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Effects of biochar application on the chemical properties of selected soil series in South-Western Nigeria

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Abstract

The present study aimed to investigate the effects of biochar application on the chemical properties of the Iwo and Egbeda soil series. The soil samples used for this study were collected from Teaching and Research Farm, OAU, Ile-Ife. The soil belongs to an Ultisol. Four agro wastes (maize cob, maize husk, maize straw and cocoa pod) were pyrolysed at 400° C, and a 8 week incubation experiment was carried out with biochars applied at the rates of 0, 5, and 10 ton.ha⁻¹. The soil chemical properties analysed include soil pH, organic carbon, total nitrogen, available phosphorus, and exchangeable cations. The assay of the biochars showed the pH values above neutral and contained appreciable amounts of carbon, phosphorus and potassium. The FTIR results of the biochars showed the presence of phenol, carboxylic groups and NH functional groups in most of the biochars, indicating the capacity of the biochars, to enhance the nutrient holding capacity of the soil. Addition of maize cob, maize husk, maize straw and cocoa pod biochars had significant effects on soil pH. Organic carbon levels improved with biochars application rising to 16.38 g.kg⁻¹ at 5 ton.ha⁻¹, with cocoa pod biochar application compared to the control. The effects of biochars on available phosphorus was modest in all the treated pots. However, the impact of biochars on total nitrogen was minimal across treatments, and no significant changes in electrical conductivity or exchangeable cations were observed except in Ca and K. Conclusively, the ameliorating effect of biochars on chemical properties of Iwo and Egbeda soil series was consistent with their chemical composition.

Key words: biochars, pH, cocoa pod, organic carbon, incubation

Introduction

Soil degradation is a worldwide issue in agricultural landscapes, particularly in regions with intensive agricultural practices, and this poses significant risks to food security, biodiversity and environmental sustainability on large scale. The problem arises from the degradation of soil quality and fertility, caused by both human and natural processes (Prăvălie, 2021). Examples of human activities that contributed to soil degradation include continuous cultivation, improper land management and high level of chemical fertilizers application. The world's population is expected to reach 9 billion by the end of 2050 (Godfray et al., 2010), and this population growth will require an increase in food supply by more than 50% (Mueller et al., 2012). This calls for enhanced nutrient management strategies for improved crop production, such as addition of biochars for soil properties improvement.

A large quantity of agro-wastes, consists of waste from cropping activities (corn stalks, corn cob and husk, cocoa pod and vegetable wastes), animal wastes (manure, animal carcasses), and food processing waste, are generated on a daily basis and poor management technique, is a great threat to the well-being of the people and the environment (Azeez et al., 2023). These agricultural wastes can be utilized as feedstock for biochar production, thereby reducing waste pollution. Additionally, the addition of biochar to soil often improves its chemical properties. Nigeria's agricultural sector produces a large volume of crop residues and animal wastes. These wastes are usually left on the field to decompose or burned. Burning of these residues contribute significantly to Greenhouse Gas (GHG) emissions, resulting in severe impact on air quality, biodiversity and the overall human health. To avoid this adverse effect, farmers can explore the conversion of these crop residues into Biochar through pyrolysis process. Biochar is a stable carbon-rich form of charcoal that is produced through the pyrolysis of organic materials. The pyrolysis process typically occurs at temperatures ranging from 300° C to 800° C in the absence of oxygen, resulting in the conversion

of organic materials into a stable form of carbon known as biochar.

Biochar has the ability to adsorb heavy metals from soils, thereby reducing their bioavailability and mobility (Oen et al., 2006; Brandli et al., 2008), and remove heavy metals from waste-waters. This is primarily due to its high surface area, porous structure, and the presence of functional groups such as carboxyl and hydroxyl groups, which can form complexes with heavy metals. Biochar immobilizes heavy metals through several mechanisms: adsorption, where heavy metals bind to the surface of biochar via physical adsorption and ion exchange; complexation, whereby functional groups on the biochar form stable complexes with heavy metal ions; and precipitation, where biochar increases soil pH, leading to the formation of heavy metal hydroxides or carbonates. Studies have shown that maize straw biochar can effectively reduce the bioavailability of Cd and Pb in contaminated soils. This is attributed to its high cation exchange capacity (CEC) and alkaline pH, which promote the adsorption and precipitation of these metals (Cao et al., 2011). Also, Maize straw biochar has been observed to reduce the mobility of Zn, enhancing soil remediation efforts (Beesley et al., 2011). Likewise, Cocoa pod biochar has demonstrated a strong ability to immobilize Cu and Ni in soils. The high lignin content in cocoa pods contributes to the stability and effectiveness of the biochar. Cocoa pod biochar has been found to reduce the bioavailability of As, making it a suitable amendment for soils contaminated with this metalloid (Santos et al., 2018). Additionally, biochar applications have been found to have positive effects on soil microbial diversity, crop productivity, and soil organisms (Singh et al., 2022).

Further studies are still needed to investigate the relevance of the biochar from these agricultural wastes on our environment. Therefore, the objective of this study was to investigate the effects of addition of maize cob, maize husk, maize straw and cocoa pod biochars on the chemical properties of Iwo and Egbeda soil series in South-western Nigeria.

Materials and methods

Description of the Study Area

The soil samples used for this study were collected from the Teaching and Research Farm, Obafemi Awolowo University (OAU), Ile-Ife. The farm is located within the tropical rainforest zone of South-western Nigeria, between latitudes 7° 32'52" N and 7° 32'51" N, and longitude 4° 32'15" E and 4° 32'18" E, at 200 meters above sea levels. The area is faced with approximately eight months of annual rainfall that is bimodal in distribution pattern with peaks in June and September. It has about four months of dry seasons each year, though the distribution of rainfall is not uniform over the years. The average annual rainfall ranges from 1200 mm to 1500 mm, while the average annual temperature ranges from 25° C to 30° C.

Sample collection and preparation

The maize cob, maize husk, maize straw and cocoa pod wastes used for production of biochar, were collected at Teaching and Research Farm, Obafemi Awolowo University, Ile-Ife. These agro wastes were selected as biochar materials because of their accessibility to farmers. The samples were spread and air dried to reduce moisture content. The wastes were crushed to smaller fraction, to increase the surface area and pyrolyzed at 400° C. It was bagged and labelled.

Surface soil samples from Iwo and Egbeda series were collected from the Teaching and Research Farm, Obafemi Awolowo University, Ile-Ife. The soil samples were collected at 0-15 cm depth, air dried, crushed gently, and sieved through 2 mm sieve. It was bagged and labelled and sub - samples were taken to the laboratory for analysis.

Incubation study

A hundred grams of soil were measured in triplicate into 500 g pots for the experiment. The biochars (maize cob, maize husk, maize straw and cocoa pods) were applied to the soil samples at rates of 0 ton.ha⁻¹, 5 ton.ha⁻¹, and 10 tons.ha⁻¹, which corresponded to 0 g/100 g, 0.25 g/100 g,

and 0.5 g/100 g of soil, respectively. The treatment with 0 g/100 g of soil served as the control. The treatments are as follow: C0 I = Control treatment for Iwo series soil, C0 E = Control treatment for Egbeda series soil, C1 I = Maize cob at 5 ton.ha⁻¹ for Iwo series soil, C1 E = Maize cob at 5 ton.ha⁻¹ for Egbeda series soil, C2 I = Maize cob at 10 ton.ha⁻¹ for Iwo series soil, C2 E = Maize cob at 10 ton.ha⁻¹ for Egbeda series soil, H1 I = Maize husk at 5 ton.ha⁻¹ for Iwo series soil, H1 E = Maize husk at 5 ton.ha⁻¹ for Egbeda series soil, H2 I = Maize husk at 10 ton.ha⁻¹ for Iwo series soil, H2 E = Maize husk at 10 ton.ha⁻¹ for Egbeda series soil, Cp1 I = Cocoa pod at 5 ton.ha⁻¹ for Iwo series soil, Cp1 E = Cocoa pod at 5 ton.ha⁻¹ for Egbeda series soil, Cp2 I = Cocoa pod at 10 ton.ha⁻¹ for Iwo series soil, Cp2 E = Cocoa pod at 10 ton.ha⁻¹ for Egbeda series soil. The treatments were arranged in a completely randomized design (CRD) with three replications. The experimental pots were watered to achieve 80% field moisture capacity. Perforated polythene covers were placed on the pots to reduce evaporation and conserve soil moisture. The incubation experiment lasted for 10 weeks, after which samples were taken from treated pots for laboratory analyses.

Also, samples were taken from each biochar from these agro wastes for Fourier Transformed Infrared spectroscopy (FTIR) analysis, in order to determine the dominant functional groups present in the maize cob, maize husk, maize straw and cocoa pods.

Laboratory analysis

Determination of elemental composition of biochars

The pH of the biochars was determined with a standardized digital pH meter in a 1:2 w/v suspension of the biochars and distilled water after a 1 hour equilibration period, using the procedure outlined by Peech et al. (1965) with a review by Jindo et al. (2014). To determine the basic cations, 1 g of the biochars was digested with 20 ml of concentrated H₂SO₄ for 2 hours, and left overnight to cool completely. The digest was transferred into 50 ml volumetric flask, made up to mark with

distilled water. The concentrations of Na and K were determined by a flame photometer, while Ca and Mg were determined using atomic absorption spectrophotometer (AAS) (Zhang et al., 2002). Organic carbon was determined on 0.2 g sample using Walkley and Black (1934) method, while the total N was determined on 0.5 g sample using micro-Kjeldahl digestion and distillation procedure (Bremner and Mulvaney, 1982).

Soil analyses

Soil pH was determined with a glass electrode pH meter in a 1:2 w/v suspension of air-dried soil in 0.01 M CaCl_2 solution and distilled water, after a 30 minutes equilibration time (Peech, 1965). Soil exchangeable cations (Na, K, Ca and Mg) were determined in the extract of 10 g soil with 100 ml 1 N neutral ammonium acetate solution, and shaken for 30 minutes (Thomas, 1983). The concentrations of Na and K were determined by a flame photometer while Ca and Mg were determined using atomic absorption spectrophotometer (AAS). Total carbon was determined using a modified chromic acid digestion method (Nelson and Sommer, 1996), available phosphorus was determined using the Bray-1 method (Bray and Kurtz, 1945) as modified by Kuo (1996), while the particle size analysis was by hydrometer method (Bouyoucos, 1962). The field moisture capacity was determined using the core method (Black, 1965).

Structural analysis

The biochars were analyzed using Fourier Transform Infrared Spectroscopy (FTIR) in the range of 400 to 4000 cm^{-1} , employing the Attenuated Total Reflectance (ATR) technique. A small amount of each sample was placed on the mounting plate using a spatula to cover the exposed surface of the crystal. The pressure arm was then lowered onto the sample, and the knob was rotated until it made contact. Each sample was scanned four times, with the force gauge indicating a pressure between 100 and 130 pascals. The scanned results were printed, and the mounting plate was cleaned with methanol to avoid contamination. This procedure was repeated for all samples.

Statistical analysis

The data obtained were analysed using R – statistical software version 3.6.0. (R core Team, 2019). The data were fitted by a generalized linear model with fixed effects representing different treatments. Data were checked for normality using Shapiro-wick test, while the Battelet test was used to check constant variance. Post-hoc multiple pairwise comparisons were analysed by Tukey's significant differences, using the CLD function implemented in the R package emmeans. For all analysis, the criterion used for statistical significance was $P < 0.05$.

Results and discussion

Elemental composition of the biochar

The results of pH, electrical conductivity, total carbon, total nitrogen, total phosphorus and basic cations of all the agro wastes pyrolysed at 400° C were shown in table 1. The pH of maize cob, maize husk, maize straw and cocoa pods biochars were above neutral values (alkaline), and ranged between 8.12 and 9.95 (table 1). This suggests that all the biochars have liming potentials for ameliorating soil acidity. The highest electrical conductivity (EC) was recorded in maize husk biochar, while the remaining biochars had very low EC. The organic carbon of the biochars was very high with the highest value recorded in cocoa pods (21.45 g.kg^{-1}), whereas the total nitrogen of all the biochars was generally low. Similar result had been reported by previous study, where an increase in pyrolysis temperature led to increase in carbon content of the biochar produced, which was attributed to the presence of certain amount of original organic plant residues, such as cellulose, in the produced biochar (Chun et al., 2004). The total phosphorus content of the biochars ranged from 10 to 14.8 g.kg^{-1} , with the highest result recorded in biochar derived from maize husk. The biochar derived from maize straw had the highest potassium content (13.3 cmol.kg^{-1}), while the maize cob biochar had the lowest potassium content (2.47 cmol.kg^{-1}). According to Zhou et al., (2013), the increase could be attributed to the increase in the ash contents of biochar materials

Table 1. Elemental composition of biochars

Parameters	Biochars			
	Maize cob	Maize husk	Maize straw	Cocoa pod
pH (H ₂ O)	9.95±0.01	8.12±0.01	9.42±0.01	9.82±0.01
Electrical Conductivity (dS.m ⁻¹)	0.0079±0.00	1.268±0.00	0.0023±0.00	0.0059±0.00
Organic carbon (g.kg ⁻¹)	7.8±0.04	8.58±0.01	10.34±0.01	21.45±0.01
Total N (g.kg ⁻¹)	0.8±0.02	0.9±0.02	0.4±0.01	0.4±0.01
Total P (g.kg ⁻¹)	12.0±0.06	14.8±0.08	12.6±0.05	10.0±0.08
Basic cations (cmol.kg ⁻¹)				
Ca	0.02±0.00	0.02±0.00	0.011±0.00	0.05±0.00
Mg	0.03±0.00	0.04±0.00	0.011±0.00	0.06±0.00
K	2.47±0.01	6.18±0.02	13.3±0.03	11.05±0.01
Na	0.001±0.00	0.001±0.00	0.009±0.00	0.007±0.00

used in this study. The contents of Ca, Mg and Na from the biochars were very low.

Fourier transformed infrared spectroscopy analysis of the biochars

The biochars obtained from maize cob, maize husk, maize straw and cocoa pods were subjected to Fourier transformed infrared spectroscopic (FTIR) analysis, to identify the functional groups that dominate the exchange sites (fig. 1-4). The figures revealed FTIR spectrum of the typical functional group at wavenumber of 2000-4000 cm⁻¹ and fingerprint from 500-1500 cm⁻¹. The most common important features are broad band around 3300-3500 cm⁻¹, associated with OH stretch of OH groups, which are important for enhancing the water retention capacity of soil, C-H stretching vibrations from alkanes appear around 2800-3000 cm⁻¹, which may influence soil organic matter stabilization and the presence of aromatic C=C bonds is detected around 1600 cm⁻¹, which indicates stable carbon structures that help in long-term carbon sequestration within the soil. Presence of carboxyl groups (C=O stretching) around 1700 cm⁻¹, will enhance the biochar's ability to form stable complexes with metal ions,

aiding in nutrient retention, consistent with previous study (McCall et al., 2024). The aromatic structures around 1600 cm⁻¹ suggest a high level of stability and carbon sequestration potential in the soil. The presence of higher functional groups in biochars, particularly in maize straw and cocoa pod (fig. 3 and fig. 4), suggests that if biochar produced from different agro wastes are applied as soil amendments, it will increase soil cation exchange capacity with consequent higher nutrient release for plant uptake.

Physical and chemical properties of the soil used for the incubation experiment

The physical and chemical properties of the soil used for the incubation study are presented in table 2. The soil textural class of Iwo series was loamy sand while that of Egbeda series was sandy loam. South-western Nigeria has soil texture mostly composed of sandy loam, sandy clay, loamy sand and clay loam (Aizebeokhai et al., 2018). The high sand content in both soil series indicates a coarse soil texture, which generally results in good drainage and aeration, but low water and nutrient holding capacity.

The pH (0.01M CaCl₂) of the Iwo soil (5.7)

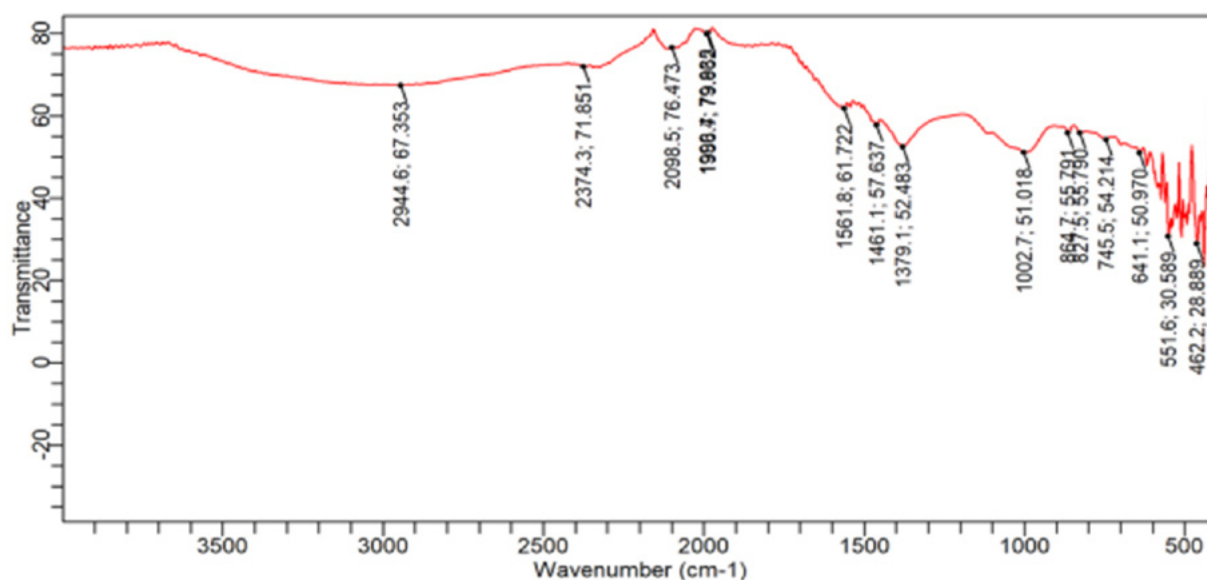


Fig. 1. Fourier Transform Infrared (FTIR) spectroscopy analysis of maize cob biochar

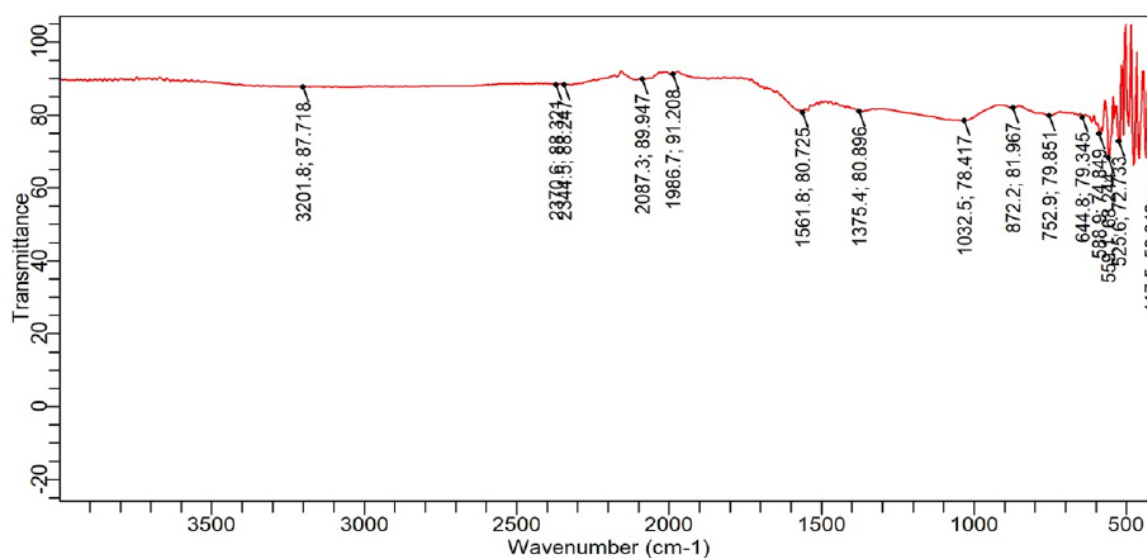


Fig. 2. Fourier Transform Infrared (FTIR) spectroscopy analysis of maize husk biochar

and that of Egbeda soil (6.1) was slightly acidic (table 2). For most crops, a pH range of 6.0 to 7.2 is considered optimal (Suleiman et al., 2017). The electrical conductivity (EC) value of Iwo and Egbeda soils were 0.105 and 0.23 dS.m⁻¹, respectively, indicating a non - saline soil, which is considered suitable for most crops. This is mainly due to the high rainfall received in humid areas,

which facilitates leaching of soluble salts from the soil profile. Soils with electrical conductivity of 4 dS.m⁻¹ and above are generally considered harmful to most crops (Wickramasinghe et al., 2021), thus, the two soils could be regarded as non-saline soils. The total organic carbon, total N, available P and exchangeable cations of both soils were low. Generally, the fertility status of

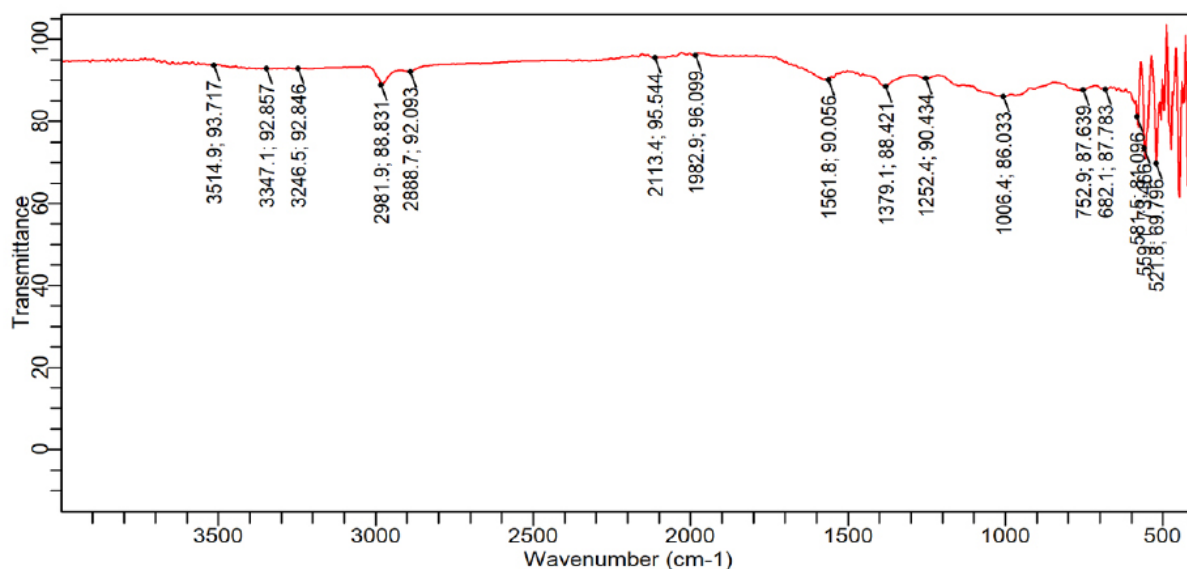


Fig. 3. Fourier Transform Infrared (FTIR) spectroscopy analysis of maize straw biochar

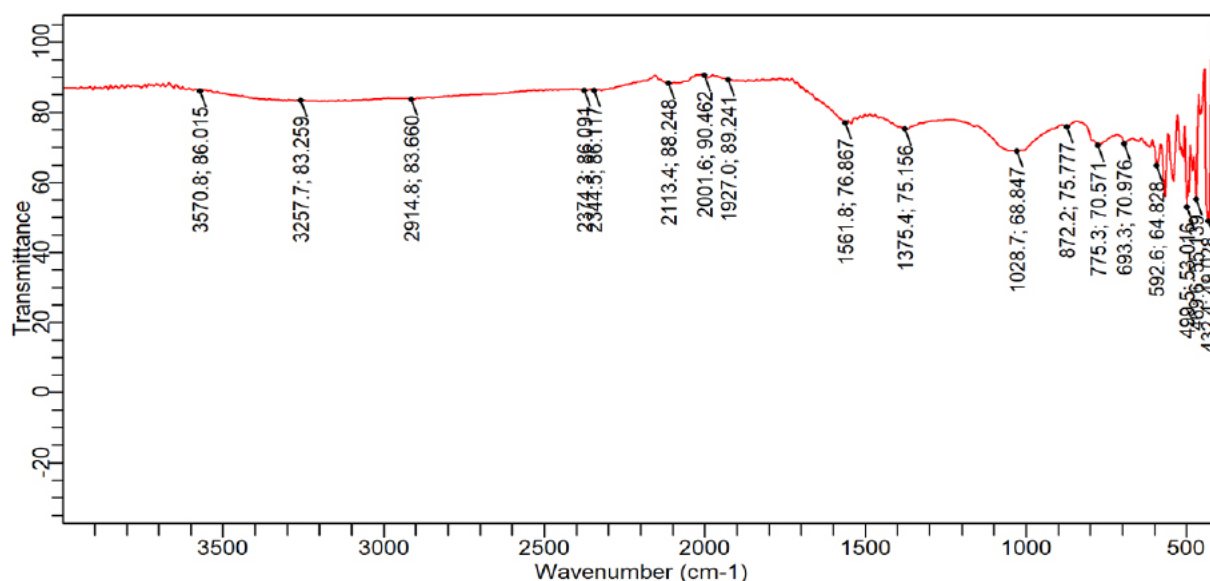


Fig. 4. Fourier Transform Infrared (FTIR) spectroscopy analysis of cocoa pod biochar

both soils was very low, thus application of organic amendments such as biochars will enhance the fertility of the soil.

Effects of biochar application on soil pH, electrical conductivities, available phosphorus, total carbon and total nitrogen of the soils after incubation

At the end of incubation experiment, addition

of biochars (maize cob, maize husk, maize straw and cocoa pods biochars) at 5 and 10 ton.ha⁻¹ significantly increased the soil pH for both Iwo and Egbeda soils (table 3). The soil pH increased with the rate of biochars application. In addition, application of cocoa pod biochar at 10 ton.ha⁻¹ in Egbeda soil (Cp2 E) had the highest soil pH (5.84). This result indicates that biochars produced from

Table 2. Physical and chemical properties of soils used for the experiment

Properties	Iwo series	Egbeda series
Sand (%)	83.68±0.1	79.68±0.03
Silt (%)	9.80±0.10	9.80±0.10
Clay (%)	6.52±0.02	10.52±0.01
Textural class	Loamy sand	Sandy loam
FMC %	16.80±0.06	19.78±0.03
pH (0.01 M CaCl ₂)	5.7±0.08	6.1±0.08
Electrical conductivity (dS.m ⁻¹)	0.105±0.00	0.23±0.01
Organic carbon (g.kg ⁻¹)	6.24±0.01	8.19±0.01
Available P (mg.kg ⁻¹)	7.87±0.01	8.99±0.01
Total Nitrogen (g.kg ⁻¹)	2.57±0.01	2.68±0.01
Exchangeable cations (cmol.kg ⁻¹)		
Ca	0.153±0.00	0.163±0.00
Mg	0.108±0.00	0.001±0.00
K	0.040±0.00	0.033±0.00
Na	0.009±0.00	0.008±0.00

maize cob, maize husk, maize straw and cocoa pods had liming potential for ameliorating soil acidity. As revealed in the FTIR analysis of the biochars, there were presence of carboxylic and phenolic functional groups in the biochars surface, which can buffer soil pH, similar to previous study (Tusar et al., 2023). Yuan and Xu (2011) have reported substantial increase in soil pH by the biochar treatment, which was attributed to the liming potential of biochar, base cation content and CaCO₃ content. The two soil series used in this study (Iwo and Egbeda) belong to Ultisol, which is highly weathered soil with low pH and nutrient status, due to high leaching of the basic plant nutrient in the soil profile, induced by high precipitation. Thus, the application of biochar to this soil will improve its pH and nutrient status. The addition of the biochars to Iwo and Egbeda soils significantly reduced the electrical conductivity (EC) except maize cob and maize husk biochars at 10 ton.ha⁻¹ in Egbeda soil (C2E and H2E, table 3), which significantly increased the EC when compared with control treatments. For instance, application of maize cob biochar to Egbeda soil at 10 ton.ha⁻¹ (C2E) increased EC by 27% when

compared with control. Previous study had reported increase in EC in acidic red soils following addition of biochar (Pandian et al., 2016). However, in a review conducted by Singh et al. (2022) on influence of biochar applications on soil physical and chemical properties, microbial diversity, and crop productivity: a meta-analysis, they reported that there was no significant increase in soil EC in different experimental settings (field, greenhouse, or laboratory). Generally, the effect of biochars in Iwo and Egbeda soils observed in this study was moderate, suggesting that the additions of the biochars produced from agro wastes will not result to saline soils, and this is very important as most arable crops could not tolerate accumulation of soluble salts. This result is consistent with previous study (Wickramasinghe et al., 2021).

In Iwo and Egbeda soils, additions of 5 and 10 ton.ha⁻¹ of maize cob, maize husk, maize straw and cocoa pod did not significantly influence the available P. However, addition of maize husk biochar to Iwo soil at 10 ton.ha⁻¹ (H2I) had the highest available P (10.06 mg.kg⁻¹) when compared with other treatments (table 3). This result could be attributed to the role of biochar in promoting

Table 3. pH, electrical conductivities, available phosphorus, total carbon and total nitrogen of the soils after incubation

Treatments	pH (0.01 M CaCl ₂)	Electrical conductivity (dS.m ⁻¹)	Available P (mg. kg ⁻¹)	Total C (g.kg ⁻¹)	Total N (g.kg ⁻¹)
C0 I	4.61j	0.73defg	3.85a	11.44bcdef	2.92bc
C0 E	5.6cde	0.84bcde	3.37a	7.67def	3.73a
C1 I	4.77hi	0.59fghi	4.25a	14.69abcd	2.33de
C1 E	5.77ab	0.94abc	2.91a	8.19def	2.57cd
C2 I	4.89g	0.57ghi	7.02a	19.76a	1.63fg
C2 E	5.73ab	1.07a	4.18a	7.8def	2.33de
H1 I	4.59j	0.51hi	3.87a	4.16f	1.52g
H1 E	5.7bc	0.91abcd	4.97a	15.99abc	2.1def
H2 I	4.58j	0.49i	10.06a	12.61abcde	1.63fg
H2 E	5.54e	0.97ab	2.45a	10.01bcdef	2.1def
S1 I	4.60j	0.44i	3.45a	11.31bcdef	1.98efg
S1 E	5.54e	0.84bcde	3.89a	11.18bcdef	2.22de
S2 I	4.67ij	0.44i	2.77a	11.18bcdef	2.57cd
S2 E	5.57de	0.77cdef	4.29a	8.45cdef	1.52g
Cp1 I	4.81gh	0.59fghi	2.37a	16.38ab	2.33de
Cp1 E	5.67bcd	0.69efgh	2.70a	10.53bcdef	3.38ab
Cp2 I	5.16f	0.51hi	5.20a	12.87abcde	2.45cde
Cp2 E	5.84a	0.75cdefg	2.60a	6.5ef	1.527g

Means with the same letters in the same column are not significantly different from each other at ($p \leq 0.05$), according to Tukey's Honest Significant Different Test,

Where: C0 I = Control treatment for Iwo series soil; C0 E = Control treatment for Egbeda series soil; C1 I = Maize cob at 5 ton.ha⁻¹ for Iwo series soil; C1 E = Maize cob at 5 ton.ha⁻¹ for Egbeda series soil; C2 I = Maize cob at 10 ton.ha⁻¹ for Iwo series soil; C2 E = Maize cob at 10 ton.ha⁻¹ for Egbeda series soil; H1 I = Maize husk at 5 ton.ha⁻¹ for Iwo series soil; H1 E = Maize husk at 5 ton.ha⁻¹ for Egbeda series soil; H2 I = Maize husk at 10 ton.ha⁻¹ for Iwo series soil; H2 E = Maize husk at 10 ton.ha⁻¹ for Egbeda series soil; Cp1 I = Cocoa pod at 5 ton.ha⁻¹ for Iwo series soil; Cp1 E = Cocoa pod at 5 ton.ha⁻¹ for Egbeda series soil; Cp2 I = Cocoa pod at 10 ton.ha⁻¹ for Iwo series soil; Cp2 E = Cocoa pod at 10 ton.ha⁻¹ for Egbeda series soil.

adsorption and precipitation of soil P, with consequent reduction in soil P availability (Ghodsad et al. 2022). However, such adsorbed and precipitated soil P could later be released to soil solution for plant uptake, similar to the report of Madiba et al. (2016) that biochar improves the P availability through P adsorption against leaching.

Application of C2 I, H1 E and Cp1 I significantly increased the total carbon, whereas other treatments had moderate influence on total carbon (table 3). This result confirmed that the biochars application enhances carbon sequestration, which

will mitigate global warming. Due to recalcitrant nature of biochar, its resistance to microbial decomposition allows it to persist in the soil for long periods, with consequent result in increasing the overall input of soil organic carbon (Leng et al., 2019; Madiba et al., 2016). It can be deduced from our results that if the biochar is applied for long period on the field, large amount of soil carbon stock will be achieved.

At the end of 8 weeks incubation experiment, biochars addition significantly reduced the total N in all the treated pots (table 3). This implies that

Table 4. Exchangeable cations of soils after incubation experiment

Treatments	Ca	Mg	K	Na
	cmol.kg ⁻¹			
C0 I	0.08d	0.0008a	0.0199g	0.0075a
C0 E	0.0967cd	0.0008a	0.0199g	0.0085a
C1 I	0.25a	0.0009a	0.1193bcde	0.0065a
C1 E	0.1807ab	0.0009a	0.0928def	0.0085a
C2 I	0.0767d	0.0009a	0.1392abcd	0.0079a
C2 E	0.15bcd	0.0009a	0.159ab	0.0073a
H1 I	0.2033ab	0.0009a	0.0861ef	0.0085a
H1 E	0.1667bc	0.0009a	0.0596fg	0.0079a
H2 I	0.19ab	0.0009a	0.0994cdef	0.0079a
H2 E	0.1cd	0.001a	0.0994cdef	0.0079a
S1 I	0.2133ab	0.0008a	0.0729ef	0.0079a
S1 E	0.1567bc	0.0009a	0.0596fg	0.0079a
S2 I	0.1933ab	0.0009a	0.0994cdef	0.0085a
S2 E	0.2033ab	0.001a	0.0795ef	0.0079a
Cp1 I	0.1467bcd	0.0009a	0.1127bcde	0.0073a
Cp1 E	0.0933cd	0.0009a	0.0994cdef	0.0073a
Cp2 I	0.16bc	0.0009a	0.1458abc	0.0073a
Cp2 E	0.1633bc	0.0009a	0.1723a	0.0085a

Means with the same letters in the same column are not significantly different from each other at ($p \leq 0.05$), according to Tukey's Honest Significant Different Test,

Where: C0 I = Control treatment for Iwo series soil; C0 E = Control treatment for Egbeda series soil; C1 I = Maize cob at 5 ton.ha⁻¹ for Iwo series soil; C1 E = Maize cob at 5 ton.ha⁻¹ for Egbeda series soil; C2 I = Maize cob at 10 ton.ha⁻¹ for Iwo series soil; C2 E = Maize cob at 10 ton.ha⁻¹ for Egbeda series soil; H1 I = Maize husk at 5 ton.ha⁻¹ for Iwo series soil; H1 E = Maize husk at 5 ton.ha⁻¹ for Egbeda series soil; H2 I = Maize husk at 10 ton.ha⁻¹ for Iwo series soil; H2 E = Maize husk at 10 ton.ha⁻¹ for Egbeda series soil; Cp1 I = Cocoa pod at 5 ton.ha⁻¹ for Iwo series soil; Cp1 E = Cocoa pod at 5 ton.ha⁻¹ for Egbeda series soil; Cp2 I = Cocoa pod at 10 ton.ha⁻¹ for Iwo series soil; Cp2 E = Cocoa pod at 10 ton.ha⁻¹ for Egbeda series soil.

nitrogen fertilizer needs to be applied whenever biochar is used as a soil amendment for viable crop production. The low amount of total nitrogen recorded in this study could be attributed to the low concentration of total nitrogen in the biochars. The mechanism behind this reduction is that the addition of biochar decreased the concentration of NH_4^+ in the soil due to the oxidation of NH_4^+ to NO_3^- . Furthermore, the oxygenated carbonyl and carboxyl functional groups present in the biochar structure may have reduced the availability of NH_4^+ for nitrification (Harter et al., 2014; Ab-

buzzini et al., 2019).

Exchangeable Ca and K were significantly increased following the application of the biochars at 5 and 10 ton.ha⁻¹ in all treated pots (table 4). However, biochars application did not influence exchangeable Mg and Na at the end of the incubation experiment. Elemental analysis of maize cob, maize husk, maize straw and cocoa pod biochars showed appreciable amounts of Ca and K, and this could explain the positive impact of these biochars on the concentrations of Ca and K in soils. Addition of biochar improves the cation

exchangeable capacity of soils with consequent increase in the bioavailability of plant nutrients (Zhang et al., 2021), and this could explain the positive impacts of biochars addition on exchangeable Ca and K in this study.

Conclusion

This study evaluated the effects of applying maize cob, maize husk, maize straw, and cocoa pod biochars on the chemical properties of the Iwo and Egbeda soil series after an eight-week laboratory incubation experiment. The higher pH values of the maize cob, maize husk, maize straw, and cocoa pod biochars indicate their liming potential in ameliorating soil acidity. FTIR analysis of the biochars revealed the presence of various functional groups, suggesting a high capacity to enhance the soil's nutrient-holding ability. Biochar applications at rates of 5 and 10 tons per hectare to the Iwo and Egbeda soils significantly increased soil pH, total carbon, and exchangeable calcium and potassium. However, only modest effects were observed on electrical conductivity and available phosphorus, while total nitrogen and exchangeable magnesium and potassium were significantly reduced. The incorporation of these highly carbonaceous biochar materials can induce beneficial changes in the chemical properties of highly weathered, acidic soils and enhance the bioavailability of essential plant nutrients, ultimately improving crop yield.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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