6.20c ± 0.10	6.40b ±0.10

Means within the same column followed by the same letter are not significantly different at P < 0.05 (DNMRT). The column represents the mean values ± standard deviation of triplicates.

Effect of SDB, PMB, and PDB Treatments on Soil Organic Matter

Significant interaction effects between the treatments and incubation days were observed on soil organic matter (SOM) in the repeated measure analysis (Table 3). The treatment combinations and incubation day also significantly affected SOM individually (Table 5). The highest value (1.927%) on 30 days after incubation (DAI) was on SDB @ 20t/ha which increased 27% compared to the control. After that, it slightly decreased but maintained the highest value at the 60th and the 75th days of incubation, the highest SOM value was increased by 90% from the same treatment at 60 DAI compare to control.

Biochar application in the soil increases the content of SOC than the untreated soil because it influences C store and C sequestration to soil due to its recalcitrant characteristic over time (Trupiano et al., 2017). According to Lehmann et al. (2006), high intrinsic carbon content is contained by biochar itself, which causes higher TOC in biochar treated soil. Zhang et al., 2011 found that the application of 20 t ha^{-1} biochar in combination with urea can increase soil organic carbon content by 25%, relative to the unmodified soil. In this work the result obtained at 30 DAI was similar to that obtained by with Sukartono et al. (2011), where treating soil with 15 t ha^{-1} biochar gave 27% increase in organic carbon content when compared with unamended.

Table 5: Effect of SDB, PMB, and PDB Treatments on Soil Organic Matter

Treatments	Soil Organic Matter (%)			
	Day 30	Day 45	Day 60	Day 75
SDB @ 20t/ha	1.927a ± 0.0025	1.652c ± 0.0021	2.117a ± 0.0020	1.788a ± 0.0025
PMB @ 20t/ha	1.652 b± 0.0020	1.723b ± 0.0023	1.516c ± 0.0015	1.723b ± 0.0020
PDB @ 20t/ha	1.516d ± 0.0015	1.583d ± 0.0025	1.376e ± 0.0016	1.169d ± 0.0015
SDB @ 10t/ha + PMB @ 10t/ha	1.583 c± 0.0020	1.927a ± 0.0032	1.653b ± 0.0021	1.445c ± 0.0035
SDB @ 10t/ha + PDB @ 10t/ha	1.309e ± 0.0015	1.238e ± 0.0015	1.653b ± 0.0020	1.169d ± 0.0015
Control	1.515c ± 0.0021	1.113f ± 0.0152	1.445d ± 0.0035	1.113e ± 0.0157

Means within the same column followed by the same letter are not significantly different at P < 0.05 (DNMRT). The column represents the mean values ± standard deviation of triplicates.

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Effect of SDB, PMB, and PDB Treatments on Total nitrogen

The total nitrogen (TN) showed significant response to the biochar treatments, incubation days and the interaction between biochar treatments and incubation day on the repeated measures analysis (Table 3). In Table 6, it is shown that PDB @ 20t/ha during the 30 days of incubation time gave the highest TN value (0.198%) with control (0.113%) the least. The control container at 45 and 60 days after incubation had the highest TN with SDB @ 10t/ha + PMB @ 10t/ha having the highest TN (0.210%) at 75 DAI.

Total nitrogen content increases with biochar application as well to soil with no biochar. Although the effect of biochar on soil total nitrogen is insignificant when compared with soil mineral nitrogen content (Zhang et al., 2012). This is because the nitrogen in biochar is not readily available for plant uptake due to its chemistry and the aromatic structure (Xie et al., 2013 and Knicker, 2007). During the pyrolysis process, the heterocyclic compounds in biochar, such as amino acid, an amino sugar, and amines, lose most of the nitrogen. This causes nitrogen immobilization, making it unavailable for plants to uptake, and causes the rise in the C/N ratio (Cao and Harris, 2010 and Koutcheiko et al., 2007). Our study is in line with their observation as seen on 45 and 60 DAI.

Table 6: Effect of SDB, PMB, and PDB Treatments on Total nitrogen

Treatments	Total nitrogen (%)			
	Day 30	Day 45	Day 60	Day 75
SDB @ 20t/ha	0.155b ± 0.00100	0.141b ± 0.00100	0.168d ± 0.00100	0.098e ±0.00100
PMB @ 20t/ha	0.126d ± 0.00152	0.141b ± 0.00173	0.155e ± 0.00108	0.112d ±0.00115
PDB @ 20t/ha	0.198a ± 0.00115	0.113c ± 0.00115	0.183c ± 0.00123	0.126c ±0.00152
SDB @ 10t/ha + PMB @ 10t/ha	0.113e ± 0.00115	0.085d ± 0.00104	0.196b ± 0.00000	0.210a ±0.00000
SDB @ 10t/ha + PDB @ 10t/ha	0.141c ± 0.00100	0.168a ± 0.00108	0.183c ± 0.00100	0.141b ±0.00100
Control	0.113e ± 0.00115	0.168a ± 0.00110	0.210a ± 0.00000	0.141b ±0.00100

Means within the same column followed by the same letter are not significantly different at $P < 0.05$ (DNMRT). The column represents the mean values ± standard deviation of triplicates.

Effect of SDB, PMB, and PDB Treatments on Available phosphorus

The studied soil had high available P after biochar application. Soil available P showed significant increased with treatment and incubation days as well as the interactions between treatment and incubation (Table 3). The maximum soil available P of 33.56mg kg^{-1} was observed in PMB @ 20t/ha on the 30th day of incubation, which slightly decreases at 45th day of incubation but subsequently rises at both 60 and 75 days of incubation to maintain the biochar treatment with the highest available P. The lowest available P in all amended soil was observed in soil treated with SDB @ 20t/ha at 45days after incubation (Table 7).

After applying the biochar amendment, the availability of soil P increased up to the first 30 days of incubation; later on, it decreased. The availability of P increases due to the increase in soil pH, exchangeable cation, and reduction of the activities of Al and Fe (Mensah and Frimpong, 2018). Also, it might be due to the Mineralization of microbial activities from the soil organic amendments may be the reason for this increment (Ch'Ng et al., 2014 and Madiba et al., 2016).The decrease observed after the 30 days incubation might be due to the fixation of soil available P by the hydrous oxides of Al and Fe, which was responsible for the

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reduction of available P (Marsi and Sabaruddin, 2011). The pattern observed in this study is in line with the findings of Haque et al. (2021) and Panhwar et al. (2020).

Table 7: Effect of SDB, PMB, and PDB Treatments on Available phosphorus

Treatments	Available phosphorus (mg kg^{-1})			
	Day 30	Day 45	Day 60	Day 75
SDB @ 20t/ha	22.36e ± 0.021	17.71d ± 0.017	22.36d ± 0.021	19.59e ± 0.020
PMB @ 20t/ha	33.56a ± 0.020	18.64c ± 0.012	35.46a ± 0.025	32.64a ± 0.020
PDB @ 20t/ha	32.64b ± 0.020	22.36b ± 0.021	21.45e ± 0.025	25.17c ± 0.015
SDB @ 10t/ha + PMB @ 10t/ha	27.06d ± 0.026	24.25a ± 0.015	24.25b ± 0.015	24.25d ± 0.017
SDB @ 10t/ha + PDB @ 10t/ha	31.71c ± 0.015	24.25a ± 0.018	20.54f ± 0.015	18.64f ± 0.012
Control	21.45f ± 0.020	18.64c ± 0.016	23.32c ± 0.020	29.85b ± 0.020

Means within the same column followed by the same letter are not significantly different at $P < 0.05$ (DNMRT). The column represents the mean values ± standard deviation of triplicates.

Effect of SDB, PMB, and PDB Treatments on Exchangeable Calcium

The results in relation to soil secondary nutrients (Ca, Mg, K and Na) status due to effect of levels of biochar on soil after different intervals of incubation is presented in Table 8, 9, 10 and 11 respectively. The exchangeable Ca content in soil differed significantly due to the application of various produced biochar at all intervals incubation days together with the interaction between biochar treatments and incubation days (Table 3). Application of PMB @ 20t/ha showed the highest significant effect on exchangeable Ca at 30 DAI (Table 8). The biochar treatment (PMB @ 20t/ha) maintain a continuous highest significant trend of exchangeable Ca content in all the incubation intervals from 30 to 75 DAI, but higher of exchangeable Ca was at 30 DAI (4.533 cmolkg^{-1}). The control (unamended) gave the lowest exchangeable Ca content at 30 DAI which did not maintain a specific trend across the incubation interval. The high exchangeable Ca content found in PMB @ 20t/ha and its maintaining the highest exchangeable Ca across the incubation days interval is because is of calcium-rich organic amendments (Table 2) and when incorporated into the soil increases soil Ca content (Ch'Ng et al., 2014).

Table 8: Effect of SDB, PMB, and PDB Treatments on Exchangeable Calcium

Treatments	Exchangeable Ca (cmolc kg^{-1})			
	Day 30	Day 45	Day 60	Day 75
SDB @ 20t/ha	1.753f ± 0.0153	2.963c ± 0.0252	2.470c ± 0.0265	2.963c ± 0.0252
PMB @ 20t/ha	4.533a ± 0.0153	4.200a ± 0.2000	4.200a ± 0.2000	4.200a ± 0.2000
PDB @ 20t/ha	2.963d ± 0.0252	3.480b ± 0.0100	3.853b ± 0.0208	3.145b ± 0.0153
SDB @ 10t/ha + PMB @ 10t/ha	3.480b ± 0.0100	4.200a ± 0.2000	3.653b ± 0.0153	2.763d ± 0.0153
SDB @ 10t/ha + PDB @ 10t/ha	3.330c ± 0.0200	3.147c ± 0.0153	2.090d ± 0.0206	2.457e ± 0.0153
Control	2.627e ± 0.0153	2.457d ± 0.0157	4.200a ± 0.2000	2.963c ± 0.0252

Means within the same column followed by the same letter are not significantly different at $P < 0.05$ (DNMRT). The column represents the mean values ± standard deviation of triplicates.

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Effect of SDB, PMB, and PDB Treatments on Exchangeable Magnesium

The biochar treatment, incubation days as well as the interaction between biochar treatment and incubation days significantly affected soil exchangeable Mg (Table 3). Table 9 shows that biochar amendments significantly changed exchangeable Mg in the soil with the highest exchangeable Mg (2.767 cmolc kg−1) observed in soil treated with PMB @ 20t/ha at 75 DAI followed by PMB @ 20t/ha on day 45. The lowest value (0.177 cmolc kg^{-1}) was noted from control treatment on the 60th day of incubation. The highest increment was 1463.28% from (PMB @ 20t/ha) on day 75 compared to the untreated soil. The current study results are in line with those of Panhwar et al. (2020), who reported an exchangeable Mg increase by 282.81% by applying lime and bio-fertilizer. Several basic cations are present in biochar ash; the content of exchangeable bases can cause the increment with the application of biochar to the soil (Abewa et al., 2013).

Table 9: Effect of SDB, PMB, and PDB Treatments on Exchangeable Magnesium

Treatments	Exchangeable Mg (cmolc kg^{-1})			
	Day 30	Day 45	Day 60	Day 75
SDB @ 20t/ha	2.260a ± 0.0100	1.050d ± 0.0100	1.740b ± 0.0200	0.870e ± 0.0200
PMB @ 20t/ha	1.920b ± 0.0100	2.627a ± 0.0153	2.440a ± 0.0100	2.767a ± 0.0115
PDB @ 20t/ha	1.233d ± 0.0152	1.393c ± 0.0252	1.570c ± 0.0200	1.743c ± 0.0153
SDB @ 10t/ha + PMB @ 10t/ha	1.743c ± 0.0153	2.260b ± 0.0100	1.570c ± 0.0200	2.090b ± 0.0200
SDB @ 10t/ha + PDB @ 10t/ha	1.920b ± 0.0101	2.260b ± 0.0100	1.743b ± 0.0153	1.233d ± 0.0157
Control	0.713e ± 0.0154	1.050d ± 0.0100	0.177d ± 0.0115	1.743c ± 0.0155

Means within the same column followed by the same letter are not significantly different at $P < 0.05$ (DNMRT). The column represents the mean values ± standard deviation of triplicates.

Effect of SDB, PMB, and PDB Treatments on Exchangeable Potassium

Exchangeable K in soil showed significant increase due to application of different biochar treatments at 30, 45, 60 and 75 DAI in soil (Table 10). The highest Exchangeable K was observed at PMB @ 20t/ha (8.027 cmolkg-1) at 30 days after incubation and the lowest at the same incubation interval was SDB @ 20t/ha (2.550 cmolkg-1) A continuous increasing trend of exchangeable K content was recorded from 30 to 60 DAI in all intervals of incubation with SDB @ 20t/ha but a slight was observed with PMB @ 20t/ha. Of all the biochar treatments, application of PMB @ 20t/ha at 75 DAI gave the overall highest in exchangeable K (9.777 cmolkg-1). The increase found in PMB was a function of the content of nutrient in the produced biochar (Abewa et al., 2013).

Finally, increase in exchangeable bases in soil at different incubation intervals can be attributed to release of basic cations from biochar. During pyrolysis, biomass acids are converted into bio-oil and alkalinity which is inherited by solid biochar (Laird et al., 2010). Most of the Ca, Mg, K, P, and plant micronutrients in feedstock are partitioned into the biochar ash fraction during pyrolysis. Ash in biochar rapidly releases free bases such as Ca, Mg and K to the soil solution thereby not only increases soil pH but also exchangeable bases. Such observations were also noticed by Chan et al. (2008).

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Table 10: Effect of SDB, PMB, and PDB Treatments on Exchangeable Potassium

Treatments	Exchangeable K (cmolc kg^{-1})			
	Day 30	Day 45	Day 60	Day 75
SDB @ 20t/ha	2.550d ± 0.017	4.253b ± 0.0153	7.860a ± 0.0000	7.820b ± 0.0000
PMB @ 20t/ha	8.027a ± 0.015	3.543d ± 0.0208	3.130c ± 0.0200	9.777a ± 0.0115
PDB @ 20t/ha	7.820b ± 0.000	3.909c ± 0.0015	7.821b ± 0.0012	7.820b ± 0.0000
SDB @ 10t/ha + PMB @ 10t/ha	7.838b ± 0.001	3.530d ± 0.0100	7.820b ± 0.0000	7.822b ± 0.0029
SDB @ 10t/ha + PDB @ 10t/ha	4.440c ± 0.010	7.820a ± 0.0000	7.820b ± 0.0000	3.909d ± 0.0026
Control	7.820b ± 0.000	7.820a ± 0.0000	7.820b ± 0.0000	5.474c ± 4.0633

Means within the same column followed by the same letter are not significantly different at $P < 0.05$ (DNMRT). The column represents the mean values ± standard deviation of triplicates.

Effect of SDB, PMB, and PDB Treatments on Exchangeable Sodium

The biochar treatments, incubation days as well as the interaction between biochar treatment and incubation days significantly affected soil exchangeable Na (Table 3). The highest exchangeable Na was from soil treated with SDB @ 20t/ha (0.1733 cmol kg^{-1}) at 30 DAI followed by PDB @ 20t/ha (0.1600 cmol kg^{-1}) at 45 DAI. Control at 60 DAI gave the lowest exchangeable Na (0.018 cmol kg^{-1}) (Table 11).

Among all the biochar treatments evaluated no specific trend was observed except with soils treated with only SDB @ 20t/ha which showed a decreasing trend across the incubation interval from 30 DAI to 75 DAI. The Specific trend observed with only SDB treated soil when compared with other biochars which could be translated to stability might be a function of type of biomass used (Nwajiaku et al. 2018).

Table 11: Effect of SDB, PMB, and PDB Treatments on Exchangeable Sodium

Treatments	Exchangeable Na (cmolc kg^{-1})			
	Day 30	Day 45	Day 60	Day 75
SDB @ 20t/ha	0.1723a±0.0021	0.0783c ± 0.0012	0.014f ± 0.0000	0.033f ± 0.0010
PMB @ 20t/ha	0.0813c±0.0006	0.0493d ± 0.0006	0.074a ± 0.0017	0.143b ± 0.0010
PDB @ 20t/ha	0.0423e±0.0006	0.1600a ± 0.0000	0.038c ± 0.0021	0.281a ± 0.0015
SDB @ 10t/ha + PMB @ 10t/ha	0.0636d±0.0020	0.1130b ± 0.0010	0.051b ± 0.0000	0.078d ± 0.0015
SDB @ 10t/ha + PDB @ 10t/ha	0.1257b±0.0012	0.0347e ± 0.0007	0.027d ± 0.0018	0.118c ± 0.0005
Control	0.0260f±0.0000	0.0270f ± 0.0010	0.018e ± 0.0006	0.041e ± 0.0007

Means within the same column followed by the same letter are not significantly different at $P < 0.05$ (DNMRT). The column represents the mean values ± standard deviation of triplicates.

Effect of SDB, PMB, and PDB Treatments on cation exchange capacity (CEC)

The repeated measures analysis (Table 3) showed that biochar treatment, incubation days and the interaction between biochar treatments and incubation days significantly influence the cation exchange capacity (CEC). The treatment and incubation days also significantly affected CEC individually. The highest CEC (43.63 cmolc kg^{-1}) was obtained in soil treated with PMB @ 20t/ha at 75 DAI while the lowest (7.43 cmolc kg^{-1}) was from the soil treated with SDB @ 10t/ha + PMB @ 10t/ha at 75 DAI (Table 12). The type of feedstock used to produce biochar and the chemical composition of the feedstock has impact on its CEC and

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thus on the nutrient holding capacity (Adhikari et al., 2024). PMB from table 2 showed highest total Ca (722.5 mgkg^{-1}) and total K (820.6 mgkg^{-1}) with a reasonable higher total Mg (782 mgkg^{-1}) when compared to SDB.

The results of the incubation days showed no progressive increase or decrease an implication that no specific trend was maintained in soil CEC by the produced biochar across the incubation intervals. Biochar prepared from different feedstock influenced the CEC of soil-biochar mix in varying extent (Adhikari et al., 2024). The way PMB react to the type of soil used might vary with the way other produced biochar will react. According to Limwikran et al. (2018), soil properties and the interaction between the soil-biochar environments are the major influence over the final CEC of the amended soil.

Table 12: Effect of SDB, PMB, and PDB Treatments on cation exchange capacity (CEC)

Treatments	CEC (cmolc kg^{-1})			
	Day 30	Day 45	Day 60	Day 75
SDB @ 20t/ha	12.41c ± 0.010	11.03e ± 0.058	10.43f ± 0.058	11.60d ± 0.100
PMB @ 20t/ha	8.27f ± 0.252	26.50a ± 0.100	16.00d ± 0.000	43.63a ± 0.152
PDB @ 20t/ha	12.00d ± 0.000	15.47d ± 0.115	19.50b ± 0.100	19.80c ± 0.000
SDB @ 10t/ha + PMB @ 10t/ha	19.10a ± 0.100	8.27f ± 0.252	12.20e ± 0.000	7.43f ± 0.057
SDB @ 10t/ha + PDB @ 10t/ha	8.57e ± 0.058	15.73c ± 0.117	16.60c ± 0.000	10.20e ± 0.000
Control	14.50b ± 0.173	17.10b ± 0.103	26.60a ± 0.200	21.30b ± 0.100

Means within the same column followed by the same letter are not significantly different at P < 0.05 (DNMRT). The column represents the mean values ± standard deviation of triplicates.

Effect of SDB, PMB, and PDB Treatments on Exchangeable Aluminum

The significant effects of biochar treatments, incubation days were observed on exchangeable Al (Table 3). In addition, the significant interaction effects of biochar treatments and incubation days on exchangeable Al are also presented in Table 3. The traced value (<0.001cmol kg^{-1}) of exchangeable Al were observed on soils treated with SDB @ 20t/ha and PMB @ 20t/ha at 30 DAI and SDB @ 20t/ha at 75 DAI. A significant increase was later observed in the above mentioned treated (Table 13) at 45 DAI which later showed a decrease at 60 DAI. In all the evaluated biochar treatments no specific trend was observed across the incubation intervals.

Biochar plays several roles in the Al toxicity amelioration of the Ultisol under experimental conditions. Besides being alkaline in nature, it contains a significant quantity of basic cations that produce OH − upon their hydrolysis. Furthermore, the biochar surface can act as an absorbent for the carboxyl and phenolic group of Al (Qian et al., 2013 and Sasmita et al., 2017). According to Ch'Ng et al. (2019) applying chicken litter biochar on soil resulted in an increase in soil pH by 0.99 units and reduces exchangeable Al and soluble Fe in the amended soil. This was attributed to the higher surface area and porous characteristics of the biochar, which decrease with soluble Al and Fe in the amended soil.

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Table 13: Effect of SDB, PMB, and PDB Treatments on Exchangeable Aluminum

Treatments	Exchangeable Al (cmolc kg^{-1})			
	Day 30	Day 45	Day 60	Day 75
SDB @ 20t/ha	0.000c ± 0.000	0.167b ± 0.057	0.200b ± 0.000	0.000d ± 0.0000
PMB @ 20t/ha	0.000c ± 0.000	0.267a ± 0.058	0.100c ± 0.000	0.233b ± 0.0577
PDB @ 20t/ha	0.200ab ± 0.100	0.100c ± 0.000	0.300a ± 0.000	0.100c ± 0.0000
SDB @ 10t/ha + PMB @ 10t/ha	0.300a ± 0.100	0.100c ± 0.000	0.200b ± 0.000	0.200b ± 0.0000
SDB @ 10t/ha + PDB @ 10t/ha	0.133b ± 0.058	0.100c ± 0.000	0.267a ± 0.058	0.300a ± 0.0000
Control	0.300a ± 0.000	0.100c ± 0.000	0.300a ± 0.000	0.200b ± 0.0000

Means within the same column followed by the same letter are not significantly different at $P < 0.05$ (DNMRT). The column represents the mean values ± standard deviation of triplicates.

Effect of SDB, PMB, and PDB Treatments on Exchangeable Hydrogen

The Exchangeable hydrogen showed significant response to the biochar treatments, incubation days and the interaction between biochar treatments and incubation day on the repeated measures analysis (Table 3). In Table 4.14, it is shown that SDB @ 10t/ha + PMB @ 10t/ha at 30 days of incubation time gave the lowest Exchangeable H (0.303 cmol kg^{-1}) with the highest exchangeable H value (0.900cmol kg^{-1}) were found on soil treated with SDB @ 10t/ha + PDB @ 10t/ha, PMB @ 20t/ha and from control at 45 DAI and 75 DAI respectively (Table 14). No specific trends were observed across the incubation intervals with the various biochar treated evaluated.

A significant negative relationship was found between soil pH and exchangeable H by the studies conducted in the past (Zhu et al., 2014; Rabileh et al., 2015; Zaidun et al. 2019). Geng et al. (2022) reported that biochar application raises soil pH by 8.48 to 79.25% while exchangeable acidity, Exchangeable Al and exchangeable H were all decreased by 56.94 to 94.95%, 34.38 to 95.6% and 58.72 to 93.2% respectively. The results obtained at 30 DAI demonstrated the same findings as seen on soil treated with SDB @ 10t/ha + PMB @ 10t/ha (Table 1, 4 and 14 respectively). Application of biochar (SDB @ 10t/ha + PMB @ 10t/ha) at 30 DAI increases the initial soil pH by 38% but decreases exchangeable H by 57 %.

Table 14: Effect of SDB, PMB, and PDB Treatments on Exchangeable Hydrogen

Treatments	Exchangeable H (cmolc kg^{-1})			
	Day 30	Day 45	Day 60	Day 75
SDB @ 20t/ha	0.713b ± 0.015	0.713b ± 0.018	0.600b ± 0.000	0.813b ± 0.028
PMB @ 20t/ha	0.600c ± 0.000	0.417c ± 0.012	0.713a ± 0.015	0.900a ± 0.000
PDB @ 20t/ha	0.417d ± 0.015	0.713b ± 0.016	0.517c ± 0.013	0.813b ± 0.015
SDB @ 10t/ha + PMB @ 10t/ha	0.303e ± 0.006	0.713b ± 0.026	0.600b ± 0.000	0.417e ± 0.016
SDB @ 10t/ha + PDB @ 10t/ha	0.813a ± 0.014	0.900a ± 0.000	0.713a ± 0.015	0.517d ± 0.017
Control	0.713b ± 0.015	0.900a ± 0.000	0.517c ± 0.016	0.600c ± 0.000

Means within the same column followed by the same letter are not significantly different at $P < 0.05$ (DNMRT). The column represents the mean values ± standard deviation of triplicates.

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The temporal dynamics of biochars from different biomass on soil chemical properties

Table 3 to 14 showed the temporal dynamics on soil chemical properties evaluated. The changes observed might be attributed to a lot of factors. According to Lehmann and Joseph (2015), feedstock types which determine the elemental composition of the biochar as well as its surface area, porosity and pH all play critical roles in determining how biochar interacts with the soil matrix. Applied biochar in the soil interacts with the soil matrix through various processes including ion exchange, adsorption and decomposition. These interactions cause shifts in soil properties such as pH, nutrient availability and microbial activity. Notably, these changes do not happen instantly; instead, they evolve over time due to the slow release of nutrients from biochar, ongoing microbial activity and changes in soil structure. However, understanding the temporal dynamics of soil chemical properties is crucial for prediction the long term impact of biochar on soil fertility and productivity Chinala et al. (2014).

Recently studies have shown that biochar's impact on soil pH, for example, may initially be significant particularly on acidic soils, due to the liming effect but may stabilize or diminish over time as the biochar ages and interacts with other soil components (Biederman and Harpole, 2013). This is in line with the observations in soil pH during incubation in table 4. Similarly, the CEC of soils may increase following biochar application, but the extent and persistence of this effect depend on factors such as the biochar's surface area, porosity and the incubation time in the soil (Mukherjee et al., 2014). The role of incubation time is critical in understanding the longer-term effects of biochar. During incubation, microbial colonization, oxidation of biochar surfaces and further decomposition of labile organic matter in biochar can alter its chemical and physical properties, leading to dynamic changes in soil properties. According to Yuan and Xu (2011), the impact of biochar on nutrient retention, soil pH and organic matter dynamics can vary depending on the length of time the biochar has been in contact with the soil.

Inter-element relationships of the soil chemical parameters at the different days of incubation study

The inter-element relationship of the soil chemical parameters at 30 and 45 days of incubation study were presented on Table 15. It was found that OM had no significant association with all the soil chemical parameters evaluated in 30 DAI whereas at 45 days after incubation (DAI), OM had significant association with almost all the evaluated soil chemical parameters. They include TN (-0.86), K (-0.94), Na (0.59), Ca (0.82) and H (-0.70). This implies that there is more OM build up at 45 DAI, which influences many soil chemical properties either positively (Ca and Na) and negatively (TN, K and H) as seen in Table 4.16. pH showed a strong positive correlation with Ca (0.70) and Avail P (0.71) but however, had a slight negative association with H (-0.57) at 30 DAI. pH also at 45 DAI correlated positively and significantly with Ca (0.75), Mg (0.95) and Avail P (0.69). TN at 30 DAI showed no significant association with other soil chemical parameters but at 45 DAI, a significant association was seen with K (0.08), Na (-0.82) and Ca (-0.69). The non-significant association observed at 30 DAI could be because of the non-availability of nitrogen at the earlier stage for plant uptake due to its chemical composition and aromatic framework (Xie et al., 2013).

CEC showed no significant associated with all the evaluated soil chemical parameters in both 30 DAI and 45 DAI except with Avail P (-0.55) at 30 DAI. Exchangeable cations showed

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association with some of the soil chemical parameters in both 30 DAI and 45 DAI. This indicates cations release by the applied biochar plays a significant effect on the soil chemical parameters.

Table 4 presented the inter-element relationship of the soil chemical properties at 60 and 75 days after incubation. It was found that OM at 60 DAI had a strong negative association with Ca (-0.69) and CEC (-0.74) while at 75 DAI, no significant association was found except a weak positive association observed with Ca (0.52). TN at 60 DAI had a lot of significant association with many of the evaluated soil chemical properties though some are weakly correlated while some are of strong association. They include K (0.69), Mg (-0.89), CEC (0.57) and Avail P (-0. 58). At 75 DAI the only significant associations TN possess was with H (-0.85). Avail. P had significant correlation with almost all the soil chemical properties evaluated except with that found with OM and CEC at 60 DAI. In 75 DAI strong positive interrelations were seen with pH (0.74), Ca (0.77), Mg (0.85) and CEC (0.83). Among all the evaluated exchangeable cations in this study, Ca is seen as the only cation with more significant associations. Ca at 60 DAI had weak positive significant correlation with pH (0.62), Na (0.51), CEC (0.51) and Avail. P (0.54) while at 75 DAI a positively and strongly associations were observed with the following soil chemical properties; K (0.64), Mg (0.73), CEC (0.94), Av. P (0.77) and H (0.75). pH correlated negatively with K (-0.57) and OM (-0.68) and positively with Na (0.88), Ca (0.62) and Avail P (0.59) at 60 DAI.

pH at 75 DAI showed a strong positive correlation with Ca (0.65), Mg (0.77), CEC (0.71) and Avail P (0.74). The correlation results obtained at the end of the incubation study (75 DAI) had pH to as the only soil chemical properties with the highest positive correlation. This implies that addition of biochar strongly improve the soil pH which on the other hand impact greatly and positively on other soil chemical properties evaluated. The inconsistence observed in some of the chemical properties especially nitrogen could be a function of the dynamic observed during the incubation study in anaerobic conditions.

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Table 15: The Inter-element relationships of the chemical parameters at 30, 45, 60 and 75 day's incubation

30

	pH	OM	TN	K	Na	Ca	Mg	CEC	Ava. P	Al	H
pH	1										
OM	-0.22	1									
TN	0.03	0.06	1								
K	0.37	-0.36	-0.21	1							
Na	-0.12	0.46	0.13	**-0.93****	1						
Ca	**0.70****	-0.41	-0.30	**0.62****	-0.34	1					
Mg	0.31	0.43	0.05	**-0.64****	**0.87****	0.06	1				
CEC	-0.01	0.16	-0.32	0.27	-0.35	-0.28	-0.29	1			
Av. P	**0.71****	-0.45	0.37	0.31	-0.10	**0.75****	0.21	**-0.55***	1		
Al	0.00	-0.48	-0.24	**0.50***	**-0.68****	-0.06	**-0.69****	**0.67****	-0.24	1	
H	**-0.57***	-0.07	-0.11	**-0.60****	0.48	-0.27	0.12	**-0.63****	-0.22	-0.39	1

45

	pH	OM	TN	K	Na	Ca	Mg	CEC	Av. P	Al	H
pH	1										
OM	0.39	1									
TN	-0.36	**-0.86****	1								
K	-0.25	**-0.94****	**0.80****	1							
Na	0.15	**0.59****	**-0.82****	**-0.68****	1						
Ca	**0.75****	**0.82****	**-0.69****	**-0.74****	0.39	1					
Mg	**0.90****	0.38	-0.20	-0.23	-0.13	**0.79****	1				
CEC	0.16	-0.21	0.46	0.05	-0.41	0.16	0.37	1			
Av. P	**0.69****	0.12	-0.41	0.07	0.35	0.35	0.46	-0.40	1		
Al	0.15	0.33	0.10	-0.42	-0.24	0.36	0.36	**0.64****	**-0.55***	1	
H	-0.33	**-0.70****	0.36	**0.80****	-0.20	**-0.73****	-0.48	**-0.53***	0.33	**-0.80****	1

60

	pH	OM	TN	K	Na	Ca	Mg	CEC	Av. P	Al	H
pH	1										
OM	**-0.68****	1									
TN	-0.11	-0.34	1								
K	**-0.57***	0.21	**0.69****	1							
Na	**0.88****	-0.41	-0.46	**-0.80****	1						
Ca	**0.62****	**-0.69****	0.19	-0.43	**0.51***	1					
Mg	0.33	0.25	**-0.89****	**-0.59****	**0.63****	-0.24	1				
CEC	0.10	**-0.74****	**0.57***	0.07	-0.19	**0.51***	**-0.72****	1			
Av. P	**0.59****	-0.19	**-0.58***	**-0.97****	**0.82****	**0.54***	**0.50***	-0.08	1		
Al	-0.31	-0.29	**0.72****	**0.78****	**-0.68****	-0.12	**-0.70****	**0.57***	**-0.82****	1	
H	0.16	0.22	**-0.62****	**-0.57***	0.45	-0.39	**0.71****	-0.45	0.47	**-0.64****	1

75

	pH	OM	TN	K	Na	Ca	Mg	CEC	Av. P	Al	H
pH	1										
OM	0.20	1									
TN	0.05	-0.33	1								
K	0.30	0.59*	-0.13	1							
Na	-0.04	-0.31	-0.13	0.19	1						
Ca	**0.65****	**0.52***	-0.42	**0.64****	0.26	1					
Mg	**0.77****	0.13	0.25	0.47	0.28	**0.73****	1				
CEC	**0.71****	0.29	-0.46	0.46	0.27	**0.94****	**0.73****	1			
Av. P	**0.74****	0.05	-0.03	0.41	0.13	**0.77****	**0.85****	**0.83****	1		
Al	0.44	-0.41	0.41	-0.32	0.02	-0.02	0.44	0.19	0.23	1	
H	0.15	0.49	**-0.85****	**0.50***	0.37	**0.75****	0.16	**0.69****	0.34	-0.47	1

**. Correlation is significant at the 0.01 level (2-tailed), *. Correlation is significant at the 0.05 level (2-tailed).

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CONCLUSION

The interaction between biochar from different biomass source and incubation time underscore the importance of tailoring biochar use to specific biomass and environmental conditions. However, the impact of biochar on nutrient retention, soil pH and organic matter dynamics can vary depending on the length of time the biochar has been in contact with the soil. PMB@20t/ha stand out as the only produced biochar in this study, which not just impact positively on almost all the soil chemical properties evaluated but also maintain a long-lasting effect on the soil. A deeper understanding of the temporal dynamics of soil chemical properties following biochar application is essential for optimizing biochar as well as maximizing its environmental and agricultural benefits. Finally, irrespective of the biochar types, the application of these biochar amendments to agricultural lands is recommended. This is because from the results obtained in this study, biochar application could be seen as an agricultural practice that have the potential of enhancing soil health and possibly crop yield. Although, the results from the study showed a clear effect of biochar and incubation time on soil chemical properties, conducting comprehensive field trials is recommended to ensure that local farmers benefit from this research finding.

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