Research Article

Comparative Potential of Different Modified Biochar Sources on the Ionic Composition of Soil and Stress Mitigation in Maize under Saline-Sodic Conditions

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Abstract | Soil salinization is a global issue regarding decline in productivity of agricultural fields. It is the major abiotic factor behind loss of crop production in arid to semi-arid zones. High temperature and low rainfall lead to accumulation of salt on the soil surface. Moreover, the low organic matter status of soils further worsens the soil conditions. All these factors have severely reduced soil productivity. There is need for some sustainable management practices for rehabilitation of degraded soils in arid zones. Application of organic matter under these conditions can restore the soil productivity. So, use of biochar for soil restoration under these conditions can be an efficient approach due to its long-term stability in soil. Thus, a pot experiment was conducted using a completely randomized design to evaluate the effect of three different modified biochar on properties of saline-sodic soil and growth of maize. Rice husk biochar (RHB), wheat straw biochar (WSB) and orange peel biochar (OPB) were applied after washing with distilled water. Results showed that all treatments improved the soil chemical properties as compared to saline-sodic control. However, maximum decrease in soil EC_e (37.63%) and soil pH_s (22.61%) was found with application of rice husk biochar @ 0.3% as compared with saline-sodic control. Similarly, maximum decrease in soil Na^+ (59.66%) and SAR (63.65%) was also observed in rice husk biochar @ 0.3% when compared with saline-sodic control. However, soil $Ca^{2+}+Mg^{2+}$ was found maximum (39.82%) for rice husk biochar @ 0.15% as compared to saline-sodic control. Similarly, all treatments improved the maize growth as compared to saline-sodic control. rice husk biochar @ 0.3% showed maximum increase in plant height (51.82%). Similarly, maximum increase in shoot dry weight (160.24%), root dry biomass (169.52%), root length (15.87%), and chlorophyll contents (53.62%) was also found for rice husk biochar @ 0.3% as compared to saline-sodic control. rice husk biochar @ 0.3% was found most effective in improving maize growth and soil properties under saline-sodic conditions.

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Introduction

Soil salinization is the most devastating and dominant constraint to agriculture production as it is continuously reducing the productivity of cultivated areas (Mahmoodabadi *et al*., 2013). It is predicted that almost 7% of world arable land is influenced by salinization, constituting 800 mha with a 1-2% annual increase (Munns and Tester, 2008). Geographically, Pakistan is situated under arid and semiarid climatic zones and comprised of 6.67 mha salt affected area (Khan, 1998). Excessive evapotranspiration and scared availability of fresh water are accelerating the salinity statistics. The presence of these salts at the surface causes specific ion toxicity and nutrient imbalances in the soils (Khakwani *et al*., 2011), leading to significant decline in crop production. This situation invokes the risk of local as well as global food security that is the most challenging issue in the current scenario. Ghassemi *et al*. (1995) reported 12 billion US$ annual loss to the global agriculture sector from salt-affected soils. Management of the existing cultivated lands and rehabilitation of marginal and dense salt-affected soils are the viable solutions to this problem. Remediation of salt-affected soils includes heavy irrigation for saline soils. While gypsum ($CaSO_4.2H_2O$) application is performed along with heavy irrigation for remediation of saline-sodic and sodic soils (Gharaibeh *et al*., 2009). Acid or acid-forming amendments are being used for calcareous soils (Gupta and Abrol, 1990). Furthermore, organic amendments like farmyard manure, press mud, green manure, poultry manure, and compost for improving the physicochemical properties of salt-affected soils and proper plant growth (Fan *et al*., 2016; Singh *et al*., 2016).

Organic amendments mainly comprise of organic wastes and are easily accessible for agricultural applications. Organic amendments improve the soil health contributing ample amount of nutrients as well as improve soil quality for plant growth. Under high temperature regimes of arid and semi-arid climates, the decomposition rate of organic amendments is very high and needs a continuous input (Gregorich *et al*., 2017). Continuous use of organic matter not only costs higher but also raise the questions on environmental safety due to carbon emissions.

Recently, biochar has been reported as novel and practical soil conditioner for the rehabilitation of degraded soils (Chaganti *et al*., 2015; Amini *et al*., 2016; Ali *et al*., 2017). It resists to decomposition at higher temperatures and contribute to rehabilitate soil quality for a long period (Wang *et al*., 2016). Biochar is a charcoal-like organic substance being produced by the pyrolysis (300-1000 °C) of organic matter in anaerobic conditions. It has porous structure, high CEC, large surface area and enriched with nutrients. It has a significant amount of essential nutrients which can enhance fertility status and productivity of salt-affected soils (Mukherjee and Zimmerman, 2013). Many studies have described an increase in nutrients status of salt-affected soils after biochar application like Mg, Ca, K, P and N (Akhtar *et al*., 2015a). Biochar application for rehabilitation of salt-affected soils has been given much importance in the past few years owing to its significant potential to improve the soil characteristics and crop production (Akhtar *et al*., 2015b; Ali *et al*., 2017). It also reduces salt stress from plants attributed to its high salt sorption capacity (Thomas *et al*., 2013). Chaganti *et al*. (2015) has found through a series of experiments that biochar increased the amount of Ca in soil which took part in improving soil aggregation and drainage. Increase in Ca through biochar application can also help in leaching of Na from root zone, thus improving physical properties of salt-affected soils (Clark *et al*., 2007). Moreover, biochar based organic molecules stay in soil for longer duration and provide sustainable soil aggregation compared to other organic materials (Bhaduri *et al*., 2016). Biochar application improves soil bulk density, aggregate structure, ion exclusion, ion exchange, hydrological properties and microbial activity leading to better crops (Lehmann *et al*., 2011; Xiao *et al*., 2016).

Maize (*Zea mays* L.) is a potential food crop with large scale cultivation. After wheat and rice, it is third major cereal crop in Pakistan with significant economic values every year. It contributed 0.5% to GDP and 2.6% to value addition in 2018-19 with 6.309-million-ton production from 1,318 (000) ha (Economic Survey Pakistan, 2018-19). It is well known that maize is a salt-sensitive crop, and it is a crucial factor in lowering the yield of maize crops. Hence, there is need to reclaim the salt-affected soils using some sustainable measurements. Biochar has been found to increase maize growth in salt-affected soils. Biochar sourced from different feedstocks and pyrolysis conditions has their specific effect in salt-affected conditions. The objective of this study was (1) to evaluate the comparative effectiveness of three different feedstock biochars on maize growth in a saline-sodic soil (2) to evaluate the suitable application rate of biochar on chemical properties of a saline-sodic soil and maize growth.

Materials and Methods

This experiment was planned to evaluate the effects of three different sources of modified biochar on the growth of *Zea mays* L. grown in saline-sodic soil. It was conducted in pots under controlled conditions in the glass house of the Institute of Soil and Environmental Sciences (ISES), University of Agriculture Faisalabad (UAF). The day temperature remained in the range of 31 to 37°C, while night temperature remained in the range of 17 to 26 °C during experiment. Relative humidity in the glass house was 64% to 80%.

Soil collection and contamination

Non-saline soil was collected from the farm area of the ISES, UAF in mid-July 2019 and contaminated artificially to designed level. EC to SAR ratio 5.5:20.75 was developed in the collected soil by mixing different amounts of salts (Na_2SO_4, $CaCO_3$, $MgSO_4$ and NaCl) calculated by using the quadratic equation (Hussain *et al*., 1989). After mixing salts, the soil was maintained at field capacity for 90 days starting from mid-July 2019 to mid-October 2019. After 90 days of incubation, the soil was air dried, grinded, sieved and filled in pots. Maize was grown as test crop in these pots on 18th October 2019 and harvested on 23rd December 2019.

Preparation and application of biochar

Biochar was prepared from three different feedstock materials including orange peel biochar (OPB), wheat straw biochar (WSB) and rice husk biochar (RHB) through the process of slow pyrolysis at the temperature of 500 °C at Department of Soil Sciences, Faculty of Agricultural Sciences and Technology, Bahauddin Zakariya University, Multan, Pakistan. The obtained biochar was brought to ISES, UAF modified by washing with distilled water to remove the extra soluble salts and to make it more valuable for the soil and plant growth. It was applied at the rates of 0.3% and 0.15% in soil before sowing.

Experimental details

24 clean ceramic pots (30 cm height and 20 cm diameter) lined with plastic sheets were used in this experiment with no provision of leaching. Each pot used to be filled with 7 kg of contaminated soil. Maize (*Zea mays* L.) crop was grown in the soil as test crop having eight treatments; T_1 = non-saline control (NSC), T_2 = saline-sodic control (SC), T_3 = orange peel biochar (OPB) @ 0.15% + salinization (S), T_4 = orange peel biochar (OPB) @ 0.3% + salinization (S), T_5 = wheat straw biochar (WSB) @ 0.15% + salinization (S), T_6 = wheat straw biochar (WSB) @ 0.3% + salinization (S), T_7 = rice husk biochar (RHB) @ 0.15% + salinization (S), T_8 = rice husk biochar (RHB) @ 0.3% + salinization (S). Seeds were sown @ 5 seeds pot^{-1} that later on thinned out to three plants pot^{-1} after complete germination of seeds. Complete Randomized Design was followed, and each treatment carried three replicates. A recommended fertilizer dose of NPK (150:100:100 kg ha^{-1}) for Maize crop was applied. For potassium the fertilizer source was sulfate of potash (SOP), for phosphorus di-ammonium phosphate (DAP) was applied, while urea was applied as a source of nitrogen. The full dose of P and K was applied at the time of sowing along with half amount of required nitrogen while the remaining dose of nitrogen was applied in two splits with irrigation water. Pots were regularly watered, and weeds were removed properly.

Pre- and post-soil analysis

A soil sample was taken for pre-soil physicochemical analysis. It was air-dried, grinded by wooden pestle mortar, sieved through a 2mm sieve and homogenized for characterization. pH_s of that soil was determined by making its saturated paste and soil saturated extract was taken to determine electrical conductivity (EC_e). Soluble cations (Ca^{2+} + Mg^{2+}) and anions (CO_3^{2-}, HCO_3^{1-}, Cl^{1-}) were determined by the titration method from the soil saturated paste extract. While Na^+ was measured by using a flame photometer. Other chemical properties of the soil like SAR, CEC, exchangeable cations were calculated. Physical properties of soil like texture and saturation percentage were also determined to characterize the soil by using the gravimetric method (Black, 1965). These pre-soil analyses are given in Table 1. Soil samples collected after harvesting of the experiments were also first air-dried and then ground by wooden pestle mortar, sieved through a 2 mm, and then analyzed. Soil ECe, pHs, soluble cations (Na^+ and Ca^{2+} + Mg^{2+}), and anions (Cl^{1-}, CO_3^{2-} and HCO_3^{1-}) were measured by following the procedures defined by the U.S. Salinity Lab. Staff (1954). Soil EC_e was calculated by using electrical conductivity meter (Hanna Model HI 8033) standardized with 0.01 N KCl solutions. Soluble sodium was analyzed by using a flame photometer. Sodium adsorption ratio (SAR) was calculated by using the equation given below from the calculated concentrations of (Ca^{2+} + Mg^{2+}) and Na^+ in me L^{-1} (Lesch and Suarez, 2009).

$$SAR = Na^+ / [(Ca^{2+} + Mg^{2+}) / 2]^{½}$$

Crop harvest and collection of morpho-physiological data

Physiological parameters including chlorophyll contents were recorded at vegetative growth with a SPAD meter. The crop was harvested after 2 months of its growth. After harvesting, crop growth parameters including plant height, and root length were measured using a measuring rod. After harvesting plant samples were oven dried at 65 °C and then root and shoot dry weight were recorded at a lab scale weighing balance.

Table 1: *Pre analysis of experimental soil and water.*

Parameter	Units	Soil	Water
EC_e	(dS m^{-1})	3.23	1.65
TSS	(me L^{-1})	32.3	16.5
Soil texture	---	Sandy clay loam	---
CO_3^{-1}	(me L^{-1})	Nil	Nil
HCO_3^{-1}	(me L^{-1})	4	6.9
Cl^{-1}	(me L^{-1})	15	6
Ca+Mg	(me L^{-1})	21	8.1
SAR	(m $mol_c L^{-1})^{1/2}$	3.48	4.17
RSC	(me L^{-1})	-	-1.2

Statistical treatment

Data were analyzed following analysis of variance using Statistix 8.1 (Analytical Software, Tallahassee, FL, USA) software. Complete Randomized Design was used to determine the results of varying biochar application on soil and plant parameters. Tukey's HSD test was applied on the obtained results to find the significant treatments.

Results and Discussion

Effect of different biochar sources on chemical attributes of saline-sodic soil

Electrical conductivity (EC_e) of the soil: Application of different biochars significantly decreased the EC_e of this saline-sodic soil (Figure 1A). Rice husk biochar @ 0.3% was remained the most effective in decreasing EC_e (37.63%) compared to that with saline-sodic control followed by RHB @ 0.15% (27.95%), WSB @ 0.3% (24.39%), WSB @ 0.15% (20.22%), OPB @ 0.3% (16.38%) and OPB @ 0.15% (13.03%). Higher application rates of biochars decreased EC_e compared to that with their lower application rates. The data on the soil electrical conductivity showed that various types of modified biochar had positive effects in salts stress mitigation as inferred from soil analysis in various treatments. So, modified biochar can facilitate decreasing soil EC and contribute to minimizing the salts stress.

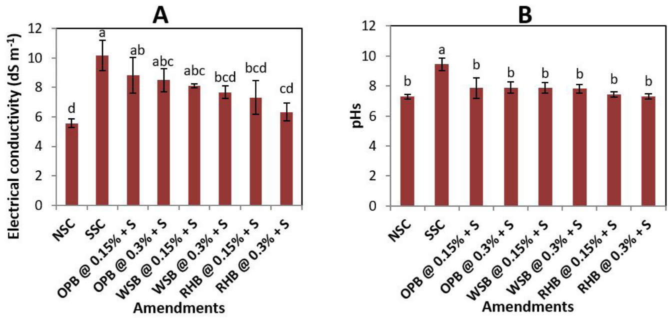

Figure 1: *Effect of different biochar sources on ECe and pHs values of soil under maize cultivation. Mean value of three replicates has been presented with bars showing standard error. Tukey's HSD was used for multiple comparisons under complete randomized design. NSC: non-saline control; SSC: saline-sodic control; OPB: orange peel biochar; WSB: wheat straw biochar; RHB: rice husk biochar; S: salinization.*

pH of the soil: The influence of different biochar sources, such as rice husk, wheat straw and orange peel on soil pH indicated that pH differed significantly. The figure 4.8 indicated that maximum decrease in pH (7.30) was recorded in RHB @ 0.3% followed by RHB @ 0.15% and WSB @ 0.3% which showed pH value of 7.42 and 7.81, respectively. All the treatments have responded positively in decreasing soil pH over saline-sodic control. Maximum decrease in pH was found for RHB @ 0.3% (22.61%) compared to saline-sodic control followed by RHB @ 0.15% (21.37%), WSB @ 0.3% (17.27%), OPB @ 0.15% (16.74%), WSB @ 0.15% (16.74%), and OPB @ 0.3% (16.36%). All biochars application significantly reduced the pH of soil in all the amended treatments (Figure 1B). RHB @ 0.3% showed significant response as compared to all other treatments and showed maximum decrease in pH while RHB @ 0.15% showed significant response in comparison to all other treatments except non-saline control.

Total soluble salts (TSS) of the soil: The influence of different biochar sources, such as rice husk, wheat straw and orange peel on soil total soluble salts indicated that TSS differed significantly. Figure 2A indicated that maximum decrease in TSS (73.33 me/L) was recorded in RHB @ 0.3% followed by RHB @ 0.15% and WSB @ 0.3% which showed TSS value of 86 me L^{-1} and 790 me L^{-1}, respectively. All the treatments have responded positively in decreasing TSS over saline control. RHB @ 0.3% showed maximum decrease (39.23%) in soil EC over saline control while OPB @ 0.15% showed minimum (13.81%) decrease in TSS. The response of OPB @ 0.15%, OPB @ 0.3% and WSB @ 0.15% were significantly positive in decreasing TSS when compared with saline control while these treatments were non-significant when compared to non-saline control. The response of WSB @ 0.3%and RHB @ 0.15%were significant as compared to both saline-sodic control and non-saline control. However, RHB @ 0.3% showed maximum response as compared to all other treatments and showed significant decrease in TSS.

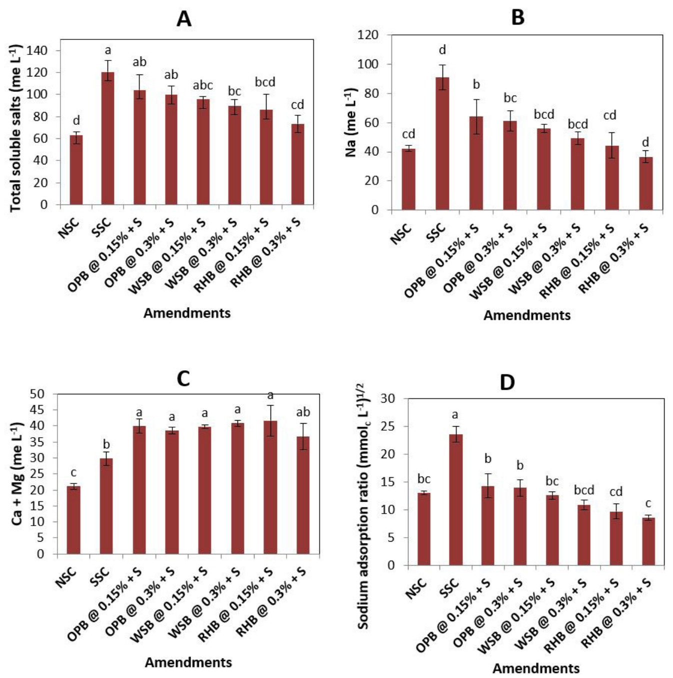

Figure 2: *Effect of different biochar sources on soil ionic composition under maize cultivation. Mean value of three replicates has been presented with bars showing standard error. Least significant difference was used for multiple comparisons under complete randomized design. NSC: non-saline control; SSC: saline-sodic control; OPB: orange peel biochar; WSB: wheat straw biochar; RHB: rice husk biochar; S: salinization.*

Sodium (Na^+) concentration in the soil: Figure 2B indicated that maximum decrease in Na^+ (36.67 me L^{-1}) was recorded in RHB @ 0.3% followed by RHB @ 0.15% and WSB @ 0.3% which showed value of 44.33 me L^{-1} and 49.15 me L^{-1} sodium, respectively. All the treatments have responded positively in decreasing sodium ions concentration over saline-sodic control. All biochars significantly reduced the sodium (Na^+) concentration but most positive results obtained for RHB @ 0.3% (59.66%) compared to saline control followed by RHB @ 0.15% (51.23%), WSB @ 0.3% (45.93%), WSB @ 0.15% (38.47%), OPB @ 0.3% (32.77%) and OPB @ 0.15% (29.54%).

Treatment RHB @ 0.3% showed significant response as compared to all other treatments and showed maximum decrease in Na^+ ions concentration while RHB @ 0.15% showed significant response in comparison to all other treatment except non-saline control. Hence, application of modified biochar can contribute to decrease the Na^+ ions concentration in soil.

Calcium and magnesium (Ca^{2+}+Mg^{2+}) concentration in the soil: It was observed that maximum Ca^{2+}+Mg^{2+} ions concentration (41.67 me L^{-1}) was recorded in RHB @ 0.15% followed by OPB @ 0.15% and WSB @ 0.3% which showed Ca^{2+} + Mg^{2+} ions concentration of 39.93 me L^{-1} and 40.87 me L^{-1} respectively (Figure 2C). Minimum Ca^{2+} + Mg^{2+} ions concentration (36.67 me L^{-1}) was observed in treatment RHB @ 0.3%. All the treatments have responded positively to both non-saline control and saline-sodic control. Maximum elevation in (Ca^{2+} + Mg^{2+}) contents was found for the RHB @ 0.15% with 39.82% compared to saline-sodic control followed by others WSB @ 0.3% (37.14%), OPB @ 0.15% (34.00%), WSB @ 0.15% (33.33%), OPB @ 0.3% (29.42%) and RHB @ 0.3% (23.04%). The data on the Ca^{2+}+Mg^{2+} ions concentration showed that various types of modified biochar had positive effects in salts stress mitigation and that might be inferred from different crop response in various treatments.

Sodium adsorption ratio (SAR) of the soil: All biochar sources significantly increased the (Ca^{2+} + Mg^{2+}) contents in the soil compared to the control treatment (Figure 2D). While sodium concentration was reduced with addition of biochar. Since SAR is the Na to (Ca + Mg) ratio; therefore, similar results were obtained for SAR. It reduced with application of biochar, maximum reduce in soil SAR was found for RHB @ 0.3% (63.65%) compared to saline-sodic control followed by RHB @ 0.15% (58.86%), WSB @ 0.3% (53.82%), WSB @ 0.15% (46.69%), OPB @ 0.3% (40.92%) and OPB @ 0.15% (39.28%). Higher application rates of different biochars decreased SAR more significantly than lower application rates.

Table 2: *Effect of different biochar applications on morphophysiological parameters of maize under saline-sodic soil conditions.*

Treatments	Chlorophyll contents (SPAD)	Plant height (cm)	Root length (cm)	Shoot dry weight (g)	Root dry weight (g)
Non-saline control	36.00±1.67 bcd	72.77±2.92 bc	17.81±1.82 a	12.51±1.48 cd	3.13±0.25 bc
Saline-sodic control	27.17±2.12 e	57.00±3.61 d	16.88±3.03 a	7.18±0.95 e	1.79±0.24 d
Orange peel biochar @ 0.15% + S	32.00±0.66 d	65.33±4.93 cd	16.84±1.13 a	11.48±1.51 d	2.74±0.59 cd
Orange peel biochar @ 0.3% + S	33.51±2.05 cd	70.67±3.21 bc	18.00±1.21 a	12.21±1.95 cd	3.19±0.40 bc
Wheat straw biochar @ 0.15% + S	36.83±1.12 bc	71.67±3.06 bc	16.80±1.20 a	14.91±1.05 bcd	3.39±0.32 bc
Wheat straw biochar @ 0.3% + S	38.33±0.91 ab	75.33±3.51 bc	18.28±1.64 a	15.39±1.22 abc	3.41±0.49 bc
Rice husk biochar @ 0.15% + S	39.30±1.25 ab	79.00±4.36 ab	19.20±1.23 a	16.75±0.55 ab	4.05±0.18 ab
Rice husk biochar @ 0.3% + S	41.73±1.16 a	86.54±4.08 a	19.56±1.77 a	18.68±1.00 a	4.84±0.14 a
*CV	2.5169	6.5201	2.9965	2.2127	0.6170

*The mean value of three replicates has been presented ± standard error. Least significant difference was used for multiple comparisons under complete randomized design. *CV is representing critical values for comparison.*

Effect of different biochar sources on maize growth

Chlorophyll contents of maize: Chlorophyll contents and plant height of maize increased significantly in the biochar amended soils compared to the saline-sodic control (Table 2). Most leading results for enhanced chlorophyll contents were found for RHB @ 0.3% (53.62%) compared to saline-sodic control followed by RHB @ 0.15% (44.66%), WSB @ 0.3% (41.10%), WSB @ 0.15% (35.58%), OPB @ 0.3% (23.34%) and OPB @ 0.15% (17.79%).

Growth parameters of maize: Plant height also showed the same results, maximum increase in plant height was obtained for RHB @ 0.3% (51.82%) compared to saline-sodic control followed by RHB @ 0.15% (38.60%), WSB @ 0.3% (32.16%), WSB @ 0.15% (25.73%), OPB @ 0.3% (23.98%) and OPB @ 0.15% (14.62%). Similarly, root length showed an increase of 15.87%, 13.72%, 8.29% and 6.62% for RHB @ 0.3%, RHB @ 0.15%, WSB @ 0.3%, and OPB @ 0.3% respectively compared to saline-sodic control. While OPB @ 0.15% and WSB @ 0.15%, showed a decrease of 0.24% and 0.49% respectively compared to saline-sodic control.

Shoot dry weight increased compliantly with RHB addition @ 0.3% (160.24%) compared to saline-sodic control followed by application of RHB @ 0.15% (133.39%), WSB @ 0.3% (114.40%), WSB @ 0.15% (107.80%), OPB @ 0.3% (70.18%) and OPB @ 0.15% (59.96%). Similarly, root dry weight increased by 169.52% for RHB addition @ 0.3% compared to saline-sodic control followed by RHB @ 0.15% (125.96%), WSB @ 0.3% (90.24%), WSB @ 0.15% (89.22%), OPB @ 0.3% (77.61%) and OPB @ 0.15% (52.53%). It was observed that plant height, shoot dry weight and root dry weight increased significantly in biochar amended soils while root length showed non-significant response for biochar addition (Table 2). Moreover, higher application rates showed better results than lower application rates.

Many factors associated with poor maize growth in saline control soil observed in this study. EC_e, pH and SAR were highest in the saline-sodic control (Figures 1A, B, 2D) and plant growth parameters were observed most affected in this treatment compared with non-saline control (Table 2). Results showed that Na^+ concentration was also highest in saline-sodic control (Figure 2B) while (Ca^{2+} + Mg^{2+}) were relatively less in that treatment (Figure 2C) which is linked with higher SAR and pH values. This indicates that higher Na^+ concentration directly contributed to the decrease in maize chlorophyll contents, plant height, shoot and root dry weight in saline-sodic control as compared to non-saline control. Many studies have reported Na^+ as a major stress factor for maize in salt affected soils which lead to poor crop growth (Farooq *et al*., 2015). Proper plant growth and efficient crop production demand for healthy soil conditions like availability of adequate nutrients, optimum water supply and minimum stress. While, soil salinity/sodicity and inadequate nutrients perilously affect plant growth and hinder production (Asch and Wopereis, 2001). Since saline-sodic soils with elevated salt concentrations have high EC_e, SAR and pH values and are considered most degraded soils. Increase in these values is associated with increased exchangeable sodium concentration (Harron *et al*., 1983). High pH values due to Na affect the availability of wide range of nutrients to the plants including N, P, K, Zn, Cu, Fe, and Mn (Amini *et al*., 2016). High prevalence of Na^+ in these soils also leads to poor soil-air relation, less pore volume, poor soil structure and specific ion toxicity (Tavakkoli *et al*., 2010). Therefore, it is negatively correlated with plant growth and production capacity (Rehman *et al*., 2016).

In the present study, chlorophyll contents, plant height, shoot and root dry weight were significantly improved in the biochar amended soils. Meanwhile, all biochar sources significantly enhanced the (Ca^{2+} + Mg^{2+}) contents of the soil as compared to saline-sodic control which might be the factor in controlling the sodium toxicity and enhancement in growth parameters of the maize. Biochar is well known for enhancing plant growth by contributing directly or indirectly. It serves as a source of various essential nutrients (Ca, K, Mg, P, etc) for plants and promotes their growth. Lashari *et al*. (2014) also reported that biochar-manure compost in conjunction with pyroligneous solution enhanced the maize growth. It significantly increased leaf phosphorus, nitrogen, potassium, leaf area index and grain yield with reduction in soil pH and sodium concentration in amended treatment compared to control. Likewise, Major *et al*. (2010) reported an increase in (Ca^{2+} + Mg^{2+}) concentration in Columbian savanna oxisol with biochar application. Laird *et al*. (2010) also reported an increase in Ca^{2+} after application of Oak biochar in Mid-western soil. Hence, (Ca^{2+} + Mg^{2+}) may be the source of Na^+ replacement from exchange sites in present study and promoter of maize growth. Biochar based increase in divalent cations in soil has also been stated by Gaskin *et al*. (2010). Among these cations, Ca^{2+} is well known for reclamation of saline-sodic soils (Gharaibeh *et al*. 2009). As Na^+ is the stress causing factor in saline-sodic soils, it requires replacement with some divalent cation like Ca^{2+} from exchange site followed by leaching and biochar can be a good amendment in this respect.

It can also be observed in Figure 2B that Na^+ concentration significantly reduced in the biochar containing treatments compared to contaminated control, which might be the adsorption capability of biochar for Na^+ ions. Biochar has high adsorption capability and is used in remediation of soils (Paz-Ferreiro *et al*., 2014). Lashari *et al*. (2013) reported biochar for amelioration of salt stress due to its significant Na^+ adsorption capacity. It served as an adsorbent for Na and helped in alleviation of sodium toxicity. Release of (Ca^{2+} + Mg^{2+}) in amended soils (Figure 2C) replaced the Na^+ from soil exchange sites compared to saline-sodic control. Similar behavior of biochar-based replacement of Na^+ with (Ca^{2+} + Mg^{2+}) has been reported by Akhtar *et al*. (2015a). This exchanged Na^+ significantly got adsorbed by biochar due to its high affinity for it in biochar amended treatment compared to saline-sodic control. Results are in accordance with Akhtar *et al*. (2015b) in which they reported biochar can mitigate salinity effects on potato due to its high sodium adsorption behavior in salt-affected soil. Hence, a significant decrease in sodium concentration in all biochar sources (Figure 2B) directly relates with adsorption capacity of biochars for sodium owing to number of functional groups that were available on their surface areas. Thomas *et al*. (2013) described high salt sorption capacity of biochar and potential to ameliorate salt stress in plants, after observing the addition of salt on biochar surface. All biochar sources significantly enhanced the maize growth, but most positive results obtained for RHB @ 0.3% which might be contributed to its high adsorption capacity for Na^+. A maximum decrease in Na^+ concentration was found with RHB @ 0.3% as shown in (Figure 2B). Decrease in bioavailable sodium concentration contributed directly to maize growth in this treatment compared to control and other biochar sources. Chlorophyll contents, plant height, shoot and root dry weight found most significant in this treatment due to its ability of bioavailable Na^+ adsorption.

Many studies have stated about increase in the pH of soil after biochar addition (Wang *et al*., 2017; Yuan and Xu, 2011; Laird *et al*., 2010) but most of these studies were performed in acidic soils having pH (< 5.5) less than pH (7.0) of biochar (Liu *et al*., 2017). This increased pH of biochar than soil might lead to increase in the pH of soil. However, results were different when biochar was added to higher pH soils like saline-sodic or sodic soils. Decrease in pH of salt-affected soils has been reported after addition of biochar by some scientists (Liu *et al*., 2017; Khalifa and Yousef, 2015). Similar results obtained in present study; all biochar sources significantly decreased the pH of saline-sodic soils compared to saline-sodic control (Figure 1B). The mechanism responsible for this decrease in pH might be due to decrease in exchangeable sodium percentage (ESP) (Lashari *et al*., 2014). ESP or Na salts are directly linked with pH of soil in saline-sodic or sodic soils and involved in its increase. Hence, decrease in pH of soil can also be associated with sodium adsorption ability of biochar. This decrease in pH might enhance the availability of nutrients and took part in increasing morpho-physiological features of maize in present study.

A decrease in Na^+ concentration in soil solution and at soil exchange sites might helped in lowering the dispersion of soil particles, while release of (Ca^{2+} + Mg^{2+}) enhanced the aggregation of soil particles leading to good soil structure, hydraulic properties, soil-air relation, and better root growth. Further, biochar enhances the biological properties of soil by providing habitat for micro-biota, which takes part in several nutrient cycles of plant. Hence, it was found in this study that biochar has high potential to improve soil chemical properties and ultimately promote crop production.

Novelty Statement

This study showed that simple modification of biochar (washing with distilled water) can help to decrease the concentration of soluble ions in the biochar and increase the cation exchange capacity of biochar. This modification of biochar can pave the application of biochar for remediation of saline-sodic soils.

Author's Contribution

Muhammad Umair: Conceptualization, project administration, funding acquisition, writing - original draft, formal analysis, writing - review & editing.
Muhammad Naeem: Conducted research, performed analysis, data collection, writing - original draft, writing - review & editing.
Asad Jamil: Writing - review & editing.
Muhammad Younas: Figures preparation, writing - review & editing.

Conflict of interest
The authors have declared no conflict of interest.

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