Khulna University Studies Special Issue ISFMRT: 1-10: 2023

ORIGINAL ARTICLE **LIFE SCIENCE**

BIOCHAR AS A POTENTIAL SOIL CONDITIONER IN SALINE PRONE COASTAL AREA OF BANGLADESH

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KUS: 1099: 23052023
Manuscript submitted: May 23, 2023 Accepted: October 7, 2023

Abstract
Soil salinity restricts normal crop production of coastal areas in Bangladesh, and increases with the desiccation of the soil. Currently, biochar has attracted great attention as a smart soil amendment for mitigating the adverse effects of salinity. In this respect, a field experiment was performed to examine the responses of biochars on soil characters and growth of okra (*Abelmoschus esculentus* L.) and to identify a suitable biochar amendment for salt-affected soils. The experiment was conducted in a completely randomized block design (CRBD) with five replications. Three types of biochar (produced from rice straw, sawdust and water hyacinth) were applied @ 10 t ha^{-1} in a silt loam soil along with the control. Results revealed that biochar application to the soil enhanced height of plant, leaf number, largest leaf area, shoot fresh weight, shoot dry weight and yield of okra as well as improving the soil quality e.g., field capacity (FC), cation exchange capacity (CEC), organic carbon (OC), total N, available P, S, K, and Ca. Water hyacinth biochar improved almost all of the growth and yield attributes of okra along with most of the soil properties than that of others. The results suggest that water hyacinth biochar might be recommended as a suitable soil amendment for better crop growth and soil quality. Moreover, water hyacinth biochar had significantly ($P<0.001$) higher surface area (205.40 m^{2}g^{-1}); consequently, higher capacity in salt and water adsorption which might prevent soil desiccation. Side by side, it significantly ($P<0.001$) increased the soil Ca content which might replace Na^+ in the root rhizosphere minimizing the Na^+ uptake by plants. Taken together, water hyacinth biochar could also be the best choice of organic amendments to reduce the detrimental effect of salt stress in coastal areas of Bangladesh.

Keyword: Char, Salinity stress, Crop growth, Soil amendment, Salt-affected soils

Introduction

The coastal areas cover nearly twenty percent of Bangladesh and more than thirty percent of the country's cultivable lands. Rasel et al. (2013) stated that about 50% of the arable lands of that coastal area was affected by soil salinity. The mangrove forest of Bangladesh Sundarbans covers around 4,500 km^2 as the most valuable share in the coastal area. The other part of the coastal area is used for agricultural production. In general, soils of the coastal regions are very low in fertility including soil organic matter content (Haque, 2006). In coastal areas, different levels of soil salinity affected the cultivable lands (Petersen and Shireen, 2001). Unfavorable situations are caused by salinity which affects normal crop growth and soil salinity increases with the desiccation of the soil. Salinity affects not only the soil properties also hampers the ecological balance, thus reducing the crop yield and economic output of an area (Parkash and Singh, 2020).

If an excess amount of Na^+ is present in the soil it depreciates the soil's physical properties, *viz.* aggregate stability, permeability, percent of pores, and infiltration rate (Kim et al., 2016). When the salinity is increased, salts are increasingly accumulated both in soil solution and in root zone. As a result, water uptake of plant roots is inhibited. The root and shoot growth are declined due to reduced root water uptake which causes decreased enzyme activity, protein synthesis, and CO_2 assimilation returns (Parkash and Singh, 2020). The higher saline condition also causes ion accumulation in the tissues of plants. Toxic effects might be produced by the ions if, it crosses the threshold levels. The toxic effects of ions result in the senescence of premature leaves, chlorosis, necrosis, and reduction in cellular metabolic activities (Panuccio et al., 2014; Zahir et al., 2012). Due to the decrease in metabolic activities the

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DOI: https://doi.org/10.53808/KUS.SI.2023.ISFMRT.1099-ls

photosynthesis activity might be inhibited (Sahin et al., 2018) and electrolyte leakage. The major electrolyte K is a vital element for ion balance, enzyme activity, phloem transport, protein synthesis, stomatal regulations, osmoregulation, and photosynthesis activity (Wang et al., 2013). So, higher soil salinity directly and indirectly hampers plant processes and ultimately plant growth.

Therefore, to alleviate the impacts of salinity, the potential practices for removing excess dissoluble salts and/or to remove exchangeable Na^+ in excess from soil solution should be adopted (Parkash and Singh, 2020). Different organic amendments *viz.* farm-yard manure, poultry manure, compost, green manure etc. are used to a great extent in soil for improving the physical and chemical along with the biological properties of saline soils to enhance their crop productivity. However, these organic amendments are highly decomposable and necessitate frequent reapplication to the soil. It is economically unfeasible as well as is not friendly for the environment as greenhouse gases emission will be increased (Al-Wabel et al., 2019).

Biochar, a carbonaceous black material which is highly recalcitrant to decompose is produced from different biomasses through the pyrolysis process under the condition of limited or no supply of O_2 in a closed furnace. It is widely applied as a soil conditioner to increase soils' productivity though improving soil physical properties (water holding capacity, hydraulic conductivity, porosity, aggregate stability etc.), chemical properties [nutrient availability and retention, pH, electrical conductivity (EC), CEC etc.] and biological properties (Lehmann and Joseph, 2009). Besides, the unique characteristic of biochar (soil amendment) which makes it potential for saline soils is its high salt adsorbing capacity due to its high surface area and CEC. However, biochar being an extremely recalcitrant material has not been widely studied to explore its potential for improving soil quality to reclaim salt-affected soils for growing plant (Parkash and Singh, 2020).

In this respect, a field experiment was carried out to examine the responses of biochars on soil properties and growth of okra (*Abelmoschus esculentus* L.) and to identify a suitable biochar amendment for salt-affected soils of coastal areas in Bangladesh.

Materials and Method

Experimental site

The research was accomplished in a farmer's field (N 22° 56.758'/E 89° 40.257') situated in Terokhada Upazila, Khulna (Figure 1). The experimental field belongs to the Agroecological zone (AEZ) 11 with the Ganges River Floodplain soil. The soil is silt loam in texture.

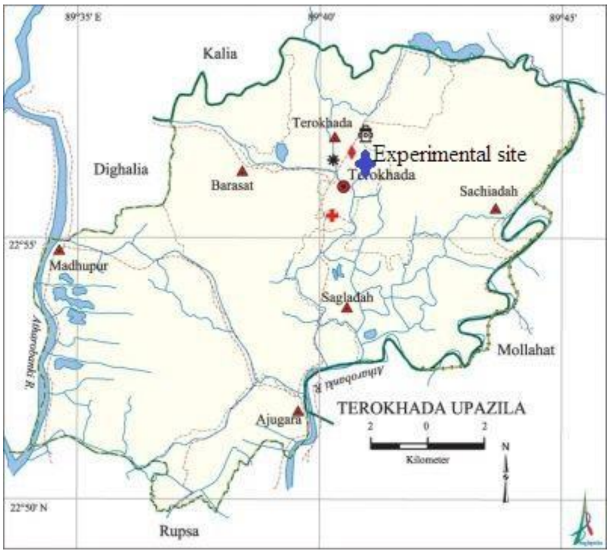

Figure 1. Map showing the location of the field experiment (Kabir, 2021)

The soils' organic matter level was poor and slightly alkaline in reaction. In general, the fertility level is low. However, the studied soil is medium in CEC, medium to high in K-bearing minerals and low to medium in Zn and B (FRG, 2012).

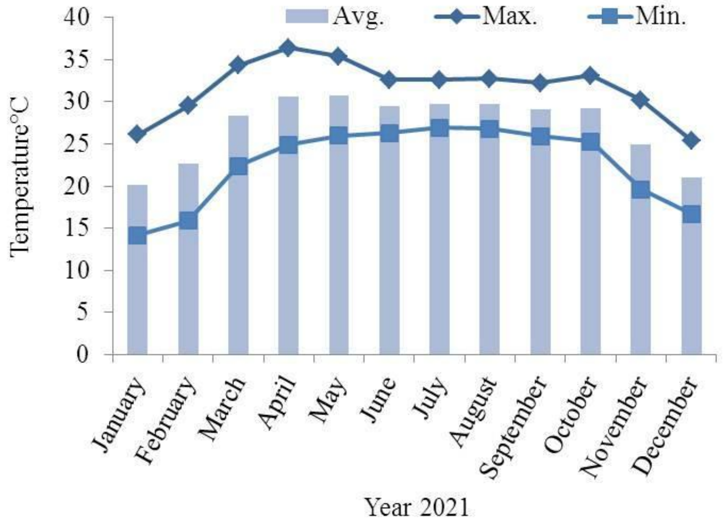

Figure 2. Monthly maximum (Max.), minimum (Min.) and average (Avg.) temperature of the year 2021 (Data collected from Bangladesh Meteorological Department, Khulna)

The climate of the areas is subtropical with extreme heat during summer with high total rainfall (Figure 2 and Figure 3).

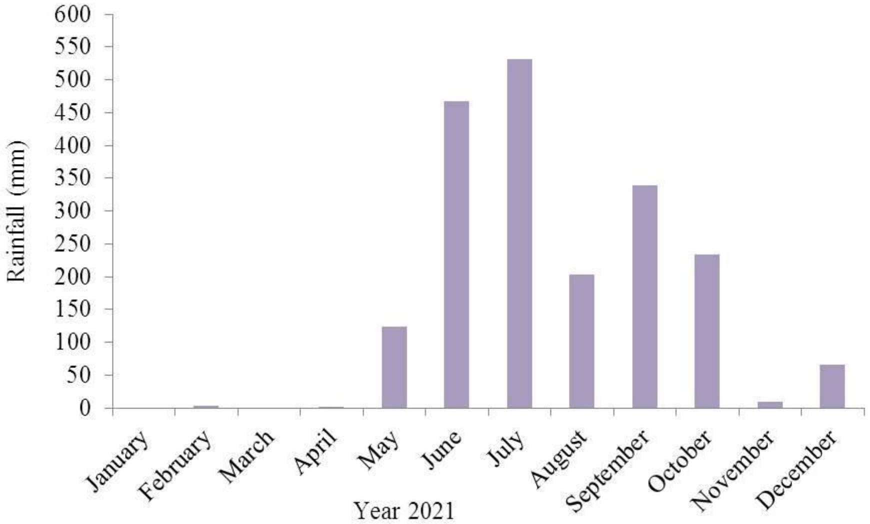

Figure 3. Monthly average rainfall of the year 2021 (Data collected from Bangladesh Meteorological Department, Khulna)

Collection and preparation of soil and biochar sample

Soil sampling was done from the 0-15 cm topsoil of the field and a composite soil sample was prepared according to USDA (1951). The sample was then air dried, sieved (<2 mm) and homogenized and preserved for characterizing them. Three biochars (Table 1) were produced in Soil, Water and Environment discipline at Khulna University in Bangladesh. The biochar samples were homogenized, ground with mortar and pestle, then passed through 2.0 mm sieve (IBI, 2015) and preserved in separate containers for laboratory analysis and further use as a soil amendment in the field.

Table 1. General information on the biochars production

Biochars	Code	Pyrolysis temperature (°C)	Residence time (min.)
Rice straw biochar	B1	400	10
Sawdust biochar	B2	350	20
Water hyacinth biochar	B3	400	10

Methods of soil and biochars analysis

The soil textural class was determined by Marshall's Texture Triangle as devised by USDA (1951) followed by particle size analysis (PSA) using the modified Bouyoucos hydrometer method (Gee and Or, 2002). Field capacity (FC) moisture of the soil, soil pH, EC, CEC, soil organic carbon (SOC), total N, and available P, K, S, and Ca were determined according to the procedures narrated in Huq and Alam (2005).

The pH and EC of the biochars were determined electrochemically with a pH meter and EC meter respectively, using modified dilution of 1:20 (w:v) biochar: deionized H_2O and equilibration at 90 minutes on the shaker, according to Rajkovich et al. (2012). Surface areas of biochars were estimated according to the procedures described by Dume et al. (2015). The carbon content of the biochars was determined by Walkley and Black's wet oxidation method as described by Jackson (1962). Total nitrogen in biochar was determined by Micro-Kjeldahl's method following H_2SO_4 acid digestion as suggested by Jackson (1967). Available P of biochar samples was determined by extraction with 2% formic acid followed by spectrophotometry (Wang et al., 2012). Available K, Ca, and SO_4-S determination were performed after extraction with 1 M HCl (Camps-Arbestain et al., 2015). The available K in the extract was analyzed at 589 nm by a flame analyzer and the SO_4-S was measured by Spectrophotometer at 420 nm. The available Ca was determined by complexometric titration method using ethylene diamine tetra-acetic acid (EDTA) (Schwartzenbech et al., 1946).

Experimental design

The experiment was carried out in a randomized complete block design (RCBD) with five replications. Blocks (8.8m × 3.2m) of consistent soil type were identified and within these blocks, 2.6m × 1.4m experimental plots were established. There were twenty experimental plots of equal size. Okra was grown as a test plant. The plant spacing was 60 cm × 40 cm. There were five rows per plot and five plants per row. During field preparation, chemical fertilizers were applied to the soil @ 90-40-40 kg ha^{-1} N, P_2O_5, K_2O (FRG, 2012). The total amount of biochar, Triple super phosphate (TSP), and Muriate of potash (MP) and half the quantity of urea and MOP were applied as basal and the rest was top-dressed 30 days after planting.

Treatments

There were three types of biochars as treatments *viz.* B1 (rice straw biochar), B2 (sawdust biochar), and B3 (water hyacinth biochar) along with the control (B0). Biochars were applied @ 10 t ha^{-1} to the field.

Seed sowing

Seeds of BARI Dherosh-2 were soaked in water overnight and were dibbled with 2 seeds hill^{-1} on 15 February 2021.

Weeding

Manual weeding was done at regular intervals for keeping the experimental field free from weeds.

Irrigation

The soil moisture level was monitored with the help of a tensiometer and irrigation was done to keep the soil moisture level within field capacity range.

Harvesting and sampling

Okra was harvested for data collection at the edible stage. The experimental plants were harvested on 18 May 2021. Different growth and yield attributes were recorded from the inner 5 plants from each plot. Data were collected for plant height (cm), leaf number, largest leaf area (cm^2), shoot fresh weight (g), shoot dry weight (g), fresh biomass (g), dry biomass (g) and yield (t ha^{-1}). Soil samples were taken from each plot and then analyzed for the same parameters as was done for the initial soil.

Statistical analysis

Data were analyzed statistically through the SPSS 16.0 statistical package. Significant variations among the treatments were analyzed through one-way ANOVA by using Tukey's tests at $P<0.05$. Other calculations and graphs were prepared using Microsoft Excel 2010.

Results

Characteristics of soil

The analytical results of some important properties of soil are presented in Table 2. The soil used in the experiment for plant growth is silt loam in texture, slightly alkaline and non-saline in nature. The soil fertility level is very low for available P, low for organic matter and total N with a medium level of available K and CEC (Table 2) according to FRG (2012) of Bangladesh.

Table 2. Important properties of the initial soil

Properties	Soil sample value	Remarks
Texture	Sand (%) 17.06 Silt (%) 61.04 Clay (%) 21.90	Silt loam
% FC	21.89	
pH	7.54	Slightly alkaline
EC(dSm^{-1})	1.13	Non-saline
CEC ($Cmol_cKg^{-1}$)	18.20	Medium
% OC	0.64	
% Organic matter (OM)	1.10	Low
P ($\mu g\ g^{-1}$)	7.05	Very low
S ($\mu g\ g^{-1}$)	18.9	Medium
K ($Cmol_cKg^{-1}$)	0.23	Medium
Ca ($Cmol_cKg^{-1}$)	21.20	Very high

Characteristics of biochar

Some important properties of the biochars are presented in Table 3. Among the analyzed properties of the biochars, B1 was significantly ($P<0.001$, Table 3) higher for pH and total N than that of B2 and B3. B2 was significantly ($P<0.001$, Table 3) higher for %OC than that of B1 and B3. B3 was significantly ($P<0.001$, Table 3) higher for surface area, EC and available P, S, K and Ca than that of B1 and B2. The biochars are statistically similar for CEC.

Table 3. Characteristics of the biochars

Characteristics	Biochars		
	B1	B2	B3
Surface area (m^2g^{-1})	164.87^c	191.53^b	205.40^a
pH	8.28^a	7.53^c	8.06^b
EC (dSm^{-1})	6.80^b	0.30^c	11.80^a
OC (%)	75.10^b	85.40^a	55.70^c
Total N (%)	1.84^a	0.53^c	1.37^b
CEC ($Cmol_cKg^{-1}$)	37.86^a	34.57^a	35.56^a
Available P ($g\ kg^{-1}$)	1.43^b	0.96^c	1.87^a
Available S ($g\ kg^{-1}$)	1.68^b	0.25^c	4.31^a
Available K ($g\ kg^{-1}$)	3.82^b	1.60^c	4.51^a
Available Ca ($g\ kg^{-1}$)	10.07^c	12.47^b	21.6^a

Mean data (n=3) followed by different letter(s) are statistically significant among the biochars; B1=Rice straw biochar, B2=Sawdust biochar, B3=Water hyacinth biochar

Effects of Biochar on plant growth

To evaluate different treatments looking to improve crop performance and yield, in the present study different traits were usually utilized such as plant height, leaf number, leaf area, fresh weight, dry weight, yield and more. Biochar application enhanced all of the studied growth and yield attributes of okra. Plant height was increased for all of the biochar-applied soils as compared to the control. The increment was significant ($p<0.05$) for B3 applied soil and insignificant for B1 and B2 applied soils (Table 4).

Due to biochar application, the leaf number of okra was significantly ($p < 0.05$) increased for B1 applied soil and insignificantly increased for B2 and B3 applied soils (Table 4). The leaf numbers for B1, B2 and B3 applied soils were statistically not different (Table 4). The leaf area was significantly ($p<0.01$) increased for all the biochars applied soils as compared to the control. But B1, B2 and B3 applied soils were statistically not different in the case of leaf area (Table 4).

Table 4. Response of biochar application on plant height, leaf number, largest leaf area, shoot fresh weight, shoot dry weight, and yield of okra

Plant growth parameters	Treatments			
	B0 (No biochar)	B1 (@10 t ha^{-1})	B2 (@10 t ha^{-1})	B3 (@10 t ha^{-1})
Plant height (cm)	96.56 ± 3.91^{b}	110.11 ±7.68^{ab}	115.67 ± 6.88^{ab}	117.89 ± 2.55^{a}
Leaf number	37.89±1.65^{b}	46.00±3.75^{a}	41.89±2.34^{ab}	44.22±2.67^{ab}
Largest leaf area (cm^{2})	143.06±2.40^{b}	152.08±4.17^{a}	153.47±2.42^{a}	159.03±0.99^{a}
Shoot fresh weight (g)	241.39±3.81^{c}	299.32±9.47^{b}	313.32±7.63^{b}	378.70±7.70^{a}
Shoot dry weight (g)	53.02±2.23^{b}	62.44±5.39^{ab}	63.42±2.26^{ab}	73.56±3.66^{a}
Yield (g plant^{-1})	196.15±7.64^{b}	254.59±9.09^{a}	211.84±5.75^{b}	268.66±9.04^{a}
Yield (t ha^{-1})	13.47±0.91^{b}	17.49±1.08^{a}	14.55±0.68^{b}	18.45±1.19^{a}

Mean values are shown ± standard deviation (n = 5); Mean data followed by different letter(s) are statistically significant among the biochars; B0= the control, B1=Rice straw biochar, B2=Sawdust biochar, B3=Water hyacinth biochar

Shoot fresh weight was increased significantly ($p < 0.001$) for all of the biochars applied soils as compared to the control (Table 4). The shoot fresh weight for B3 applied soil was significantly higher than that of B1 and B2 applied soils (Table 4). Whereas the shoot dry weight was increased for all of the biochar applied soils as compared to the control but significant ($p < 0.05$) only for B3 applied soil (Table 4). The shoot dry weight for B1, B2 and B3 applied soils were statistically similar (Table 4).

The yield was increased for all the biochar-applied soils than that of the control but significant ($p < 0.01$) for B1 and B3 applied soils (Table 4). The yield was expressed in g plant^{-1} and t ha^{-1} but in both cases, the highest average yield was observed for B3 applied soil and the lowest was observed for the control (Table 4).

Effects of Biochar on soil properties

Post-harvest soil analysis results are summarized in Table 5. With a few exceptions, biochar application results the soil FC, pH, EC, CEC, OC, total N, available P, S, K and Ca were increased from that of the control. Statistical analysis of the post-harvest soil properties revealed that for biochars application, the field capacity moisture was significantly ($p < 0.001$) increased in compare to the control (Table 5). Among the biochar treatments, field capacity was significantly higher for B1 than that of B2 whereas for B3 it was statistically similar to that of B1 and B2. The highest average field capacity moisture (28.58±0.84%) was observed for B1-applied soil and the lowest (21.50±0.73%) was observed for the control (Table 5).

Table 5. Important properties of the post-harvest soil

Parameters	Treatments			
	B0 (No biochar)	B1 (@10 t ha^{-1})	B2 (@10 t ha^{-1})	B3 (@10 t ha^{-1})
% FC	21.50±0.73^{c}	28.58±0.84^{a}	26.76±0.23^{b}	27.06±0.37^{ab}
pH	7.80±0.10^{a}	7.97±0.06^{a}	7.93±0.06^{a}	7.83±.05a
EC (dSm^{-1})	1.05±0.02^{b}	1.23±0.05^{a}	1.02±0.02^{b}	1.21±0.01^{a}
CEC (Cmol$_{c}$Kg^{-1})	17.00±0.35^{b}	22.21±1.20^{a}	24.21±0.69^{a}	23.81±1.83^{a}
% OC	0.61±0.01^{c}	0.87±0.03^{ab}	0.89±0.01^{a}	0.83±0.02^{b}
% Total N	0.081±0.01^{a}	0.092±0.02^{a}	0.091±0.006^{a}	0.096±0.01^{a}
P (µg g^{-1})	5.23±0.20^{c}	15.25±0.25^{a}	13.76±0.48^{b}	15.36±0.56^{a}
S (µg g-1)	16.73±0.83^{b}	22.00±0.63^{a}	23.97±0.50^{a}	24.18±1.26^{a}
K (Cmol$_{c}$Kg-1)	0.211±0.0004^{b}	0.240±0.002^{a}	0.232±0.001^{a}	0.243±0.007^{a}
Ca (Cmol$_{c}$Kg^{-1})	14.90±0.15^{c}	21.44±0.58^{b}	22.45±0.55^{ab}	23.45±0.25^{a}

Mean values are shown ± standard deviation (n = 5); Mean data followed by different letter(s) are statistically significant; B0= The control, B1=Rice straw biochar, B2=Sawdust biochar, B3=Water hyacinth biochar

Soil pH insignificantly ($p > 0.05$) increased due to biochar application. The highest average soil pH (7.97±0.06) was observed for B1-applied soil and the lowest (7.80±0.10) was observed for the control (Table 5). Soil EC was significantly ($p < 0.001$, Table 5) increased with the application of B1 and B3 and that for B2 was decreased insignificantly ($p > 0.05$) than that of the control. Among the biochar treatments, soil EC was significantly higher for B1 than that of B2 whereas for B3 it was statistically similar to that of B1 and B2. The highest average EC (1.23±0.05 dSm^{-1}) was observed for the B1 application and the lowest (1.02±0.02 dSm^{-1}) was observed for B2 (Table 5).

The CEC of the post-harvest soil was significantly ($p < 0.001$) increased with the application of all the biochars than that of the control (Table 5). Among the biochar treatments, they were statistically similar in the case of soil CEC. The highest average CEC (24.21±0.69 $Cmol_cKg^{-1}$) was observed for the B2 application and the lowest (17.00±0.35 $Cmol_cKg^{-1}$) was observed for the control (Table 5).

Soil OC was significantly ($p < 0.001$) increased with the application of all the biochars than that of the control (Table 5). Among the biochar treatments, soil OC was significantly higher for B2 than that of B3 where soil OC for B2 and B1 were statistically similar. The highest average Soil OC (0.89±0.01 %) was observed for B2 application and the lowest (0.61±0.01%) was observed for the control (Table 5). Therefore, the soil C storage was decreased in the control and increased with the application of all the biochars from the initial soil. The result illustrated the biochars' stability against decomposition and also indicated the increased soil C storage capacity.

The total N of the post-harvest soil was insignificantly ($p > 0.05$) increased with the application of all the biochars than that of the control (Table 5). The highest average total N (0.096±0.01%) was observed for the B3 application and the lowest (0.081±0.01%) was observed for the control (Table 5).

The available P of the soil was increased significantly ($p < 0.001$) with the application of all the biochars than that of the control (Table 5). Among the biochar treatments, the available P content of the post-harvest soils was significantly higher for B1 and B3 than that of B2 where B1 and B3 were statistically similar to that. The highest average soil available P (15.36±0.56 μgg^{-1}) was observed for B3 application and the lowest (5.23±0.20 μgg^{-1}) was observed for the control (Table 5).

The soil available S content was significantly ($p < 0.001$) increased with the application of all the biochars than that of the control (Table 5). Among the biochar treatments, they insignificantly differed in the available S content of the post-harvest soils. The highest average soil available S content (24.18±1.26 μgg^{-1}) was observed for B3 application and the lowest (16.73±0.83 μgg^{-1}) was observed for the control (Table 5).

The available K of the soil was increased significantly ($p < 0.001$) with the application of all the biochars than that of the control (Table 5). The biochar treatments were statistically similar to soil available K. The highest average soil available K was observed for B3 application (0.243±0.007 $Cmol_cKg^{-1}$soil) and the lowest (0.211±0.0004 $Cmol_cKg^{-1}$soil) was observed for the control (Table 5).

In the case of soil available Ca content, it was significantly ($p < 0.001$) increased with the application of all the biochars than that of the control (Table 5). Among the biochar treatments, soil available Ca was significantly higher for B3 than that of B1 where available Ca for B2 was statistically similar to that of B1 and B3. The highest average available Ca (23.45±0.25 $Cmol_cKg^{-1}$soil) was observed for B3 application and the lowest (14.90±0.15 $Cmol_cKg^{-1}$soil) was observed for the control (Table 5).

Discussion

The study was mainly aimed to select a suitable biochar amendment among the three studied biochars for sustainable crop production which can be applied as a potential soil amendment for salt-affected soils in coastal areas of Bangladesh. The present study demonstrated that as a result of biochar application, the growth and yield of okra were increased. The highest values of plant height (117.89±2.55 cm), leaf area (159.03±0.99 cm^2), shoot fresh weight (378.70±7.70 g), shoot dry weight (73.56±3.66 g) and yield (18.45±1.19 t ha^{-1}) were observed for B3 applied soil and the lowest values of those were observed for the control (Table 4). The highest average leaf number (46.00±3.75) was observed for B1applied soil and the lowest (37.89±1.65) was observed for the control (Table 4). Farias et al. (2020) also found enhanced growth and yield of okra for biochar application to soil, and improved soil chemical characteristics. Inal et al. (2015); Muhammad et al. (2017); Parkash and Singh (2020); Abd El-Azeim et al. (2021); Hammam et al. (2022) and Almaghamsi et al. (2023) also reported that for different crops the crop production was increased applying biochar to the soil which is an agreement with the findings of the present study.

The results also illustrated that application of different types of biochar significantly improved almost all the analyzed soil properties which might increase okra productivity. Due to biochar application the field capacity moisture level was increased to 32.93%, 24.47% and 25.86%, the OC level was increased to 42.62%, 45.90% and 36.07%, total

N level was increased to 13.58%, 12.35% and 18.52%, and the available P level was increased to 191.59%, 163.09% and 193.69% for application of B1, B2 and B3, respectively from that of the control. These are the most important soil properties for plant growth and the studied soil was deficient for most of them (Table 2) which were increased by the applied biochars. Previous study reported an increase in soil nutrient content for biochar application (Biederman and Harpole, 2013). Similar findings were presented by Hamzah and Shuhaimi (2018). Farias et al. (2020) also observed improved soil chemical characteristics. Faye et al. (2021) explored an increase in soil pH, total N, SOC and available P for biochar addition to soil. Nepal et al. (2023) also reported increased soil fertility for amending soil with biochar.

The results of the experiment revealed that among the three biochars, B3 was significantly higher in most of the nutients (available P, S, K and Ca) than others (Table 3) and when they were applied almost all of the growth and yield properties of okra along with most of the soil properties were considerably higher total N, available P, S, K and Ca) in compare to that of B1and B2 (Table 4 and 5). Therefore, the result of the present experiment explored that water hyacinth biochar (@ 10 t ha^{-1}) could be a suitable soil amendment for better crop growth and improved soil quality among the studied three biochars. Moreover, water hyacinth biochar had significantly ($P<0.000$) higher surface area (205.40 m^{2}g^{-1}) than that of others (Table 3) for which it will be highly capable in salt adsorption. Besides, it significantly ($P<0.000$) increased the soil Ca content (Table 5) than that of others which will replace Na^+ and thus minimize the Na^+ uptake by plants.

Parkash and Singh (2020) reported biochar potentiality in mitigating the detrimental effects of soil salinity and enhanced the growth and yield of eggplant. Farhangi-Abriz and Torabian (2018) reported that under salt stress, Na^+ content could be reduced through biochar addition in the roots which is favorable for root growth. Thus, under salinity stress the root growth could be increased by biochar addition and consequently growth and yield of the plant might be enhanced. From the result of the current study revealed that water hyacinth biochar could be the best choice of organic amendments for reducing the harmful effect of salt stress in coastal areas of Bangladesh.

Conclusion

Biochar application to the soil improves the soil quality and enhanced the growth and yield of okra. Water hyacinth biochar performed the best result among the three studied biochars. This biochar also could be a good choice of organic amendments to reduce the detrimental effects of salinity stress of coastal areas in Bangladesh. However, further study using saline soil with different crops should be necessary.

Acknowledgement

The authors would like to acknowledge the Khulna University Research and Innovation Centre for providing financial assistance.

Conflict of Interests

The authors declare no conflict of interest.

References

Abd El-Azeim, M. M., Salah, Z. M. & Hammam, A. A. (2021). Assessment of water hyacinth biochar as a soil amendment for sandy soils. *Journal of Soil Sciences and Agricultural Engineering*, *12* (6):431-445.

Almaghamsi, A.A., ALosaimi, J. S. R., Alharby, H. F. & Alayafi, A. A. M. (2023). The importance of initial application of biochar on soil fertility to improve growth and productivity of tomato plants (*Solanum lycopersicum* L.) under drought stress. *Gesunde Pflanzen*. https://doi: org/10.1007/s10343-023-00868-7

Al-Wabel, M. I., Usman, A. R. A., Al-Farraj, A. S., Ok, Y. S., Abduljabbar, A., Al-Faraj, A. I. & Sallam, A. S. (2019). Date palm waste biochars alter soil respiration, microbial biomass carbon, and heavy metal mobility in contaminated mined soil. *Environmental Geochemistry and Health*, *41*:1705–1722, https://doi: 10.1007/s10653-017-0049-9

Biederman, L. A. & Harpole, W. S. (2013). Biochar and its effects on plant productivity and nutrient cycling: a meta-analysis. *Bioenergy,* 5, 202–214. https://doi: org/10.1111/gcbb.12037

Camps-Arbestain, M., Amonette, J.E., Singh, B., Wang, T. & Schmidt, H.P. (2015). A biochar classification system and associated test methods. In E.J. Lehmann, & S. Joseph, (Eds.), Biochar *for Environmental Management: Science, Technology and Implementation*, (pp. 165–194). Rutledge.

Dume, B., Berecha, G., & Tulu, S. (2015). Characterization of biochar produced at different temperatures and its effect on acidic nitosol of jimma, southwest Ethiopia. *International Journal of Soil Science, 10:*63-73. https://doi: 10.3923/ijss.2015.63.73

Farhangi-Abriz, S. & Torabian, S. (2018.) Biochar increased plant growth-promoting hormones and helped to alleviate salt stress in common bean seedlings. *Journal of Plant Growth Regulation*, *37*:591–601, https://doi: 10.1007/s00344-017-9756-9.

Farias, D., Freitas, M. I. D., Lucas, A. & Gonzaga, M. (2020). Biochar and its impact on soil properties, growth and yield of okra plants. *Colloquium Agrariae*, *16*(2). https://doi: 10.5747/ca.2020.v16.n2.a356

Faye, A., Stewart, Z. P., Diome, Khady., Edward, C. T., Fall, D., Ganyo, D. K. K., Akplo, T. M., & Prasad, P. V. V. (2021). Application of biochar increases fertilizer efficiency, c sequestration, and ph over the long-term in sandy soils of Senegal. *Sustainability*, *13*(21): 11817; https://doi.org/10.3390/su132111817

FRG (2012) Fertilizer recommendation guide, Bangladesh agricultural research council (BARC), Farmgate, Dhaka 1215, pp 1-274.ISBN: 978-984-500-000-0

Gee, G. W. & Or, D. (2002). *Particle-Size Analysis*. In Dane, J.H. & Topp, C.G. (Ed.), *Methods of Soil Analysis: Part 4 Physical Methods*, *Soil Science Society of America*, (pp. 255-293).

Hammam, A. A., Mohamed, E. S., El-Namas, A. E., Abd-Elmabod, S. K. & Eldin, B. R. M. (2022). Impacted application of water-hyacinth-derived biochar and organic manures on soil properties and barley growth. *Sustainability*, *14*(20): 13096, https://doi.org/10.3390/su142013096

Hamzah, Z. & Shuhaimi, S. N. A. (2018). Biochar: effects on crop growth. *IOP Conference Series: Earth and Environmental Science*, 215012011

Haque, S. A. (2006). Salinity problems and crop production in coastal regions of Bangladesh. *Pakistan Journal of Botany, 38*(5): 1359-1365.

Huq, S. M. I. & Alam, M. D. (2005). A handbook on analysis of soil, plant and water, BACER-DU, University of Dhaka, Bangladesh.

IBI. (2015). Standardized product definition and product testing guidelines for biochar that is used in soil. Version 2.1. International Biochar Initiative. <http://www.biochar-international.org/sites/default/files/IBI_Biochar_Standards_V2.1_Final.pdf>.

Inal, A., Gunes, A., Sahin, O., Taskin, M. B. & Kaya, E. C. (2015). Impacts of biochar and processed poultry manure, applied to a calcareous soil, on the growth of bean and maize. *Soil Use and Management*, *31*(1):106–113. https ://doi.org/10.1111/sum.12162

Jackson, M. L. (1962). *Soil Chemical Analysis*. Prentice Hall, Inc. Englewood Cliffs, N. Jersey, USA.

Jackson, M. L. (1967). *Soil Chemical Analysis*. Prentice Hall of India Pvt. Ltd. New Delhi.

Kabir, E. (2021). Terokhada Upazila. In: Islam, S., Miah, S., Khanam, M. Ahmed, S. (Eds.). Banglapedia: The National Encyclopedia of Bangladesh (Online Ed.). Dhaka, Bangladesh: Banglapedia Trust, Asiatic Society of Bangladesh.

Kim, H. S., Kim, K. R., Yang, J. E., Ok, Y. S., Owens, G., Nehls, T., Wessolek, G. & Kim, K. H. (2016). Effect of biochar on reclaimed tidal land soil properties and maize (*Zea mays* L.) response. *Chemosphere*, *142*:153–159.

Lehmann, J. & Joseph, S. (2009). *Biochar for environmental management: An introduction,* p. 1–12. In: Lehmann, J. and Joseph, S. (Eds.). Biochar for environmental management: Science and technology. Earthscan, Dunstan House, London, U.K.

Muhammad, N., Aziz, R., Brookes, P. C. & Xu, J. (2017). Impact of wheat straw biochar on yield of rice and some properties of Psammaquent and Plinthudult. *Journal of soil science and plant nutrition, 17*(3). https://doi:org/10.4067/S0718-95162017000300019

Nepal, J., Ahmad, W., Munsif, F., Khan, A. & Zou, Z. (2023). Advances and prospects of biochar in improving soil fertility, biochemical quality, and environmental applications. *Frontiers in Environmental Science,* Soil Processes (11). https://doi.org/10.3389/fenvs.2023.1114752

Panuccio, M., Jacobsen, S. E., Akhtar, S. S. & Muscolo, A. (2014). Effect of saline water on seed germination and early seedling growth of the halophyte quinoa. *AoB Plants,* 6. https://doi: 10.1093/aobpla/plu047.

Parkash, V. & Singh, S. (2020). Potential of biochar application to mitigate salinity stress in eggplant. *HortScience, 55*(12):1946–1955. https://doi:org/10.21273/HORTSCI15398-20

Petersen, L. & Shireen, S. (2001). Soil and water salinity in the coastal area of Bangladesh. SRDI.

Rajkovich, S., Enders, A., Hanley, K., Hyland, C., Zimmerman, A.R. & Lehmann, J. (2012). Corn growth and nitrogen nutrition after additions of biochars with varying properties to a temperate soil. *Biology and Fertility of Soils,* 48: 271–284. https://doi:10.1007/s00374-011-0624-7.

Rasel, H. M., Hasan, M. R., Ahmed, B. & Miah, M. S. U. (2013). Investigation of soil and water salinity, its effect on crop production and adaptation strategy. *International Journal of Water Resources and Environmental Engineering*, *5*(8): 475-481. https://doi: 10.5897/IJWREE2013.0400

Sahin, U., Ekinci, M., Ors, S., Turan, M., Yildiz, S. & Yildirim, E. (2018). Effects of individual and combined effects of salinity and drought on physiological, nutritional and biochemical properties of cabbage (*Brassica oleracea* var. capitata). *Scientia Horticulturae*, 240:196–204, https://doi: 10.1016/j.scienta.2018.06.016.

Schwarzenbach, G., Biedermann, W. & Bangerter, F. (1946). Complexons VI. New simple, titrimetric method for determining water Hardness. *Helvetica Chimica Acta*, *29*, 811–818.

USDA (United States Department of Agriculture). (1951). *Soil Survey Manual by Soil Survey Staff,* Bureau of Plant Industry, Soil and Agricultural Engineering, Handbook No. 18, pp. 205.

Wang, M., Zheng, Q., Shen, Q. & Guo, S. (2013). The critical role of potassium in plant stress response. *International Journal of Molecular Sciences*, *14*:7370–7390, https://doi:10.3390/ijms14047370.

Wang, T., Camps-Arbestain, M., Hedley, M. & Bishop, P. (2012). Predicting phosphorus bioavailability from high-ash biochars, *Plant and Soil,* 357, pp. 173–187, https://doi:10.1007/s11104-012-1131-9.

Zahir, Z. A., Akhtar, S. S., Ahmad, M., Saifullah, & Nadeem, S. M. (2012). Comparative effectiveness of Enterobacter aerogenes and Pseudomonas fluorescens for mitigating the depressing effect of brackish water on maize. *International Journal of Agriculture and Biology*, 14:337–344.