Beneficial Effects of Biochar Application on Improving Sandy Soil Properties

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ABSTRACT: The objective of this study was to evaluate the effect of corncob waste-derived biochar (locally produced via slow pyrolysis – 500°C) on improved sandy soil properties (physical and chemical properties). The soil used in the present study was sandy texture collected from the surface layer (0 – 30 cm depth). The soil mixed with soft and hard parts of corncob biochar produced by pyrolysis at a high temperature (500 °C)**.** The sandy soil was mixed with biochar at rates of 0, 1, 3, and 5% (w/w). The mixture was wetted at field capacity and incubated at room temperature (25±2 °C) for one month with rewetting every 7 days. The soil-biochar mixtures were subjected to physical and chemical analysis**.** The biochar application to sandy soil did not alter the distribution of particle size. The results indicated that the application of biochar significantly improved the saturation water content (SWC), field capacity (FC), permanent wilting point (PWP), and available water content (AWC). The hydrophysical properties of sandy soil treated with biochar were significantly improved by about 5.02, 6.83, 6.31, and 7.08%, respectively. The soil bulk density (BD) of the sandy soil significantly decreased ($p < 0.05$) with the application of biochar. Soft biochar was more effective in decreasing the soil bulk density by 5.12%. The biochar type (Hard and Soft) has a significant effect on θr (Permanent Wilting Point) and n (Exponent) parameters in which hard biochar has more effect in increasing the values. Also, the biochar application rate significantly (p<0.005) increased both θr and θs (Saturation water content) parameters by about 75.68 and 15.00%, respectively. The increase in soil pH after amendment application could be attributed directly to the higher pH of the biochar used in the study. Soluble cations (i.e. Ca, Mg, Na, and K) in soil treated with biochar were significantly increased with increasing the biochar application rate. Also, the soil's organic carbon increased linearly with biochar application rates. Available nutrient contents (N, P, K, Fe, Mn, CU, and Zn) significantly increased with increasing the biochar application rate. The results of the present study showed that biochar applications can improve soil properties. Therefore, further research must be performed on biochar applications to soil and include the following:

i. Long-term effects of biochar application on soil physicochemical properties and crop yield, ii. Effects of biochar type, pyrolysis temperature, and application rate on other soil types, and

iii. Factors that influence the ways of biochar application technologies by farmers.

***Keywords**: Biochar, soil physical properties, soil chemical properties, SEM, EDX, soil fertility, FTIR. Soil-biochar mixture.*

INTRODUCTION

The pyrolysis of biomass materials in low oxygen environments produces biochar, a dark porous substance with high carbon content, developed pore structure, strong stability, highly focused surface area, and rich functional groups (**Tenenbaum, 2009**). Numerous earlier studies have demonstrated that adding biochar to soil increases its organic carbon content and modifies its physicochemical characteristics, such as the distribution of soil pores (**Fu et al., 2019; Gb et al., 2016**) and the stability of soil aggregates (**Baiamonte et al., 2019**), which are connected to the soil's ability to retain water and preserve fertilizers (**Ouyang and Zhang, 2013**).

Improvements in soil features for agricultural production, regulatory function, and habitat function may interact considerably with changes in soil structure (**Verheijen et al., 2019**). Biochar may reduce the bulk density of the majority of mineral soils since it has a lower bulk density than agricultural soil (between 0.3 and 0.6 g/cm3) (**Verheijen et al., 2014**).

Additionally, through influencing aggregation, biochar may indirectly impact bulk density (**Obia et al., 2016; Ouyang et al., 2013**). The hydrophobicity of some biochar, changes in the pore structure of the biochar, and the distribution of biochar particles in the soil matrix

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may have an impact on the hydraulic conductivity of the soil biochar mixture, which could have a greater impact on soil hydraulic properties than the change in bulk density effect (**Kinney et al., 2012**).

It has been demonstrated that wood-based biochar is superior to herb-based biochar in terms of improving water retention; this may be because wood-based biochar particles have larger pore space (**Masiello et al., 2015**). As applied biochar was increased, it was discovered that the soil's ability to keep water and its effective water content frequently increased as well (**Peake et al., 2014**), as did the soil's porosity, soil water retention, and soil structure index (**Baiamonte et al., 2019**).

Biochar can significantly improve the wind erosion resistance of desert sandy soil, which is reflected in the fact that biochar significantly increases soil porosity and the number of pores and micropores. Likewise, studies that were conducted in the Qinghai-Tibet Plateau region of China have confirmed that biochar effectively developed, the irrigation water utilization efficiency of cultivated land by 2.0-9.43% (**Wang et al., 2022**).

Additionally, it has been noted that biochar affects soil hydraulic characteristics more favorably in soils with a larger proportion of coarse particles than in soils with a higher proportion of fine particles (**Edeh et al., 2020; Razzaghi et al., 2020**). The aforementioned studies collectively show how effective biochar is at enhancing soil. It is important to emphasize the potential risks to the soil from improper biochar use, which must be disregarded. Biochar may release hazardous compounds during pyrolysis, posing unnecessary risks to soil water quality and permanently altering the environment (**Ouyang et al., 2013**).

All investigations show how biochar significantly improves the hydrophysical characteristics of the soil. The issue of deep drainage of agricultural irrigation water still exists even though a single application of biochar can successfully enhance the number of soil aggregates (**Kang et al., 2022**). The basis for soil aggregation is the organic connection between soil particles, and the replenishment of the soil carbon pool necessitates the input of external carbon sources (**Shao et al., 2022; Wang et al., 2022**). One amendment cannot fundamentally improve the low utilization efficiency of water and fertilizer in desert soil or its potential to effectively resist drought, especially in desert soil with low carbon content. cannot fundamentally enhance the low utilization efficiency of water and fertilizer in the desert soil, as well as its capacity to effectively resist severe weather such as sudden drought and sand storms (**Kang et al., 2022**).

The objective of this study was to evaluate the effect of corncob waste-derived biochar (locally produced via slow pyrolysis – 500°C) at limited oxygen on improving the sand soil properties (physical and chemical properties).

MATERIALS AND METHODS

Soil sample

The soil sample used in the present study was collected from the surface layer(0 – 30 cm**)** of the El-Shagaa Village, Nubaria region, Behiera Governorate.

The soil was air-dried and passed through a 2.0 mm sieve. Some physical and chemical properties of the soil sample are reported in Table (1). The soil properties were performed according to the procedures outlined in **(Carter and Gregorich 2008).**

<u>Biochar</u>

The biochar material used in the present study was taken from the Biochar Production Unit related to the project **"Development of Biochar Technology Production from Agricultural Residues and its Application to Solve some Existing Environmental Problems in Egyptian Community"**, Central Laboratory for Agricultural Climate, Albossaly site, Financially by the Academy of Scientific Research and Technology, Egypt.

The biochar was produced from soft and hard parts of corncob by pyrolysis at a high temperature (500 °C) under limited oxygen conditions using the fabricated stove for this purpose (Figure 1).

Table(1). Physical and chemical analysis of soil used in the present study

Parameters	Values
Particle-size distribution (%)	
Sand	94.00
Silt	5.00
Clay	1.00
Textural class	Sand
EC, dS/m (1:1, water extract)	0.477
pH (1:1, water suspension)	7.67
Organic carbon (%)	1.38
$CaCO_3$ (%)	2.50
Soluble cations (me/l)	
Ca^{2+}	1.753
Mg^{2+}	1.550
Na^{+}	0.803
K^{+}	0.351
Soluble anions (me/l)	
$CO_3^{=}+HCO_3^{-}$	0.352
Cl^{-}	2.533
$SO_4^{=}$	1.863
Available Nutrients (mg/kg)	
N	52.1
P	15.08
K	351.67

Figure (1). Picture of the Soft and Hard biochar used in the present study

The biochar was subjected to chemical analysis and the result is illustrated in Table (2) according to **(Carter and Gregorich 2008).**

The Biochar (BC) was subjected to analysis by Scanning electron microscopy (SEM), Fourier Transform Infrared (FTIR), and Energy Dispersive Spectroscopy (EDX). These methods were used to characterize their surface functional groups.

Scanning Electron Microscopy (SEM) was used to recognize the surface structure and morphology of the samples using a HITACHI S2600N-type, operating at 20kV in a vacuum. The SEM studies were performed on powder samples. For the elemental analysis, the electron microscope was equipped with an energy-dispersive X-ray attachment (EDAX/2001 device).

Fourier Transform Infrared spectra (FTIR) were recorded. The functional groups present in the prepared powder and the powders calcined at different temperatures were identified by FTIR (Spectrum BX Spectrometer). For this 1% of the powder was mixed and ground with 99% KBr, then the spectrum was taken in the range of 4400 to 350 cm^{-1}.

Soil-Biochar mixture preparation

The sandy soil was mixed with biochar at rates of 0, 1, 3, and 5% (w/w). The mixture was wetted at field capacity and incubated at room temperature (25±2 °C) for one month with rewetting every 7 days. At the end of the incubation time, the soil-biochar mixtures were air-dried and pass-through a 2.0 mm sieve and stored for analysis.

The soil-biochar mixtures were subjected to physical and chemical analysis. The physical properties included; saturation water content, field capacity, permanent wilting point, available water content, soil bulk density, particle-size distribution by dry sieve analysis, Mean weight diameter, Geometric mean diameter, structure coefficient, and soil water retention parameters (θ_r, θ_s, α, n, and m).

Table (2). Chemical analysis of soft and hard Biochar

Parameters	Soft Biochar	Hard Biochar
EC (1:10, water extract), dS/m	2.556	2.985
pH (1:10, water suspension)	7.50	8.10
Soil organic carbon, %	37.00	41.00
Cation Exchange Capacity (CEC), me/100 g	10.385	19.686
Soluble nutrients, %		
N	0.044	0.085
P	0.017	0.710
K	0.403	0.680
Ca	0.160	0.385
Mg	0.115	0.077
Total Elements, %		
N	0.945	1.272
P	0.980	1.079
K	1.350	1.750
Ca	1.340	1.450
Mg	1.360	0.780
Na	0.800	1.200

Laboratory soil analysis:

Soil physical characteristics:

The soil samples were taken from each treatment after incubation and analyzed for the following properties:

Soil particle density (Mg/m^3) was determined by the Pycnometer method (**Carter and Gregorich, 2008**).

Soil bulk density (Mg/m^3) was determined using the soil core method (**Carter and Gregorich,2008**).

Mean Weight Diameter (MWD) was estimated according to the method reported by **Dimoyiannis (2009)** using the following equation:

$$MWD = \sum_{i=1}^{n} f_i \times d_i \quad (1)$$

Where: di is the mean diameter of any particular size range of aggregates separated by sieving (mm), and fi is the weight of aggregates in that size range as a fraction of the total dry weight of soil used (%).

Geometric Mean Diameter (GMD) was estimated according to the method of **Shirazi and Boersma (1984)** using the following equation:

$$GMD = EXP\left[\sum_{i=1}^{n} f_i \times \log d_i\right] \quad (2)$$

Structure coefficient (Cr) as described by (**Pieri, 1992**) using the following equation:

$$Cr = \frac{\text{mass of particle} >0.25 \text{ mm diameter}}{\text{mass of particle} <0.25 \text{ mm diameter}} \quad (3)$$

Soil water retention at tensions of 0.0, 0.1, 0.33, 1, 5, 10, and 15 bar was measured using a pressure cooker device and pressure membrane apparatus, and soil water constants (FC, PWP, and AW) deduced from the values of soil moisture content percentage at different pressures according to van Genuchten's model (**van Genuchten, 1980**):

$$\theta(h) = \theta_r + \frac{(\theta_s - \theta_r)}{\left[1+(\alpha h)^n\right]^m} \quad (4)$$

Where:
h is the soil matric suction (cm),
$\theta(h)$ is the soil volumetric water content ($cm^3\ cm^{-3}$),
θ_s is the soil saturated water content ($cm^3\ cm^{-3}$),
θ_r is the soil residual water content ($cm^3\ cm^{-3}$),
α is a parameter, the inverse of which, $1/\alpha$, is an indication of the suction at the air-entry point (cm^{-1}), and n and m (1-1/n) are the dimensionless parameters related to the homogeneity of the pore size distribution.

The reported data for soil water retention fitted van Genuchten's model with the optimization software RETC (**van Genuchten et al., 1991**).
Soil saturated hydraulic conductivity (Ks) was determined using undisturbed soil cores under constant water head in the laboratory following the method recommended by **(Klute 1986).** Darcy's equation is used to calculate the (Ks) value (**Richards, 1954**).

<u>Soil chemical characteristics:</u>
Electrical conductivity (EC): The soil: water extract, 1:1 (w/v) was measured using a conductivity meter according to **(Jackson 1973)**.
Soil pH was determined in the 1:1, soil: water suspension using a pH meter **(Jackson, 1973).**
Soil Organic Carbon (SOC) was determined using the modified Walkley-Blacks titration method (**Carter and Gregorich, 2008**). The soil organic matter content (SOM) was calculated using the suitable constant (1.724).
Soluble cations (meq/l): soluble Ca and Mg were determined titrimetry using EDTA titer according to the methods outlined in **(Carter and Gregorich 2008).** Na and K were determined by flame photometry according to the methods **(**outlined in **Jackson 1973).**
Soluble anions (meq/l): Soluble HCO_3, Cl, and SO_4 were determined according to the methods outlined in **(Carter and Gregorich 2008).**
Total calcium carbonates (%), were determined according to the methods outlined in **(Carter and Gregorich 2008)**

<u>Soil available nutrients:</u>
<u>Soil-available macronutrients (N, P, and K)</u>
Soil available nitrogen content (mg/kg): The soil sample was extracted by 2M KCl (1:20), and available N was determined in soil extract by using the micro-Kjeldahl method described by **(Paech and Tracey 1956).**
<u>Soil available phosphorus content (mg/kg)</u>: Available phosphorus extracted with 0.5 M $NaHCO_3$ solution and adjusted to pH 8.5 according to **(Olsen et al. 1954)** and determined by ascorbic acid molybdenum blue method according to **(Jackson 1973).**
<u>Soil available potassium content (mg/kg):</u> available K extracted by ammonium acetate (1N of pH 7.0) and determined by flame photometry according to **(Jackson 1973).**
<u>Soil-available micronutrients (Fe, Mn, Cu, and Zn)</u>
DTPA-extractable micronutrients: A ten grams of air-dried soil sample shaken with 20 ml of extracting solution (0.005 M DTPA + 0.01 M calcium chloride + 0.1 M TEA, pH 7.3) for two hours. The soil suspension was filtered using Watman No. 42 filter paper and the contents of Fe, Mn, Cu, and Zn were measured by atomic absorption spectrophotometer (**Lindsay and Norvell, 1978**).
<u>Statistical analysis</u>
The collected data were subjected to analysis of variance (**Snedecor and Cochran, 1991)** using the STATISTIX 10 software **(Statistix, 2019).** The difference between treatments was tested by Least Significant Difference (LSD) at a 0.05 probability level.

RESULTS AND DISCUSSION
Biochar chractristics

Scanning electron micrograph (SEM) images are very useful to obtain accurate details about the surface structure of biochar. The comparison of the images between soft and hard biochars might then

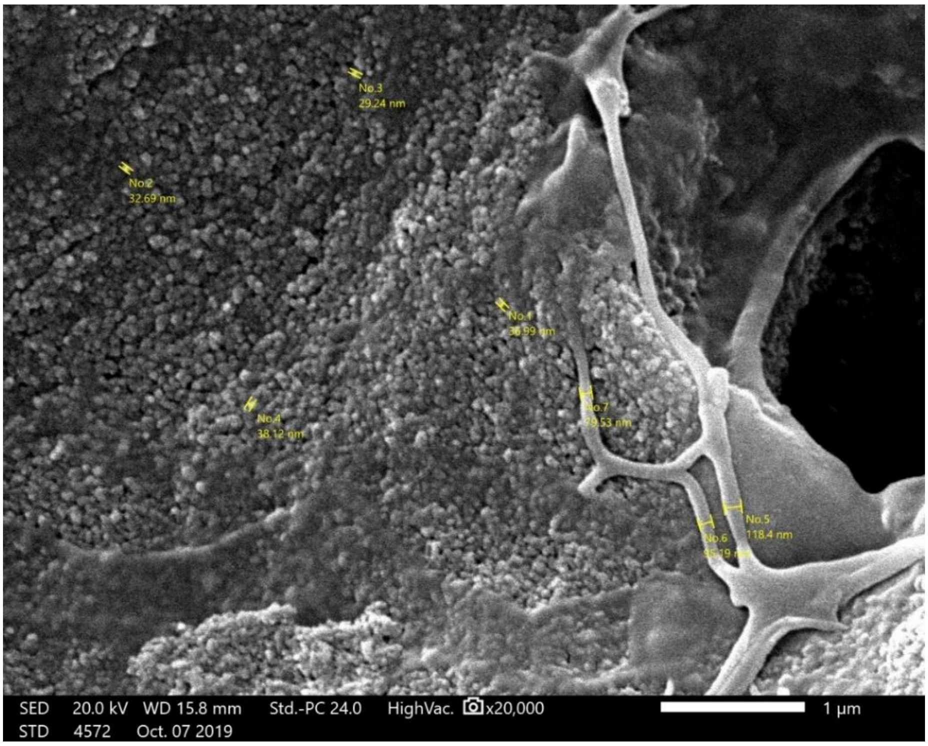

Plate (1). SEM micrograph of Soft biochar

allow us to understand morphological changes during the carbonization stage **(Özçimen and Ersoy–Mericboyu, 2010)**. The SEM pictures of soft and hard biochar produced at 500˚C are given in Plates (1 and 2), respectively. The surfaces of BC were imaged with many hollow channels in diameters of around 29 and 95 nanometers for soft biochar and from 27 to 89 nm for hard biochar. These porous structures of the biochar are likely to provide a high internal surface area and adsorption ability for elements and increase the ability for water retention. The structural difference may reflect the specific surface area and the adsorption capacity of water.

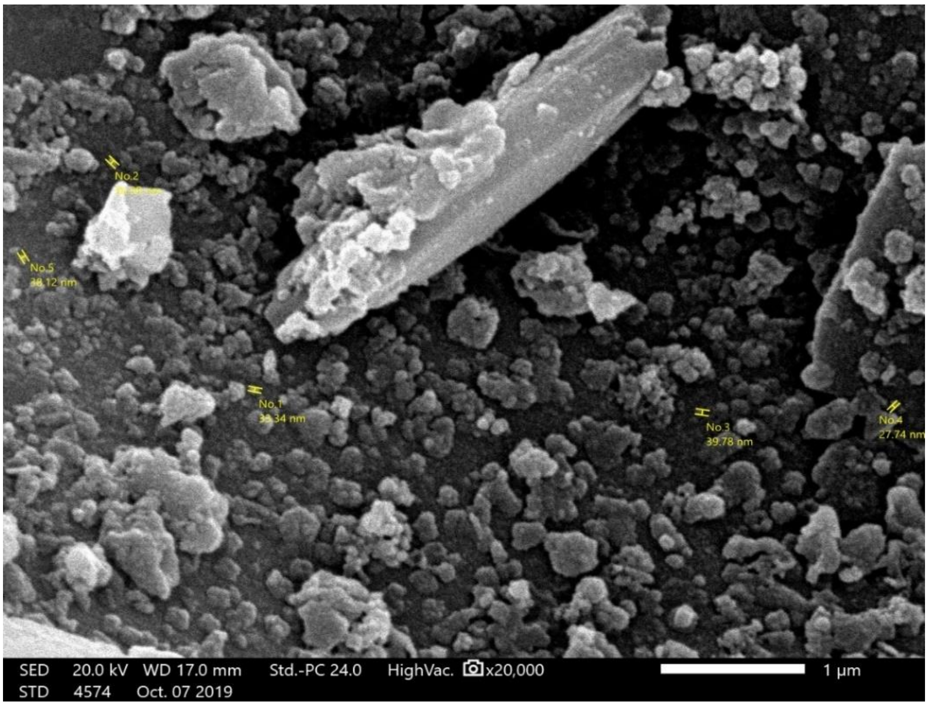

Plate (2). SEM micrograph of Hard biochar

The functional groups identified from the FTIR spectra for the soft and hard biochar samples are illustrated in Figures (2 and 3). The spectra of soft biochar demonstrated many bands at 3318 cm^{-1} (amides group), 2924 cm^{-1} (aromatic group), 1597 cm^{-1} (carboxyl group), 1432 cm^{-1}(nitro group), 793 cm^{-1}(thiocarbonyl), and 551 cm^{-1}(alkyl group) as shown in Figure 2. The spectra of Hard biochar demonstrated many bands at 3394 cm^{-1} (amides, carboxyl groups), 1618 cm^{-1} (nitro group), 1433 cm^{-1} (nitro group), 1099 cm^{-1} (carbonyl group), 668 cm^{-1}(alkyl group) Figure(3).

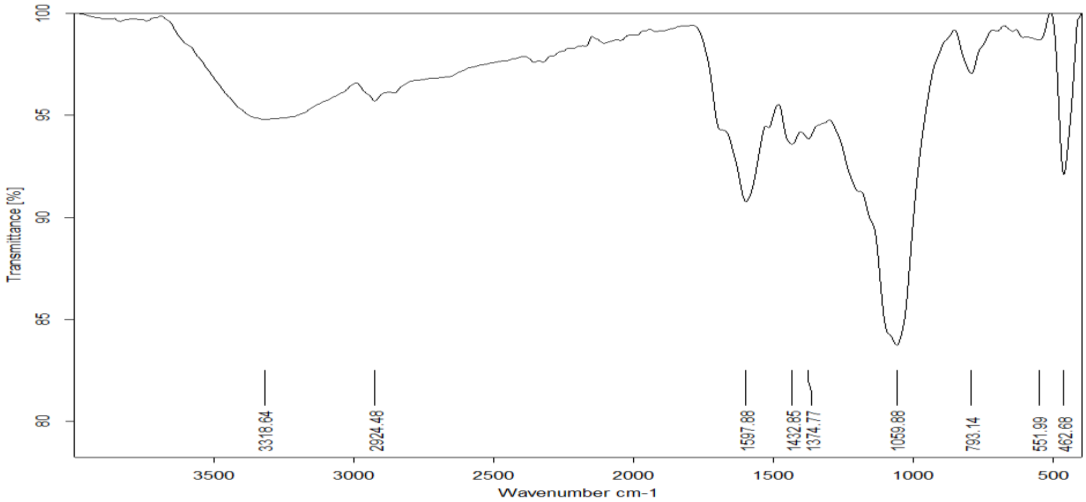

Figure (2). FTIR Spectra of soft biochar

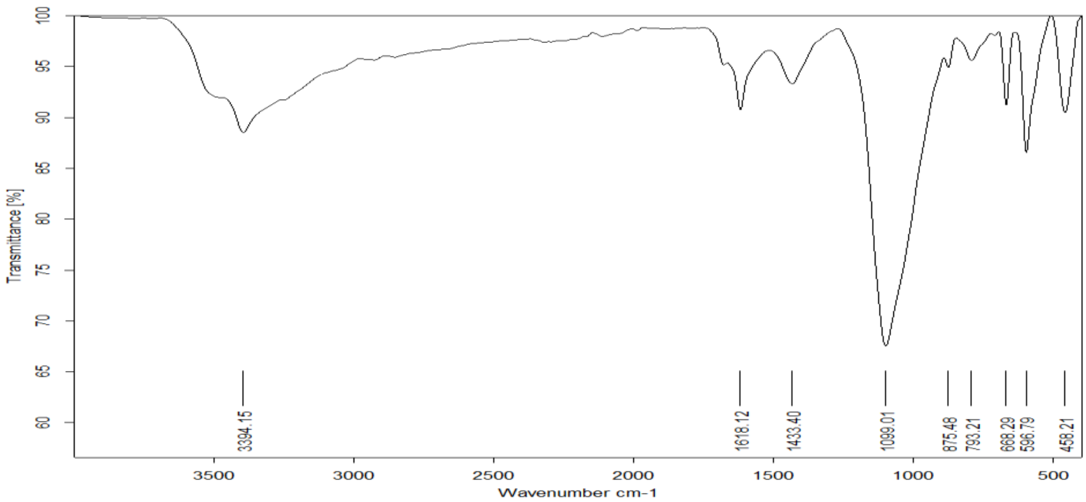

Figure (3). FTIR Spectra of hard biochar

The energy-dispersive X-Ray Microanalysis (EDX) of the soft and hard biochars are described in Figures (4 and 5). For EDX quantification of these features, an accelerating voltage of 10 kV was used since this was enough to generate all elemental peaks of interest. To optimize the chemical analysis of elements in biochar present in the samples, the analyzer mode in the INCA software was used to find the optimal choice of accelerating voltage. In Figures (4 and 5), the synthesized spectrum for an accelerating voltage of 4 kV is seen. It is clear that with a lower accelerating voltage, the carbon peak is much stronger compared to the other peaks. A lower accelerating voltage is preferred. Table (3) shows the approximate chemical analysis of both soft and hard biochars. Soft biochar contains less amount of carbon, but more oxygen than hard biochar. This may be responsible for more retention of water and nutrients.

Table (3). The EDX elemental analysis of soft and hard biochar samples

Elements	Soft Biochar		Elements	Hard Biochar	
	Mass %	Atom %		Mass %	Atom %
C	61.77	69.49	**C**	66.67	73.61
O	34.52	29.15	**N**	1.03	0.97
Mg	0.25	0.14	**O**	29.03	24.07
Si	0.45	0.22	**Si**	1.92	0.91
P	0.28	0.12	**P**	0.06	0.03
K	1.42	0.49	**K**	0.72	0.24
Ca	0.81	0.27	**Ca**	0.38	0.13
Fe	0.16	0.04	**Fe**	0.19	0.05
Cu	0.34	0.07			
Total	100.00	100.00	**Total**	100.00	100.00

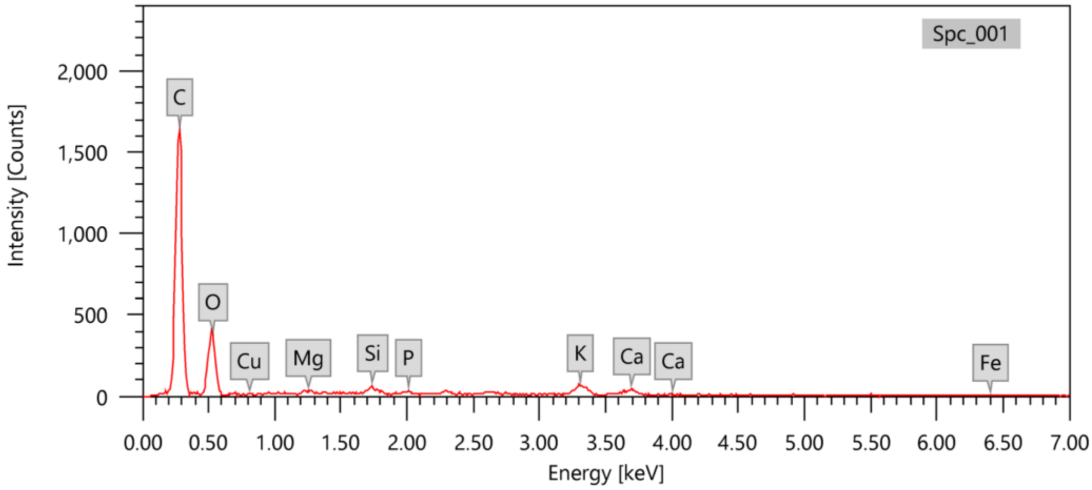

Figure (4). EDX spectra of soft biochar sample

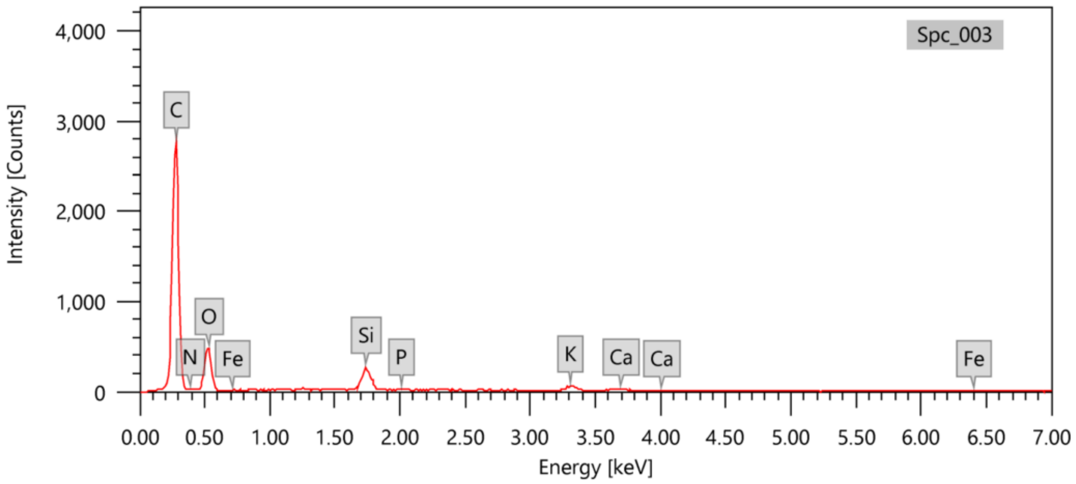

Figure (5). EDX spectra of hard biochar sample

Effect of biochar application on soil physical properties

The results from the present study showed that soil physical properties improved after biochar applications to the soil as described in Tables (4 to 6).

Particle size distribution

The particle-size distribution of sandy soil treated with biochar is illustrated in Table (4). The biochar application to sandy soil did not alter the distribution of particle size. There is no significant difference between the hard and soft types of biochar. Also, the application rate of biochar did not have significant differences in altering the particle size distribution.

Aggregate stability as described by MWD (Mean weight diameter), GMD (Geometric mean diameter), and Cr (structure coefficient) did not improve by application of biochar (type and rate) to the sandy soil.

Hydrophysical properties

Data presented in Table (5) illustrate the hydrophysical properties of sandy soil treated with biochar. The results indicated that the application of biochar significantly improved the saturation water content (SWC), field capacity(FC), permanent wilting point (PWP), and available water content(AWC). The hydrophysical properties of sandy soil treated with biochar were significantly improved by about 5.02, 6.83, 6.31, and 7.08%, respectively. The effect of biochar applications on all hydrophysical parameters increased with increasing the application rate of biochar.

The same results have also been reported in other studies on sandy soils **(Uzoma et al., 2011; Abel et al., 2013; Barnes et al., 2014, and Prakongkep et al. 2020**) also reported that the FC and PWP were increased by biochar application due to an increase in the porosity of the soil matrix. **Cornelissen et al.(2013** and **Martinsen et al. (2014)** reported similar findings where the addition of 5% biochar significantly increased the FC and PAW of three sandy soils from 9% to 15%. The modification of biochar has two effects on soil water holding capacity, WHC **(Liu et al., 2016a).** Firstly, biochar itself can retain water in its internal pores, thus directly increasing soil moisture content.

The total porosity of sandy soil treated with biochar was increased by 14.29% at a 5% rate of biochar as compared with the control treatment (Table 5). Also, hard biochar was more effective than soft biochar in increasing the total porosity of sandy soil treated with biochar by about 9.43%.

The soil bulk density (BD) of the sandy soil significantly decreased ($p < 0.05$) with the application of biochar. In sandy soil, the bulk density decreased by 7.53% at 5% biochar application as compared to that of the control soil. Biochar has low density but a high surface area. When it is mixed with denser particles such as sandy soil; the bulk density and particle density of the biochar-mixed soil are reduced. Soft biochar was more effective in decreasing the soil bulk density by 5.12%.

The effect of biochar application on soil physical properties has been widely studied (**Burrell et al., 2016**; **Glab et al., 2016**; **Liu, et al., 2016a&b**; **Obia et al., 2016; Blanco-Canqui, 2017**; and **Trupiano et al., 2017**). Both positive and negative effects of biochar application on soils' physical properties have also been reported (**Blanco-Canqui, 2017)**. The soil's physical properties directly or indirectly influence the soil's chemical and biological processes. For example, the physical property of soil can be used as an indicator for plant root growth, aeration, erosion, nutrient uptake, and water retention (**Blanco-Canqui, 2017**).

Table (4). Particle size distribution (%) of sandy soil treated with biochar

Biochar Type	Biochar rate (%)	Particle diameter, mm						MWD mm	GMD mm	Structure coefficient Cr
		2 - 1	**1 – 0.5**	**0.5 – 0.25**	**0.25 – 0.125**	**0.125 –0.063**	**< 0.063**			
Hard Biochar	0	18.19	25.20	21.06	20.81	12.73	2.02	0.589	0.399	1.817
	1	19.58	25.60	21.60	19.61	11.52	2.08	0.612	0.417	2.021
	3	20.58	27.88	21.65	18.07	8.36	3.47	0.641	0.438	2.400
	5	20.07	25.61	22.34	19.65	10.32	2.02	0.619	0.430	2.147
Soft Biochar	0	18.19	25.20	21.06	20.81	12.73	2.02	0.589	0.399	1.817
	1	18.20	25.21	21.07	20.82	12.68	2.02	0.589	0.400	1.820
	3	19.89	26.13	21.18	19.56	11.24	1.99	0.618	0.427	2.128
	5	19.40	30.96	19.98	19.33	8.71	1.61	0.641	0.460	2.594
Mean effect of Biochar type										
Hard		19.60	26.87	21.663	20.129	11.338	2.396	0.615	0.421	2.096
Soft		18.92	26.07	20.825	19.533	10.734	1.910	0.609	0.421	2.089
LSD 0.05		3.69ns	2.92ns	3.199 ns	3.086 ns	1.839 ns	1.875ns	0.052 ns	0.028 ns	0.315 ns
Mean effect of Biochar rate (%)										
0		18.18	25.19	21.05	20.80	12.73	2.020	0.588	0.399	1.817
1		18.88	25.40	21.34	20.21	12.09	2.051	0.600	0.408	1.920
3		20.23	27.00	21.41	19.48	9.79	2.730	0.629	0.432	2.263
5		19.73	28.28	21.16	18.81	9.51	1.811	0.630	0.445	2.370
LSD 0.05		3.68 ns	4.405 ns	1.42 ns	2.68 ns	3.59 ns	1.627 ns	0.065 ns	0.065 ns	0.752 ns
Interaction effect (Type X Rate)										
LSD 0.05		5.58 ns	5.97 ns	3.45 ns	4.29 ns	4.69 ns	2.606 ns	0.092 ns	0.084 ns	0.961 ns

Table (5) Hydrophysical properties of sandy soil treated with biochar

Biochar Type	Biochar rate (%)	Saturation (SWC) %	Field capacity (FC) %	permanent wilting point (PWP) %	Available water (AWC) %	Total porosity cm^3/cm^3	Soil bulk density (BD) g/cm^3
Hard	0	28.34	14.54	5.78	8.76	0.341	1.747
	1	30.37	16.37	6.50	9.88	0.373	1.661
	3	33.05	17.68	7.17	10.51	0.397	1.599
	5	34.54	20.85	8.22	12.63	0.425	1.524
Soft	0	28.41	14.18	5.36	8.82	0.326	1.787
	1	29.37	15.39	6.24	9.15	0.342	1.744
	3	29.81	16.68	6.84	9.84	0.348	1.727
	5	32.67	18.76	7.57	11.19	0.388	1.623
Mean effect of Biochar type							
Hard		31.57	17.36	6.91	10.44	0.383	1.720
Soft		30.06	16.25	6.50	9.75	0.350	1.632
LSD0.05		0.88**	3.22ns	0.13**	0.16**	0.045**	0.122**
Mean effect of Biochar rate (%)							
0		28.81	14.64	6.09	8.79	0.343	1.740
1		30.43	16.29	6.33	9.51	0.358	1.700
3		31.42	16.83	5.79	10.17	0.375	1.655
5		32.60	19.56	7.61	11.91	0.392	1.609
LSD0.05		2.71*	3.57**	1.14*	0.69**	0.038ns	0.101*
Interaction effect (Type X Rate)							
LSD0.05		3.42ns	3.55ns	1.40ns	0.86ns	0.062ns	0.166ns

Soil water retention parameters

The parameters of the soil water retention as described by the model of van Genuchten (**van Genuchten, 1980**) were calculated and the results are described in Table(6). The biochar type (Hard and Soft) has a significant effect on θr and n parameters in which hard biochar has more effect in increasing the values. Also, the biochar application rate significantly (p<0.005) increased both θr and θs parameters by about 75.68 and 15.00%, respectively. The rest of the parameters were increased but not significant.

Table (6) Water retention parameters of sandy soil treated with biochar

Biochar	Biochar	θr	θs	α	n	m
Hard	0	0.031	0.466	0.0144	0.867	0.384
	1	0.050	0.509	0.0121	1.137	0.389
	3	0.065	0.517	0.0164	0.956	0.412
	5	0.092	0.578	0.0195	1.089	0.497
Soft	0	0.043	0.495	0.0193	0.784	0.463
	1	0.041	0.504	0.0174	0.813	0.427
	3	0.042	0.528	0.0184	0.774	0.436
	5	0.039	0.526	0.0133	0.916	0.359
Mean effect of Biochar type						
Hard		0.059	0.517	0.0156	1.0122	0.4206
Soft		0.041	0.513	0.0171	0.8217	0.4213
LSD 0.05		0.018**	0.037ns	0.0077ns	0.2294**	0.1134ns
Mean effect of Biochar rate (%)						
0		0.037	0.480	0.016	0.8253	0.4234
1		0.045	0.506	0.014	0.9749	0.4082
3		0.053	0.522	0.017	0.8651	0.4240
5		0.065	0.552	0.016	1.0027	0.4282
LSD 0.05		0.005**	0.016**	0.003ns	0.1917ns	0.0610ns
Interaction effect (Type X Rate)						
LSD 0.05		0.019**	0.040**	0.008*	0.312ns	0.128*

Effect of biochar application on soil chemical properties

The pH of sandy soil treated with biochar was higher as compared to the control treatment. The pH of biochar applied at 5% was higher than biochar applied at 3%. Increasing the compost application rate resulted in an increased pH. Biochars are mostly alkaline (pH > 7) with higher base cation concentrations. Consequently, biochar applied to soils can release base cations into the soil solution to reduce acidity through proton consumption reactions as indicated by **(Chintala et al. 2014).**

The increase in soil pH after amendment application could be attributed directly to the higher pH of the biochar used in the study. The result corresponds with the results of previous studies **(Mensah and Frimpong, 2018**; **Manolikaki and Diamadopoulos, 2019**; and **Sigua et al., 2019)**. It was concluded that biochar can be used as an alternative to lime materials to ameliorate soil acidity. Since soil pH can change under changing climatic conditions and land-use practices, it is recommended that the biochar effect on soil pH should be evaluated in the long term to further understand the dynamics in pH of soils with differing acidity**.**

The EC of sandy soil treated with biochar was higher than the untreated soil. The EC consequently increased with increasing biochar application rates. In this study, the highest EC was recorded in the hard biochar application than in the soft biochar application.

In previous studies, **(Shareef et al. 2018** and **Chintala et al. 2014)** found that EC increased with the increasing application rate of biochar. **(Chintala et al. 2014)** attributed the increase in EC to alkalinity, CaCO3 content, proton consumption capacity, and base cation concentration of the biochar used. They further explained that biochar contains higher soluble salts which are released into the soil solution which increases the soil EC. The increase in EC was also attributed by **(Shareef et al. 2018)** to the release of weakly bound ions of the biochar into the soil solution.

Table (7). Chemical properties of sandy soil treated with biochar

Biochar Type	Biochar rate (%)	pH	EC dS/m	Soluble cations, me/l				SOC %	CEC meq/kg
				Ca	Mg	Na	K		
Hard	0	7.13	0.447	1.763	1.550	0.803	0.351	1.38	2.57
	1	7.67	2.567	9.776	6.731	6.258	2.901	1.42	3.61
	3	7.93	2.800	11.008	8.267	4.773	3.952	1.47	3.73
	5	8.67	2.967	13.014	7.048	5.542	4.062	1.55	3.94
Soft	0	7.67	0.447	1.763	1.550	0.803	0.351	1.38	2.57
	1	7.80	2.777	9.303	8.034	6.831	3.599	1.41	2.53
	3	7.83	2.463	9.122	7.864	3.962	3.685	1.44	2.81
	5	7.87	2.867	11.173	6.654	5.452	5.388	1.48	3.06
Mean effect of Biochar type									
Hard		7.658	2.195	8.7117	5.723	4.213	2.703	1.456	3.463
Soft		7.792	2.138	7.6842	5.844	4.135	3.124	1.428	2.743
LSD 0.05		0.798ns	0.947ns	3.7157ns	2.516ns	1.779ns	1.346**	0.012**	0.212**
Mean effect of Biochar rate (%)									
0		7.666	0.447	1.730	1.503	0.780	0.337	1.380	2.570
1		8.033	2.672	9.348	7.160	6.348	3.118	1.415	3.073
3		7.666	2.632	9.863	7.825	4.235	3.663	1.456	3.268
5		7.533	2.917	11.850	6.645	5.332	4.537	1.516	3.500
LSD 0.05		0.537ns	0.849**	3.901**	2.196**	1.612**	1.333ns	0.015**	0.339**
Interaction effect (Type X rate)									
LSD 0.05		0.978ns	1.341ns	5.807ns	3.508ns	2.535ns	2.026ns	0.021**	0.456*

Soluble cations (i.e. Ca, Mg, Na, and K) in soil amended with biochar were significantly increased with increasing the biochar application rate. The increase in soluble cations may be attributed to that biochar contains higher soluble salts which are released into the soil solution which increases the soil soluble cations. The effects of biochar on soil organic carbon (SOC), in sandy soil amended with biochar are shown in Table (7). The application of biochar to soil significantly improved the organic carbon for both soft and hard biochar ($p < 0.05$). The increase in the organic carbon in sandy soil by the addition of biochar may be due to an increase in the organic carbon of biochar.

The content of SOC increased linearly with biochar application rates (Table 7). This is probably because biochar also undergoes biodegradation, although it is considered stable in the soil system. According to **(Bird et al. 1999)**, the time required for the soil-charred particle's biodegradation is related to their granulation. These authors estimated that the half-life of particles smaller than 2 mm is lower than 50 years and that of particles larger than 2 mm is lower than 100 years. Small changes in the soil organic carbon content in areas where biochar has been recently applied may be explained by the stability of pyrogenic carbon. According to **(Petter et al. 2012),** the high molecular stability of pyrogenic carbon in biochar hinders the complete oxidation of the material derived from pyrolysis via this method.

The values of cation exchange capacity increased with the increasing rate of biochar (Table 7). These results confirm that biochar altered the intensity of the pH-dependent negative charges, as a result of the continuous oxidation of surfaces, and the sorption of organic acids by biochar. The CEC is expected to increase further with time, as observed in the study by **(Cheng et al. 2008).** These authors reported that the incubation of biochar for one year raised its CEC from 1.7 to 71.0 mmol kg^{-1}.

Generally, the research indicated that biochar application to sandy soil increases the CEC and exchangeable bases, thereby improving the fertility of the soil and invariably increasing soil productivity. This result is in line with the previous research by **(Yusif et al. 2016)** who reported that biochar applications have the potential to improve soil chemical properties. **(Agegnehu et al. 2016, and Hardy et al. 2017)** reported an increase in CEC of soil amended with biochar.

Effect of biochar application on soil fertility status

Soil available Nitrogen:

The effects of biochar applications on available nitrogen content in sandy soil were highly significant effect (Table 8). The addition of different rates of biochar had higher available nitrogen contents of soil compared with no addition of biochar. The highest nitrogen content (132.58 mg kg^{-1}) was found from 5% biochar application which was significantly higher ($p<0.05$) than other treatments. The lowest (48 mg kg^{-1}) nitrogen content was obtained without biochar-amended soil. The increase in available N content was about 176.21% over the control treatment. Also, the sandy soil amended with Hard biochar has more content of soil N (93.62 mg kg^{-1}) than sandy soil amended with soft biochar(79.12 mg kg^{-1}).

Soil available phosphorus:

Available phosphorus content in soil was significant ($p<0.05$) among the various rates of biochar application (Table 8). The addition of different rates of biochar had higher available phosphorus contents of soil compared with without the addition of biochar. The highest phosphorus content (73.42 mg kg^{-1}) was found from 5% biochar application which was significantly higher ($p<0.05$) from other treatments. The lowest (15.08 mg kg^{-1}) phosphorus content was obtained without biochar-amended soil. The increase in available P content was about 386.87% over the control treatment. Also, the sandy soil amended with Hard biochar application has a lower content of soil available P (41.71 mg kg^{-1}) than the sandy soil amended with soft biochar(52.81 mg kg^{-1}). The present results were compatible with **(Timilsina et al. 2017)**

Soil available potassium:

The effects of biochar applications on available potassium contents in sandy soil were highly significant ($p<0.05$). The increased rates of biochar application increased the available potassium content in the soil. The highest available potassium content (600 mg kg^{-1}) in soil was found from 5% biochar application which was significantly higher ($p<0.05$) than other treatments. The lowest available potassium content (391.67 mg kg^{-1}) was found without biochar-amended soil. The increase in available K content was about 53.19% over the control treatment Also, the sandy soil amended with Hard biochar application has a higher content of soil available K(525.00 mg kg^{-1}) than the sandy soil amended with soft biochar(443.75 mg kg^{-1}).

The observed increase in N, P, and K contents of soil due to the application of biochar could be due to the presence of high contents of N, P, and K in biochar. **(Chan et al. 2008),** also reported the addition of biochar to soil increased the available N, P, and K of soil. **(Mukherjee and Zimmerman 2013)** reported that the application of biochar into soil increased the availability of nitrogen in the soil.

Table (8) Fertility status of sandy soil (mg/kg) treated with biochar

Biochar Type	Biochar rate (%)	N	P	K	Fe	Mn	Cu	Zn
		mg/kg						
Hard	0	48.00	15.08	391.67	2.32	0.67	0.26	0.13
	1	73.50	22.50	550.00	2.97	1.42	0.29	0.13
	3	103.50	58.83	525.00	3.30	1.49	0.29	0.22
	5	149.50	70.43	633.33	4.37	2.13	0.29	0.26
Soft	0	48.00	15.08	391.67	2.32	0.67	0.26	0.13
	1	64.00	59.17	350.00	2.34	1.47	0.27	0.11
	3	88.83	60.58	466.67	2.41	1.70	0.20	0.18
	5	115.67	76.42	566.67	2.94	1.74	0.26	0.23
Mean effect of Biochar type								
Hard		93.62	41.71	525.00	3.24	1.420	0.284	0.186
Soft		79.12	52.81	443.75	2.50	1.396	0.247	0.159
LSD 0.05		6.68**	3.06*	232.89*	0.37**	0.171ns	0.045**	0.074*
Mean effect of Biochar rate (%)								
0		48.00	15.08	391.67	2.32	0.66	0.25	0.12
1		68.75	40.83	450.00	2.64	1.44	0.28	0.12
3		96.17	59.71	495.83	2.85	1.59	0.24	0.19
5		132.58	73.42	600.00	3.65	1.93	0.27	0.34
LSD 0.05		8.83**	5.10**	105.42*	0.75**	0.27**	0.09ns	0.02**
Interaction effect (Type X Rate)								
LSD 0.05		12.32*	6.81**	252.39ns	0.97ns	0.37ns	0.12ns	0.08ns

Soil available micronutrients:

The application of biochar to sandy soil resulted in increasing the available micronutrients such as Fe, Mn, Cu, and Zn. Increasing the application rates of biochar significantly increases the available micronutrients by about 57.33, 192.42, 8.00, and 183.33%, respectively for a 5% rate over the control treatment (Table 8). Also, the sandy soil amended with hard biochar has a higher content of available micronutrients than the sandy soil amended with soft biochar.

In general, the application of biochar increased soil's available nitrogen, available phosphorus, available potassium contents, and available micronutrients of soil amended with biochar. It can be thus concluded that the addition of biochar to soil would be of immense value to increase soil fertility. Thus, biochar application provides an innovative method for handling excess organic waste to sequester carbon and potentially improve soil and plant productivity which ultimately leads to sustainable soil management.

Carbon sequestration in soil is of significant importance because it can enhance soil fertility **(Lehmann, 2007 and 2009)** and reduce carbon dioxide emissions to the atmosphere **(Zhang et al., 2012)**. Because of its relative inertness, biochar can increase soil carbon sequestration **(Lu et al., 2014**; **Singh and Cowie, 2014).** However, the mechanisms by which biochar impacts soil organic carbon and then soil fertility remain unclear. Biochar may also have a significant ability to improve soil structure and soil water capacity, which might contribute to positive priming (**Zimmerman et al., 2011).** In addition, organic carbon mineralization may be suppressed in the presence of biochar because of the direct adsorption of native labile organic matter or the induced stabilization of relatively labile organic matter **(Kasozi et al., 2010; Lin et al., 2012)**.

The supplement of biochar to soil has been reported to improve soil nutrient availability and plant growth **(Farrell et al., 2014).** Biochar application can also increase the number of extractable nutrients in the soil solution regardless of the temperature used for biochar production **(Zhao et al., 2014).** The effect of biochar on soil nutrients is related to its chemical composition and surface characteristics. The biochar itself may be a potential nutrient source. **(Qian et al., 2013)** investigated the effects of the environmental status on the release of nutrients from biochar. Their results showed that the number of nutrients released from biochar was influenced by the retention time, coexisting anions, and the contents of other nutrient elements.

The results of the present study showed that biochar applications can improve soil properties. The soil's physical properties (bulk density, water holding capacity, and aggregate stability) were significantly improved by all biochar application rates. The bulk density of soil decreased with the increasing application of biochar. Conversely, the water-holding capacity of soil improved with the increasing application of biochar. The improvement in soil physical properties resulted in an improvement in the soil chemical properties (pH, EC, CEC, available N, P, K, and micronutrients). For example, the WHC represents the soil nutrient retention capacity, and therefore soils with high WHC can retain nutrients more than soils with low WHC.

CONCLUSION

As a result of the present study, the following recommendations are made:

i. Farmers in the study area should use corncob biochar as an amendment to improve soil properties and fertility and then increase crop yield. Corncob biochar application not only adds nutrients to the soil but also develops the soil's physical characteristics making the soil more efficient in supporting and retaining water and nutrients.

ii. Biochar should be seen as an alternative used for organic waste. Organic waste management is a major problem. Particularly from environmental pollution, improper management of organic waste has public health implications that can affect the quality of life of the people leaving in such an environment.

iii. Agricultural policies on soil fertility improvement and environmental relative policies on organic waste management should be geared towards large-scale adoption of biochar technologies. In other to achieve that, large-scale research on biochar should be conducted by interested stakeholders on all the agroecological zones and all soil types. The results of such research will enable the recommendation of biochar sources, and application rates for each soil type in the agroecological zones.

Therefore, furthermore, research must be performed on the effects of biochar applications on soil properties and include the following:

i. Long-term effects of biochar addition on physicochemical properties of soil and crop yield.

ii. Effects of biochar types, application rates, and pyrolysis temperature on soil properties. and

iii. Factors that influence the ways of biochar application technologies by farmers

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الملخص العربي

التأثيرات المفيدة لاضافة البيوتشار على تحسين خواص التربة الرملية

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تهدف هذه الدراسة إلى تقييم تأثير الفحم الحيوي المشتق من نفايات الذرة (المنتج محليًا عن طريق الانحلال الحراري البطيء عند 500 درجة مئوية) على تحسين خصائص التربة الرملية (الخواص الفيزيائية والكيميائية والخصوبية). التربة المستخدمة في هذه الدراسة عبارة عن تربة رملية تم جمعها من الطبقة السطحية (بعمق 0 – 30 سم). تم خلط التربة الرملية مع البيوتشار الناتج من الأجزاء الناعمة والخشنة من قوالح الدرة والناتج عن الانحلال الحراري عند درجة حرارة عالية (500 درجة مئوية). تم خلط التربة الرملية مع الفحم النباتي بمعدلات 0 ، 1 ، 3 ، 5٪ (وزن / وزن). تم ترطيب الخليط عند السعة الحقلية والتحضين عند درجة حرارة الغرفة (25 ± 2 درجة مئوية) لمدة شهر مع إعادة ترطيب كل 7 أيام.

خضعت مخاليط التربة والفحم الحيوي للتحليل الفيزيائي والكيميائي. أشارت النتائج إلى أن اضافة البيوتشار أدى إلى تحسن كبير في محتوى الماء عند التشبع (SWC) ، والسعة الحقلية (FC) ، ونقطة الذبول الدائمة (PWP) ، والمحتوى المائي المتاح (AWC). تم تحسين الخواص الفيزيائية المائية للتربة الرملية المعالجة بالفحم الحيوي بشكل ملحوظ بحوالي 5.02 ، 6.83 ، 6.31 ، و 7.08٪ على التوالي. انخفضت الكثافة الظاهرية (BD) للتربة الرملية بشكل ملحوظ (p <0.05) مع اضافة البيوتشار. كان الفحم الحيوي الناعم أكثر فعالية في تقليل الكثافة الظاهرية للتربة بنسبة 5.12٪. نوع البيوتشار (صلب وناعم) له تأثير كبير على قيم θ_r و n حيث يكون للفحم الحيوي الصلب تأثير أكبر في زيادة القيم. أيضًا ، زاد معدل اضافة الفحم الحيوي بشكل كبير (p <0.005) كلا من قيم θ_r و θ_s بحوالي 75.68 و 15.00٪ على التوالي. يمكن أن تعزى الزيادة في درجة الحموضة في التربة بعد اضافة البيوتشار إلى درجة الحموضة الأعلى للفحم الحيوي المستخدم في الدراسة. تمت زيادة الكاتيونات الدائبة أي Ca و Mg و Na و K في التربة المعالجة بالفحم الحيوي بشكل كبير مع زيادة معدل اضافة الفحم الحيوي. أيضًا ، زاد الكربون العضوي في التربة خطيًا مع معدلات اضافة الفحم الحيوي. وقد زادت محتويات المغذيات الميسرة N ، P، K، Fe، Mn، CU، Zn بشكل ملحوظ مع زيادة معدل اضافة الفحم الحيوي. أظهرت نتائج الدراسة الحالية أن اضافة الفحم الحيوي يمكن أن تحسن خصائص التربة. لذلك ، يجب إجراء مزيد من البحث على اضافة البيوتشار للتربة وتشمل ما يلي: التأثيرات طويلة المدى لاضافة البيوتشارعلى الخصائص الفيزيائية والكيميائية للتربة وإنتاجية المحاصيل تأثيرات نوع الفحم الحيوي ، ودرجة حرارة الانحلال الحراري ، ومعدل الاضافة على أنواع التربة الأخرى ، و العوامل التي تؤثر على طرق تقنيات اضافة البيوتشار من قبل المزارعين.