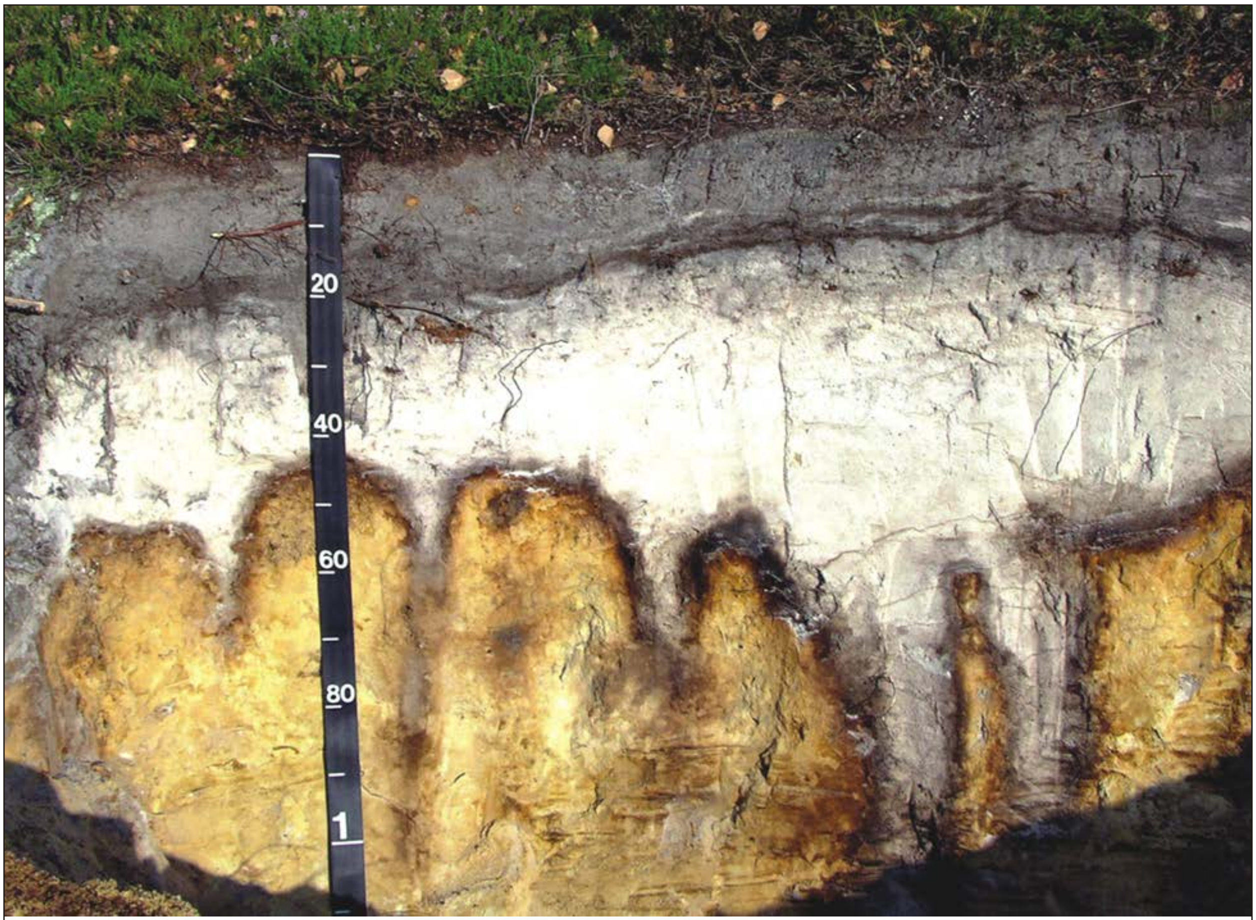

International Journal of
Soil Science

ISSN 1816-4978

Academic
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www.academicjournals.com

International Journal of Soil Science 10 (2): 63-73, 2015
ISSN 1816-4978 / DOI: 10.3923/ijss.2015.63.73

Characterization of Biochar Produced at Different Temperatures and its Effect on Acidic Nitosol of Jimma, Southwest Ethiopia

[1]Bayu Dume, [2]Gezahegn Berecha and [2]Solomon Tulu
[1]Department of Natural Resource Management,
[2]Department of Horticulture and Plant Sciences, College of Agriculture and Veterinary Medicine, Jimma University, P.O. Box 307, Jimma, Ethiopia

Corresponding Author: Gezahegn Berecha, Department of Horticulture and Plant Sciences, College of Agriculture and Veterinary Medicine, Jimma University, P.O. Box 307, Jimma, Ethiopia

ABSTRACT

Physical and chemical properties of the biochar varied as a function of feedstock selection and pyrolysis temperatures. Biochar additions to acidic soils have the potential to improve soil fertility and crop yield. Biochar materials were produced from coffee husk and corn cob at temperatures of 350 and 500°C and characterized by their physical and chemical properties. These were mixed with acidic soil at the rates of 0, 5, 10 and 15 t ha^{-1} and were laboratory incubated for 2 months at ambient temperature to examine changes in soil properties. Types of feedstock used at two different pyrolysis temperatures and application rate had no significant effects on soil textural classes but showed highly significant effects ($p<0.01$) on soil pH, Electrical Conductivity (EC), Cation Exchange Capacity (CEC), Organic Carbon (OC), Organic Matter (OM), Total Nitrogen (TN), exchangeable cations and available phosphorous. Application of coffee husk biochar showed relatively better improvement in soil chemical properties (pH, EC, CEC, OC, OM, TN, exchangeable cations and available phosphorous) than corn cob biochar at all application rates. The highest values of chemical properties were recorded when coffee husk biochar produced at 500°C temperature was applied at a rate of 15 t ha^{-1}. Therefore, we generated an evidence that application of biochar is very important to improve physical and chemical properties of acidic soil.

Key words: Biochar, pyrolysis temperature, feedstock, acidic soil, soil chemical, physical properties

INTRODUCTION

Biochar is a byproduct of the pyrolysis processing of organic feedstock (Antal and Gronli, 2003). Its addition to soils has attracted extensive attention as a method to increase soil carbon (C) sequestration while a lso reducing atmospheric carbon dioxide (CO_2) concentrations (Lehmann, 2007; Laird, 2008). Increased soil Carbon (C) sequestration can also improve soil quality because of the crucial role that C plays in chemical, biological and physical soil processes and many interfacial interactions (Stevenson, 1994). Pyrolysis is the heating of biomass in an oxygen limited atmosphere, causing release of volatile C structures, H, CH_4 and CO. The volatile C structures (alcohols, oils, tars, acids and so on) can be re-condensed as bio-oil (Antal and Gronli, 2003) and the biochar that remains consists mainly of C and contains some N and ash Ca, K.

Elements such as Ca, K and P entrained within the biochar, bones and other refuse materials increase soil nutrient levels and promote plant growth (Glaser *et al*., 2002). The ability of biochar to store C and improve soil fertility will depend on its physical and chemical properties which can be varied in the pyrolysis process or through the choice of feedstock. Because infertile soils in different regions around the world have specific quality issues and hence it follows that one biochar type will not solve all soil quality problems (Lehmann *et al*., 2003). For example, biochar with a highly aromatic composition may best suited for long term C sequestration because of their recalcitrant nature (Glaser *et al*., 2002; Novak *et al*., 2009). Biochar with large amounts of C in poly-condensed aromatic structures is obtained by pyrolyzing organic feedstock at high temperatures (400-700°C) but also have fewer ion exchange functional groups due to dehydration and decarboxylation potentially limiting its usefulness in retaining soil nutrients (Glaser *et al*., 2002; Baldock and Smernik, 2002; Hammes *et al*., 2006). On the other hand, biochar produced at lower temperatures (250-400°C) have higher yield recoveries and contains more C = O and C-H functional groups that can serve as nutrient exchange sites after oxidation (Glaser *et al*., 2002). Moreover, biochar produced at these lower pyrolysis temperatures has more diversified organic character, including aliphatic and cellulose type structures. These may be good substrates for mineralization by bacteria and fungi (Alexander, 1977) which have an integral role in nutrient turnover processes and aggregate formation (Thompson and Troeh, 1978). Feedstock selection also has a significant influence on biochar surface properties (Downie *et al*., 2009) and its elemental composition (Amonette and Joseph, 2009; Gaskin *et al*., 2008). Because both feedstock and pyrolysis conditions affect physical (Downie *et al*., 2009) and chemical (Amonette and Joseph, 2009) properties, biochar producers may wish to consider the goals for the biochar amendment and adjust their feedstock and pyrolysis protocol to create a designer biochar that is tailored to remedy a specific soil issue.

Biochar improves soil quality through its effects on key soil processes. Many of the benefits of biochar derive from its highly porous structure and associated high surface area. Charges on the high surface area can increase cation exchange capacity thereby increasing a soil's ability to retain and supply nutrients. Increased porosity can increase soil water holding capacity and the small pore spaces with positively charged surfaces can improve soil water retention and in turn reduce nutrient loss through leaching (Lehmann and Joseph, 2009; Verheijen *et al*., 2010). Charcoal in soils has also been linked to increased soil microbial populations which may increase beneficial soil processes mediated by soil organisms including nutrient availability (Kolb *et al*., 2009; Lehmann *et al*., 2011). The majority of biochar adds little in terms of available nutrients to the soil and as such can be thought of as a soil conditioner, as opposed to a fertilizer (Sohi *et al*., 2009).

Therefore, the objective of this study was to characterize physical and chemical properties of biochar produced from two different feedstock under two different pyrolysis temperatures and to examine the effects of these different types of biochar on physicochemical properties of acidic soils.

MATERIALS AND METHODS

Description of sampling area: The soil sample was collected from Eladale research site of College of Agriculture and Veterinary Medicine, Jimma University. The site is located at 7°33'N and 36°57' E at an altitude of 1710 m above sea level. The mean annual maximum and minimum temperatures are 26.8 and 11.4°C and the relative humidity are 91.4 and 39.92%, respectively. The mean annual rainfall of the study area is 1500 mm. The soils of the study area are dominated by Nitisols (World Reference Base, 2006).

Production of biochar: Biochar was prepared from coffee husk and corn cob at Jimma University College of Agriculture and Veterinary Medicine (JUCAVM) using a pyrolysis unit at two different pyrolysis temperatures (350, 500°C) and 3 h of residence time. The prepared biochar materials were grinded and sieved through a 0.25 mm square-mesh sieve.

Soil sampling and preparation: The top 0-20 cm soil samples were collected using soil auger. The samples were air-dried, crushed using mortar and pestle and passed through a 2 mm square-mesh sieve.

Characterization of biochar: Biochar samples were evaluated for physical and chemical properties including surface area, pH, EC, Ex. Bases (Ca, Mg, Na and K), CEC, OC, OM, TN and available phosphorus (Av. P). The surface area was estimated according to Sears's method for silica-based materials. This can be obtained by agitating 1.5 g of each of the produced sample in 100 mL of diluted hydrochloric acid (pH 3). Then a 30 g of sodium chloride was added with stirring and the volume was made up to 150 mL with deionized water. The solution was titrated with 0.10 M NaOH and the volume, V, needed to raise the pH from 4-9 was then recorded. S (m^2 g^{-1}) = 32V-25 where, V is the volume of sodium hydroxide require raising the pH of the sample from 4-9 and S is the surface area. Biochar pH and Electrical Conductivity (EC) were measured in distilled water at 1:10 biochar to water mass ratio after shaking for 30 min (ASTM Standard, 2009). Biochar organic carbon content was determined by the Walkley-Black method and Total Nitrogen (TN) by the Kjeldahl method (Chintala *et al*., 2014). Available phosphorous (P) was determined by using the Olsen extraction method (Shaheen *et al*., 2009). Total exchangeable bases were determined after leaching the biochar with ammonium acetate. Concentrations of Ca and Mg in the leachate were determined by atomic absorption spectrometer. K and Na were determined by flame photometer. Cation exchange capacity was determined at soil pH 7 after displacement by using 1N ammonium acetate method and then estimated titrimetrically by distillation of ammonium that was displaced by sodium (Gaskin *et al*., 2008).

Laboratory incubation of soil with biochar: The effects of different levels of the biochar materials produced from different feedstock as well as with different pyrolysis temperatures on physicochemical properties were examined through a laboratory incubation experiment. One kilogram air-dried soil (<2 mm) weighed and put in different beakers and biochar was added at rates of 0, 5, 10 and 15 t ha^{-1} which is equivalent to 0, 1.4, 2.7, 4.1 g kg^{-1}, respectively and thoroughly homogenized. The moisture content of the soil-biochar mixture was maintained at field capacity throughout the incubation period, by adding distilled water whenever necessary. Three replicates of each treatment were prepared, randomly placed and incubated in the laboratory at ambient temperature for 2 months. At the end of 2 months, samples (≈100 g) were removed from all the treatments and analyzed for pH, OC, OM, TN, Av.P and the other parameters were also analyzed as per the standard methods.

Physicochemical characterization of the field received soil sample and the soil-biochar mixture: The particle size distribution (texture), of the soil sample and the soil-biochar mixture was determined by the Boycouos hydrometric method (Van Reeuwijk, 1992) after destroying OM using hydrogen peroxide (H_2O_2) and dispersing the soils with sodium hexametaphosphate $(NaPO3)_6$. Soil bulk density was determined by the undisturbed core sampling method after drying the soil samples in an oven at 105°C to constant weights.

The pH of the soil and soil-biochar mixture was determined in water suspension at 1:2.5 soil/soil-biochar: liquid ratio (w/v) potentiometrically using a glass-calomel combination electrode (Van Reeuwijk, 1992). Electrical Conductivity (EC) was measured from a 1:5 (w/v) soil to water ratio after a one hour equilibration time as described by ASTM Standard (2009). The Walkley and Black, (1934) wet digestion method was used to determine carbon content and, percent OM was obtained by multiplying percent soil OC by a factor of 1.724 following the assumptions that OM is composed of 58% carbon. Total N was analyzed using the Kjeldahl method by oxidizing the OM in (0.1N H_2SO_4) as described by Black (1965). Cation exchange capacity and exchangeable bases (Ca, Mg, K and Na) were determined after extracting the soil samples by 1N NH4OAc at pH 7. Exchangeable Ca and Mg in the extracts were analyzed using Atomic Absorption Spectrometer (AAS), while Na and K were analyzed by flame photometer (Rowell, 1994). Cation exchange capacity was there after estimated titrimetrically by distillation of ammonium that was displaced by sodium from NaCl solution (Chapman, 1965). Available P was determined by using 1M HCl and 1M NH_4F solutions as an extractant by Bray II method for soils having pH values <7. The sample-extractant mixtures were shaken for 30 min on a horizontal shaker (Shaheen *et al*., 2009), then centrifuged for 10 min at 1500 rpm and filtered by using Whatman no. 42 filter paper. The clear supernatant solutions were collected and analyzed using spectrophotometer at 882 nm.

Data analysis: Data analysis was done using SAS version 9.2. Three way analysis of variance (ANOVA) namely two feedstock biochar materials, two different pyrolysis temperatures and four application rates were performed to see the significance of differences in the effects of the various soil parameters and among each treatment, using the General Linear Model (GLM) procedure of SAS 9.2. Means separation was done using Least Significant Difference (LSD) after the treatments were found significant at p<0.05.

RESULTS AND DISCUSSION

Selected physicochemical properties of the studied soil: Results of the physicochemical properties of the acidic soil (Table 1) indicate that the soil is strongly acidic. As a result, the soil might possibly be affected by Al toxicity, excessive levels of micronutrients such as Co, Cu, Fe, Mn, Zn and deficiency of macronutrients such as Ca, K, Mg, Mo, S, N and P. The low EC value shows that the soil is non-saline which indicates that the total concentration of the major dissolved inorganic solutes (essentially Na^+, Mg^{2+}, Ca^{2+}, K^+, Cl^-, SO_4^{2-}, HCO_3^-, NO_3^- and CO_3^-) in the soil

Table 1: Selected physicochemical properties of the acidic soil studied

Parameters	Mean±SD	Optimum range for agricultural soil	Remarks
Bd (g cm^{-3})	1.02±0.02	0.9-1.2	In expected ranges in most mineral soils
pH-H_2O (1:2.5)	5.12±0.05	5.5-7	Strongly acid
EC (mS cm^{-1}) (1:5)	0.02±0.0	<2	Non-saline
Exch. Ca (me/100 g)	5.64±1.2	60-80% of soil CEC	39.27% of soil CEC
Exch. Mg (me/100 g)	1.57±0.1	10-20% of soil CEC	10.93% of soil CEC
Exch. K (me/100 g)	2.70±0.0	2.8-4% of soil CEC	18.8% of soil CEC
CEC (me/100 g)	14.36±1.2	15-25	Low
Organic carbon (%)	3.23±0.2	4-10	Low
Organic matter (%)	5.57±0.4	5-8	Medium
Nitrogen (%)	0.28±0.01	0.2-0.5	Medium
Available P (mg kg^{-1})	10.02±0.09	20-40 (Bray II)	Very low
Texture	Silty Clay		
Sand (%)	4.00±3.15		
Clay (%)	42.00±4.16		
Silt (%)	54.00±0.00		

Bd: Bulk density, CEC: Cation exchange capacity, SD: Standard deviation

Table 2: Selected physicochemical properties of the biochar materials produced from coffee husk and corn cob at 350 and 500°C

Parameters	CHB350	CHB500	CCB350	CCB500
Specific surface area (m^2 g^{-1})	14.07±0.02	26.20±0.01	4.460±0.05	18.14±0.04
pH-H_2O (1:10)	9.62±0.06	11.04±0.02	8.154±0.01	9.44±0.03
EC (mS cm^{-1}) (1:10)	4.29±0.03	6.44±0.13	0.891±0.23	1.81±0.24
Exch. Ca (me/100 g)	50.48±0.68	61.48±0.81	37.380±0.56	48.36±0.06
Exch. Mg (me/100 g)	6.71±0.11	8.21±0.06	4.930±0.04	6.43±0.06
Exch. K (me/100 g)	1.96±0.27	2.77±0.43	1.711±0.26	2.16±0.14
Exch. Na (me/100 g)	3.43±0.02	5.15±0.11	0.710±0.18	1.45±0.19
CEC (me/100 g)	64.75±0.76	79.23±0.33	47.520±0.66	62.03±0.80
OC (%)	16.45±1.96	26.91±7.22	13.980±2.45	20.57±1.40
OM (%)	28.35±3.38	46.39±12.45	24.090±4.23	35.46±2.41
TN (%)	1.42±0.17	2.32±0.62	1.200±0.21	1.77±0.12
Av. P (mg kg^{-1})	9.79±1.34	13.87±2.16	8.550±1.31	10.81±2.41

CEC: Cation exchange capacity, OC: Organic carbon, OM: Organic matter, TN: Total nitrogen, Av. P: Available phosphorus, CHB350: Coffee husk biochar at 350°C, CHB500: Coffee husk biochar at 500°C, CCB350: Corn cob biochar at 350°C, CCB500: Corn cob biochar at at 500°C. Values are Mean±SD

solution is low (Brady and Weil, 2002). Phosphorus is also deficient in this studied soil. Probably soluble inorganic P is fixed by Al and Fe and this reaction may contributes to less availability of P for crops (Adnan *et al*., 2003).

Results of the various selected physicochemical properties of the biochar (Table 2) showed that the types of feedstock and pyrolysis temperature have a major impact on the properties and composition of biochar. The coffee husk biochar produced at 500°C has a large surface area (Table 2), which reflects its fine-pore structure generated through a well-controlled activation process. The increased surface area of biochar produced from coffee husk at higher pyrolysis temperatures is attributable to the removal of -OH, aliphatic C-O and ester C = O groups from outer surfaces of the feedstock (Chan *et al*., 2008). Moreover, the biochar with the highest surface area (26.2±0.01 m^2 g^{-1}) was produced at the highest temperature, suggesting this sample may possess some fine-pore structures.

The coffee husk biochar was more alkaline and has higher base cation concentration relative to that of the corn cob biochar (Table 2). The pH, EC, CEC, P and base cation concentration were higher in the coffee husk biochar produced at 500 and 350°C followed by corn cob biochar produced at 500 and 350°C. The high pH values of coffee husk biochar may be due to hydrolysis undergone by carbonates and bicarbonates of base cations such as Ca, Mg, Na and K which were present in the feedstock's materials (Gaskin *et al*., 2008). The EC value of coffee husk biochar was found to be higher than that of corn cob biochar, indicating the existence of more water soluble salts in coffee husk biochar than in corn cob biochar.

The CEC of coffee husk biochar was also found to be higher than that of corn cob biochar. This could be due to high negative charge potential of surface functional groups in coffee husk than in corn cob. As pyrolysis temperature increased, there was associated increase in available P in both coffee husk biochar and corn cob biochar and this increment was higher in coffee husk biochar than corn cob biochar produced at the same pyrolysis temperature attributable to a concentration effect as this element is not lost during volatilization. The C content of the biochar was increased with increasing temperature. This is a typical feedstock response during pyrolysis process, where the feedstock loses surface functional -OH groups due to dehydration and at higher temperatures loses C-bound O and H atoms due to structural core degradation (Antal and Gronli, 2003). In general, results of the characterization studies of the biochar are clear demonstrations of the significant difference in the composition of biochar produced from different feed-stock even when they are pyrolyzed under the same temperature. This fact was also reported in a study carried out by Novak and co-workers (Novak *et al*., 2009). Available P, organic carbon and total nitrogen were also higher in coffee husk biochar than in corn cob biochar.

Table 3: Effect of biochar prepared from different feedstock and their application in different rate on soil texture (particle size distribution)

Biochar materials and rate of biochar (t ha^{-1})	Sand (%)	Clay (%)	Silt (%)	Textural class
Control				
0	4.00±0.01	42.67±1.06	53.33±1.06	Silty clay
CHB350				
5	4.00±0.04	43.40±1.06	52.60±0.00	Silty clay
10	4.00±1.04	44.00±1.00	52.00±3.16	Silty clay
15	3.34±1.04	44.60±1.06	52.33±1.06	Silty clay
CHB500				
5	4.00±0.01	44.33±1.06	51.67±1.00	Silty clay
10	4.00±0.01	45.00±1.00	51.00±1.00	Silty clay
15	3.33±0.01	45.67±1.06	51.00±1.06	Silty clay
CCB350				
5	4.00±0.01	45.00±1.00	51.00±0.00	Silty clay
10	4.33±1.04	45.00±1.00	50.67±1.06	Silty clay
15	4.33±1.05	45.00±1.00	50.67±2.01	Silty clay
CCB500				
5	4.33±1.01	45.00±1.00	50.67±3.16	Silty clay
10	4.00±0.01	45.33±1.06	50.67±1.06	Silty clay
15	4.00±0.01	45.00±1.00	51.00±1.00	Silty clay
p-value<0.05	ns	ns	ns	
LSD	3.28	4.56	5.52	

ns: Non significant, CHB350: Coffee husk biochar produced at 350°C, CHB500: Coffee husk produced at 500°C, CCB350: Corn Cob biochar produced at 350°C, CCB500: Corn cob biochar produced at 500°C, LSD: Least significant difference

Effect of biochar application on soil texture (particle size distribution): The particle size distribution of the control and mixtures of soil with two biochar materials (coffee husk and corn cob) were analyzed and the results obtained (Table 3) clearly showed that the sand, clay and silt fractions were not significantly affected by the application of either of the biochar materials. But, numerically the average sand content (4±0.01%) was observed in the control (0 t ha^{-1}) and the lowest (3.33±0.01%) was recorded in the soil treated with 15 t ha^{-1} coffee husk biochar produced at 500°C pyrolysis temperature. On the other hand, the highest average clay fraction (45.67±1.06%) was recorded in the soil treated with 15 t ha^{-1} coffee husk biochar produced at 500°C pyrolysis temperature. These increased values of clay particles could be due to the particles of biochar added to the soil and the inherent characteristics of biochar feedstock and high surface area and porous nature of biochar (Sohi *et al.*, 2009). In all the treatments, the silt fractions were observed to decrease with application of either of the biochar materials but not significant. There was no textural class change of the soil as a result of biochar treatment, however, the textural class of each of the untreated and biochar treated soils was Silty Clay.

Effect of biochar application on pH and EC of acidic soil: Application of biochar materials significantly ($p<0.01$) affected the pH and EC of acidic soil (Table 4). The highest mean values of pH and EC were observed in the soil treated with 15 t ha^{-1} coffee husk biochar produced at 500°C, while the lowest values were recorded in the control. The increase in the pH and EC of the soil due to the application of biochar was generally attributed to an increase in ash content, as ash residues are generally dominated by carbonates of alkali and alkaline earth metals, phosphates and small amounts of organic and inorganic N (Arocena and Opio, 2003). Khanna *et al.* (1994) also concluded that the increase in soil pH and EC following the application of biochar could be due to the high surface area and porous nature of biochar that subsequently increased the CEC of the soil.

Effect of biochar application on organic carbon, organic matter, total nitrogen and available phosphorus: The application of biochar significantly $p<0.01$ increased the mean soil

Table 4: Effect of biochar application on the soil pH and Electrical conductivity

Biochar materials and rate of biochar (t ha^{-1})	pH-H$_2$O	Electrical conductivity (mS m^{-1})
Control		
0	5.18±0.02^{d}	0.02±0.0^{bc}
CHB350		
5	5.78±0.04^{abc}	0.04±0.0^{bc}
10	5.79±0.03^{abc}	0.05±0.0^{bc}
15	6.08±0.01^{ab}	0.06±0.0^{abc}
CHB500		
5	5.84±0.05^{abc}	0.04±0.01^{bc}
10	5.96±0.10^{abc}	0.06±0.01^{abc}
15	6.14±0.04^{a}	0.09±0.01^{a}
CCB350		
5	5.66±0.12^{bc}	0.03±0.01^{bc}
10	5.76±0.05^{abc}	0.05±0.03^{bc}
15	5.78±0.03^{abc}	0.06±0.01^{abc}
CCB500		
5	5.68±0.13b^{c}	0.05±0.02^{bc}
10	5.78±0.01^{abc}	0.06±0.01^{abc}
15	5.82±0.02^{abc}	0.07±0.01^{ab}
p-value<0.05	<0.0001	<0.0001
LSD	0.4922	0.048

CHB350: Coffee husk biochar at 350°C, CHB500: Coffee husk biochar at 500°C, CCB350: Corn cob biochar at 350°C, CCB500: Corn cob biochar at 500°C, LSD: Least significant difference

Table 5: Effect of biochar application on the soil organic carbon, organic matter, total nitrogen and available phosphorus (Mean±SD)

Biochar materials and rate of Biochar (t ha^{-1})	OC (%)	OM (%)	TN (%)	Available P (ppm)
Control				
0	3.70±0.17^{g}	6.38±0.21^{g}	0.32±0.01^{g}	4.51±0.20^{e}
CHB350				
5	5.31±0.10^{f}	9.15±0.10^{f}	0.46±0.01^{f}	8.54±0.14^{cde}
10	5.34±0.05^{ef}	9.21±0.10^{ef}	0.46±0.01^{ef}	8.92±0.11^{cde}
15	5.41±0.03^{def}	9.33±0.05^{def}	0.47±0.00^{def}	11.33±0.30^{bcd}
CHB500				
5	5.83±0.04^{cde}	10.05±0.05^{cde}	0.50±0.00^{cde}	12.36±1.12^{bcd}
10	6.00±0.03^{cde}	10.34±0.05^{cde}	0.52±0.00^{cde}	16.19±0.46^{ab}
15	6.24±0.02^{a}	10.76±0.05^{a}	0.54±0.00^{a}	18.21±0.03^{a}
CCB350				
5	5.53±0.04^{cd}	9.53±0.10^{cd}	0.48±0.012^{cd}	7.42±1.02^{de}
10	5.53±0.02^{cd}	9.53±0.05^{cd}	0.48±0.00^{cd}	8.64±0.12^{cde}
15	5.62±0.04^{cb}	9.69±0.10^{cb}	0.48±0.01^{cb}	10.20±1.11^{cd}
CCB500				
5	5.66±0.06^{cb}	9.76±0.11^{cb}	0.49±0.01^{cb}	10.72±1.21^{cd}
10	5.69±0.06^{ab}	9.81±0.12^{ab}	0.49±0.06^{ab}	12.55±1.01^{bcd}
15	6.69±0.02^{ab}	9.88±0.05^{ab}	0.49±0.00^{ab}	14.12±2.12^{abc}
p<0.05	<0.0001	<0.0001	<0.0001	<0.0001
LSD	0.40	0.62	0.036	7.82

OC: organic carbon, OM: Organic matter, TN: Total nitrogen, CHB350: Coffee husk biochar at 350°C, CHB500: Coffee husk biochar at 500°C, CCB350: Corn cob biochar at 350°C, CCB500: Corn cob biochar at 500°C, LSD: Least significant difference, values are Mean±SD

OC, OM, TN and available P content of acidic soil (Table 5). The untreated acidic soil had 3.7±0.17% OC, 6.38±0.21% OM and 0.32±0.01% TN and 4.51±0.2 ppm available phosphorus level. However, after the incorporation of biochar and 2 months incubation period the OC, OM, available P and TN level of the acidic soil increased by 38.84% OC, 36.48% OM, 40.74% TN and 55.78% available phosphorus. The highest OC, OM, TN and available P levels were recorded in soil amended with 15 t ha^{-1} of coffee husk biochar produced at 500°C pyrolysis temperature and incubated for 2 months. The high carbon and organic matter content in coffee husk biochar might have enriched the soil with organic carbon and organic matter content. The increased OC, OM, TN and available P could be due to the decomposition of biochar added to soil.

Table 6: Effect of biochar application on cations exchange capacity and exchangeable cations

Biochar materials and rate of biochar (t ha^{-1})	CEC (me/100 g)	Calcium (cmol (+)/kg)	Magnesium (cmol (+)/kg)	Potassium (cmol (+)/kg)
Control				
0	14.37 ± 1.05^{e}	5.57 ± 0.82^{e}	1.53 ± 0.11^{e}	2.85 ± 0.04^{g}
CHBC350				
5	16.43 ± 0.52^{d}	6.98 ± 0.40^{d}	3.45 ± 0.05^{d}	3.46 ± 0.03^{efg}
10	17.87 ± 1.21^{cd}	8.80 ± 0.95^{cd}	3.56 ± 0.13^{cd}	3.55 ± 0.03^{efg}
15	18.27 ± 0.46^{bcd}	9.50 ± 0.36^{bcd}	3.66 ± 0.05^{cd}	3.99 ± 0.15^{bcd}
CHBC500				
5	15.70 ± 0.46^{bcd}	7.06 ± 0.36^{bcd}	3.76 ± 0.05^{cd}	4.15 ± 0.19^{bcd}
10	16.03 ± 1.15^{bcd}	8.32 ± 0.90^{bcd}	3.83 ± 0.12^{cd}	5.01 ± 0.04^{cd}
15	20.99 ± 0.70^{a}	10.84 ± 0.55^{a}	3.98 ± 0.07^{a}	5.96 ± 0.09^{a}
CCBC350				
5	14.55 ± 1.09^{bcd}	6.94 ± 0.85^{bcd}	3.18 ± 0.11^{bcd}	3.25 ± 0.22^{fg}
10	15.46 ± 1.07^{bcd}	7.65 ± 0.84^{bcd}	3.28 ± 0.11^{bcd}	3.46 ± 0.04^{fg}
15	15.69 ± 1.09^{bcd}	7.83 ± 0.85^{bcd}	3.37 ± 0.11^{bcd}	3.72 ± 0.29^{cdef}
CCBC500				
5	16.03 ± 1.03^{bcd}	7.10 ± 0.80^{bcd}	3.63 ± 0.10^{bcd}	3.85 ± 0.34^{cdef}
10	17.31 ± 0.86^{ab}	8.09 ± 0.67^{ab}	3.67 ± 0.09^{bcd}	4.23 ± 0.27^{bc}
15	18.46 ± 1.07^{ab}	8.99 ± 0.84^{ab}	3.88 ± 0.11^{ab}	4.50 ± 0.54^{ab}
p-value<0.05	<0.0001	<0.0001	<0.0001	<0.0001
LSD	3.60	3.26	0.36	0.46

CEC: Cations exchange capacity, me: Milliequivalents, cmol: Centimol, CHB350: Coffee husk biochar at 350°C, CHB500: Coffee husk biochar at 500°C, CCB350: Corn cob biochar at 350°C, CCB500: Corn cob biochar at 500°C, LSD: Least significant difference

The highest values of available phosphorous was recorded after application of 15 t ha^{-1} coffee husk biochar produced at 500°C temperature and after incubation for 2 months at pH of 6.14. The observed increase in available phosphorus could be due to the presence of phosphorous in the coffee husk. The increase in soil pH and CEC, that reduced the activity of Fe and Al, could also contribute to the highest values of available phosphorous in soils treated with biochar Zwieten *et al.* (2010) and Chan *et al.* (2008) also reported the increase in available phosphorous after the application of biochar. Significant differences were observed between soil available P levels of successive rate of the biochar amended soils. The biochar from both coffee husk and corn cob produced at 350 and 500°C and applied at different levels increased available P levels compared to the control. The increase in available P with duration of incubation reported in this study is comparable to those reported by Laboski and Lamb (2003) and Spychaj-Fabisiak *et al.* (2005). The observed increase in available P with an increase in the duration of incubation could be due to microbially mediated mineralization of soil organic P to form inorganic P (Opala *et al.*, 2012).

Effect of biochar application on cations exchange capacity and exchangeable cations: The addition of biochar significantly affected ($p<0.01$) CEC and exchangeable cations of the acidic soil (Table 6). The Cations Exchange Capacity (CEC) and exchangeable cations increased after amendment of the acidic soil with both coffee husk and corn cob biochar materials. The untreated (control) acidic soil had 14.37 me/100 g level, however, due to the incorporation of biochar and after 2 months of incubation period the CEC level increased from14.37±1.05 to 20.99±0.70 me/100 g and the increase is 31.53% and highest increase in CEC was recorded in the soil amended with 15 t ha^{-1} coffee husk biochar produced at 500°C (Table 6).

The observed increase in CEC due to the application of biochar could have resulted from the inherent characteristics of biochar feedstock. Biochar has high surface area, is highly porous, possesses organic materials of variable charge that have the potential to increase soil CEC and base saturation when added to soil (Glaser *et al.*, 2002). Available evidences also suggest that, the intrinsic CEC of biochar is consistently higher than that of whole soil, clays or soil organic matter

(Sohi *et al*., 2009). Therefore, it is quite logical that soil treated with biochar had a highest CEC than the corresponding soil untreated with biochar. Studies by Masulili *et al*. (2010) and Chan *et al*. (2008) have also revealed the increase in soil CEC after the application of biochar. Application of 15 t ha^{-1} CHB500 significantly ($p<0.01$) increased exchangeable K, Ca and Mg levels of the acidic soil from 2.85±0.04-5.96±0.09, 5.57±0.82-10.84±0.55 and 1.53±0.11-3.98±0.01 me/100 g, respectively. The increase was 52.52% in K, 48.61% in Ca and 61.55% in Mg. The observed increase in exchangeable cations in the biochar treated soils might be attributed to the ash content of the biochar. The ash content of biochar helps for the immediate release of the occluded mineral nutrients like K, Ca, Mg and Na for crop use (Scheuner *et al*., 2004; Niemeyer *et al*., 2005).

CONCLUSION

Our results clearly showed that the physical and chemical properties of biochar varied as a function of feedstock selection and pyrolysis temperatures. Higher pyrolysis temperatures resulted in biochar with higher surface areas, pH, EC, OC, OM, TN, Av.P, CEC and basic cations. The findings of the study also showed that, application of biochar materials prepared from both feedstock improved physicochemical properties of acidic soil. The application of biochar has also increased the pH and CEC of the soil. Application of coffee husk residue biochar produced at 500°C and applied at the rate of 15 t ha^{-1} significantly improved physicochemical properties of soil as compared to corn cob produced at the same temperature and the same application rate. Nevertheless, corn cob could still improve soil physicochemical properties. This study revealed several interesting aspects of the effects of pyrolysis temperature and feedstock types on biochar chemical properties and how these biochar materials influenced the physicochemical properties of acidic soil is convincing. Moreover, further field researches are needed to evaluate the effect of biochar on soil physicochemical properties.

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