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Opportunities and challenges of applying biochar to boost agricultural output and repair salt-damaged soils

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Abstract

Soil salinization is recognized as a serious form of soil degradation, affecting crop production and compromising food security. It is crucial to remediate the negative impacts of soil salinization to improve the associated soil functions. Biochar amendments are used to reclaim the salt-affected lands. Therefore, the main objective of the present paper was to review and discuss the recent studies investigating a role of biochar in improving soil properties and plant growth in salt-affected soils. Recently, biochar (solid carbonaceous residue, produced under oxygen-free or oxygen-limited conditions at temperatures ranging from 300 to 1000 C) has attracted considerable attention as a soil amendment. An emerging pool of knowledge shows that biochar addition is effective in improving physical, chemical and biological properties of salt-affected soils. Biochar amendments improve not soil properties but also support plant growth and ameliorate soil problems. However, some studies have also found an increase in soil salinity with biochar application at high rates. Further, the high cost associated with production of biochar and high application rates remains a significant challenge to its widespread use in areas affected by salinity. Therefore, the underlying mechanisms of such beneficial effects provided by biochar amendment of soils are highly complex. Therefore, more in-depth studies are needed to understand biochar interactions with soil organisms under extreme environments, which would help achieve maximum benefits of biochar under saline soil conditions.

Keyword: biochar, nutrient avalibils, remediation, salt affected soil, soil property.

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Introduction

Soil salinization is global issue owing to it's sever impact on agricultural productivity and sustainability. In arid and semi-arid area, Excesses ions such as sodium (Na) magnesium, calcium chlorides and sulphates ($SO4^{-2}$) accumulate to form saline soil causing the impairment of plant growth and development about 831 M ha arable land is affected by soil salinity. And salinization is predicted to impact 50% of the total world and by 2050 (Sun *et al*., 2022) various reason such as low precipitation weathering of native rain full, high surface evaporation and poor cultural practice have contributed the expiation of saline soil (sharivastatava and Kumar , 2015). Salt-affected soils are found in > 100 countries and their distribution is extensive and widespread in arid and semi-arid regions of the world, Salt affected soils are extensive in arid and semi-arid regions of Australia, Africa, Asia and South America (Ajay *et al*., 2021). According Ajay, (2021) reported that total area of salt affected soil is about one billion hectares and is likely to expand Worldwide in the future due to poor management of land resources (Gorji *et al*., 2017).

In Ethiopia, about 44 million ha (36% of the total land area) is potentially susceptible to salinity problems of which 11 million ha have already been affected by different levels of salinity and mainly concentrated in the Rift valley (Daba *et al*., 2021). Ethiopia ranked as 7^th^ in the world in terms of percentage of the total land area affected with salinity (Daba *et al*., 2021). This has resulted in the degradation of natural habitats, ecosystems and agricultural lands. This has threatened the productivity of irrigated lands, which is producing more than 40% of the total food requirement of the world (Daba *et al.*, 2021). In order to meet the challenges of global food security, it is imperative to bring barren salt-affected soils under cultivation (Biswas and Biswas, 2014).

Using of organic amendments such as biochar could be effective in improving salinity problem through their beneficial impacts on physical, nutritional, chemical and biological properties of saline, saline-sodic and sodic soils (Srivastava *et al*., 2016). In saline soils, biochar amendments provide essential nutrients and help increase the leaching of salts out of the soil by: (i) improve soil structure and creates water channels to increase water movement in and (ii) refining and maintaining soil porosity and thus improving water movement in soil (Anwari *et al*., 2020).

Biochar as a natural organic and rich- C matter containing its carbon percentage is about 60-80 %, with a high active surface area and functionality (Anwari *et al*., 2020). And it is carbon rich highly porous substance obtained after pyrolysis of organic biomass. It is produced by burning organic biomass under complete absence or incomplete absence of oxygen at temperatures ranging from 300 to 1000 ^{0}C (Rumi *et al.*, 2015*)*. It produced by heating any kinds of organic waste materials at high temperature through the process of pyrolysis (Leng *et al*, 2018). A great amount of waste such as forest waste and crop residues is left in the field after harvesting in several agricultural and forest production (Mendez *et al*., 2014). Many of the agricultural and forestry waste can be used to produce biochar, a product that when applied to agricultural land can both sequester carbon and improve crop production potential (Lehmann and Joseph, 2015).

Not all types of biochar exert similar effects on a particular soil and likewise not a single type of biochar could be equally effective on all types of soils, because of the striking influence of feedstock and pyrolysis conditions, including temperature and duration, on biochar properties (Rumi *et al.*, 2015). Biochar produced from non-woody feed stocks such as manures and plant residues is richer in nutrients and has less stable carbon and higher pH than biochar produced from lingo-cellulosic feed-stocks such as wood. Chemical composition of the low-temperature biochar is similar to that of the biomass used for pyrolysis, whereas high temperature biochar properties may deviate from those of the feedstock. Biochar produced at low temperature is likely to have a higher content of volatiles, but lower fixed C and ash contents than the high-temperature counterpart (Rafiq *et al*., 2016). Likewise, concentration of elements such as K, P and Ca, pH, surface area, and the C: O and C: N ratios in biochar increase with temperature (Huff *et al.*, 2014).

Biochar application to agricultural soils is an interesting emerging technology with promising potential for long-term carbon storage, sustainable waste disposal, and soil fertility enhancement (Gale *et al*., 2016). Application rate of biochar, soil type and biochar aging in soil produce variable improvements in soil and plant quality (Butnan *et al*., 2015). For example, Kolb *et al.* (2009) Biochar application increases total porosity and water holding capacity of salt-affected soils, but the effect appears to depend primarily on the feedstock type, pyrolysis conditions and the amount of biochar added to the soil (Anwari *et al*., 2020)

Recently, biochar has involved considerable attention as a soil improvement with carbon-residence time varying from tens of years to millennia (Wang *et al*., 2016). An emerging pool of knowledge shows that biochar addition is very effective in improving physical, biological and chemical properties of salt-affected soils (Sun *et al*., 2017). In addition, Biochar is a form of relatively stable carbon that can effectively act as long-term carbon storage and therefore substantially contribute to climate change mitigation strategies (Montanarella *et al*., 2013). However, the high cost associated with production of biochar, transport and high application rates remains a significant challenge to its widespread use in areas affected by salinity and sodicity (Wang *et al*., 2016). However, recent advances in our understanding of biochar warrant an evaluation of the relationship between biochar properties and its impact on the properties of salt affected soils and plant growth. Thus, the main objective of this paper is to review the effects of biochar in improving soil properties, enhancing plant growth and improving crop production in salt-affected soils.

Effect of biochar on soil properties and crop production

Biochar is a pyrogenic carbon or biomass substance that is usually produced from carbon-rich materials, especially agricultural residues (Inyang *et al*., 2015). Methods used for the production of biochar include pyrolysis, gasification, hydrothermal carbonization, and flash carbonization (Wang *et al.*, 2018). The pyrolysis temperature alters from 300 °C to 1,000 °C, and its duration can be a fast or slow process, nevertheless, slow pyrolysis is preferred for biochar production (Lian, *et al*., 2017). Differences in chemical and physical properties of biochar mainly depend on the type of feedstocks, methods of production and temperature (Wei, *et al.*, 2017 and Webe, 2018). Under special conditions, biochar produced from toxic solid waste may present secondary pollution hazards (Yu, *et al*., 2019). However, most of the biochars are beneficial to soils as amendments (Xiao *et al.*, 2018 and Dai, *et al.*, 2017). The function and properties of biochar are summarized in which include surface area and porosity, surface function group, exchangeable cations, and organic C and N compounds. The role of surface area/porosity of biochar relates to the soil structure improvement, water and nutrient retention, immobilization organics and heavy metals. The surface function group is of great importance for improving soil moisture, enhancing binding between biochar and soil, and reducing soil nutrient leaching loss. Therefore, the exchangeable cations feature has a great influence to metals; improve soil pH and CEC, and nutrient bioavailability (Yu, *et al*., 2019).

Effect of Biochar on Soil physical Properties

Being a highly porous material, biochar application improves total porosity, water holding capacity, bulk density and infiltration rate , hydraulic conductivity and Permant wilting point of salt-affected soils (Burrell *et al*., 2016), although the effect appears to depend primarily on pyrolysis conditions, the feedstock nature and amount of biochar added to soil (Zhang *et al*., 2012). Biochar can also improve structure of salt affected soils through its influence on the structure building processes in soil such as aggregation, through improving above and below ground plant growth that ultimately impact the root zone processes and activity of soil microorganisms (Kolton *et al*., 2016). Because calcium increases aggregation and facilitates washing of Na out of the soil profile, the increase in Ca content of soils through biochar could help improve the physical properties (especially structure) of degraded salt-affected soils (Rostamian *et al*., 2018). Mahmoud**, (**2017) reported biochar application improves different soil physical properties in salt affected soil as shown in Table 1 and Figure 1.

Table 1. Biochar impacts on selected soil physical properties, on salt affect soil **(**Mahmoud, 2017).

No	Treatment	Hydraulic conductivity(K) cm h^{-1}	Basic inflation rate	Bulk density g cm^{-3}
1	Control	0.654g	0.555^{g}	1.61^{a}
2	BW5	1.092^{ed}	0.8949^{de}	1.39^{de}
3	BW10	1. 286cb	1.032^{c}	1.32^{de}
4	BW19	1.339b	1.1431^{b}	1.23^{f}
5	BM5	1.207^{cd}	0.993^{dc}	1.37^{dce}
6	BM10	1.363^{b}	1.142^{b}	1.31^{e}
7	BM19	1.489^{a}	1.2488^{a}	1.19^{f}
8	LSD(0.05)	0.1247	0.1014	0.0726

Where: C: Control; BW5: Wood sawdust at 5 t ha^{-1}; BW10: Wood sawdust at10 t ha^{-1}; BW19: Wood sawdust at 19 t ha^{-1}; BM5: Maize stalk biochar 5 t ha^{-1}; BM10: Maize stalk biochar at 10 t ha^{-1}; BM19: Maize stalk biochar at 19 t ha^{-1}

The organic molecules help bind polyvalent cations and clay particles to improve aggregation in degraded salt-affected soils (Somerville *et al*., 2015). Even though a great majority of studies report positive effects of biochar addition on soil physical properties, it is not unusual to find no effect or even negative impacts of biochar on soil structural stability (Yu *et al*., 2019)

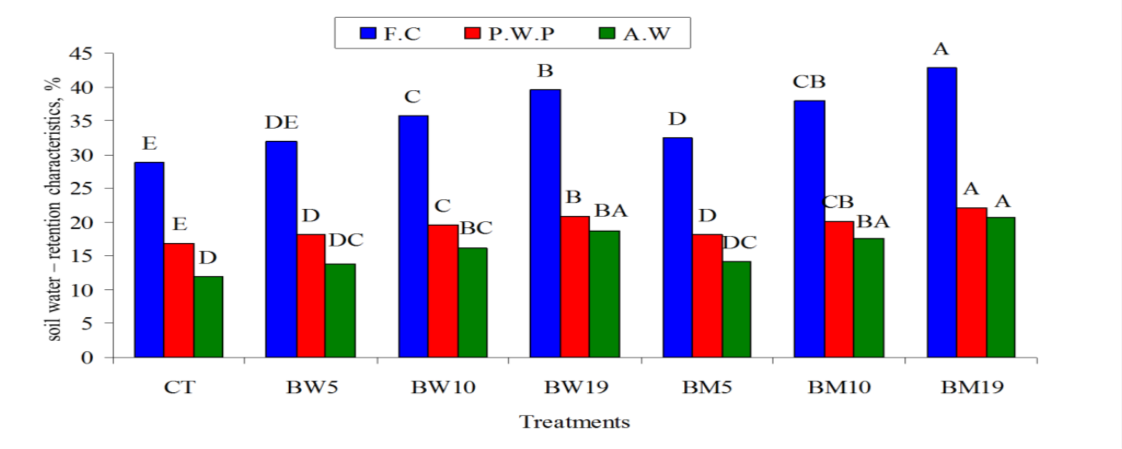


Figure 1. Effects of different types and rates of biochar on soil water –retention characterizes on salt affected soil (Mahmoud, 2017).

Effect of biochar in improving chemical properties of salt-affected soils

The major soil chemical properties that could be impacted by the quantity and type of salts are pH, EC and SAR or exchangeable sodium percentage. Excess soluble salts in saline soils can be lowered through leaching, provided the depth of the water table is not too high to impact drainage (Anwari, *et al.*, 2020). However, a high sodium adsorption ratio and/or exchangeable sodium percentage of saline sodic and sodic soils can only be reduced through the addition of inorganic and organic amendments to replace sodium from the exchange sites followed by frequent irrigation to move sodium below the root zone (Xiaofang *et al.*, 2022). Given that pH of saline-sodic and sodic soils is high mainly due to hydrolysis of exchangeable Na or Na_2CO_3, and there is a direct relationship between ESP and pH, removal of Na salts can decrease the pH of such soils (Shaygan *et al.*, 2017). Additionally Sun *et al*, (2016), report effect of biochar application on soil chemical properties present in table 2.

Table 2. The effect of biochar addition on chemical properties of saline soil (Sun *et al*., 2016).

	pH(1:20)	EC (S/cm)	AC (mg/g)	TOC (mg/g)	AP (mg/kg)	AK (mg/g)	CEC (cmol/kg)
Soil	8.59	239	–	4.24	12	698	11.4
WS	6.93	3975	415	490	237	9601	18.8
CS	8.01	5210	291	418	800	10780	50.0
PS	7.71	404	345	382	314	3392	48.9

Where: WS wheat straw biochar, CS= corn stalk biochar, PS = peanut shell biochar, EC= electric conductivity, AC = adsorption capacity, TOC= total organic carbon, AP = available P, AK= available potassium, CEC= cation exchange capacity.

Biochar effect on soil electrical conductivity of salt-affected soils

To avoid excessive accumulation of salts in the root zone, large amounts of water need to be applied with irrigation to exceed evapotranspiration and facilitate drainage, providing the groundwater is relatively deep. Soil drainage can be improved through a number of methods, including addition of ameliorants that not only increase leaching of salts but also improve porosity, thus providing an environment suitable for the growth and development of plant roots (Daba *et al.*, 2021). The reduction in electrical conductivity was attributed to the biochar-induced improvement in soil porosity and hydraulic conductivity that accelerated leaching of salts. Chaganti *et al*. (2015) also noted measurable decreases in electrical conductivity of a saline-sodic soil by 84, 83 and 82% under, respectively, biochar, bio-solids compost and green waste compost compared to the non-amended control soil because of improvements in soil hydraulic conductivity facilitating leaching of salts. Correspondingly, a 42% reduction in electrical conductivity of saline-sodic soil was noted in a two year field experiment under the combined application of biochar and poultry manure compost compared to non-treated control soil (Lashari *et al*., 2015).

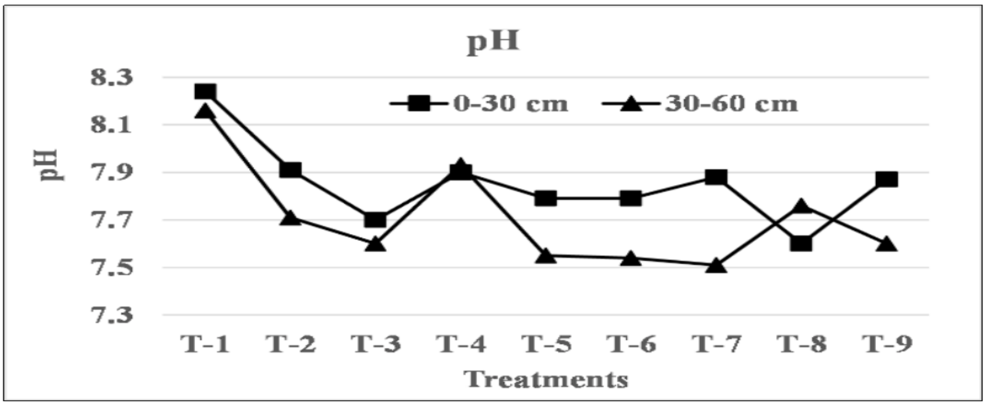
Biochar impact on pH of salt-affected soils

Many researches stated an increase in the soil pH due to biochar application (Wang *et al.*, 2017). Most of these studies were conducted on soils with a lower pH (pH<5.5) in comparison to the pH of added biochar (pH >7.0) (Liu *et al.*, 2017). However, the results could be opposite when low-pH biochar is added to high-pH soils, especially saline-sodic and sodic soils (Liu *et al*., 2017). Although many recent studies revealed a considerable decrease in pH values of salt affected soils with the addition of biochar (Sun *et al*., 2017), the mechanisms responsible for pH reduction are elusive. Due to high pH of saline-sodic and sodic soils is mainly associated with high exchangeable sodium percentage (Shaygan *et al*., 2017), a reduction in soil exchangeable sodium percentage with biochar could be one of the mechanisms responsible for the decrease in pH of such soils (Lashari *et al*., 2015). PH of different biochar produced from different feed stock in different temperature summarized in Table 3.

Table 3. pH of biochar produced from various feedstock sources under different production temperatures

Biochar feedstock	pH (H_2O)	Production (°C)	Information source
Oak wood (*Quercus spp.*)	4.8	350	Nguyen &Lehmann 2009
Oak wood (*Quercus spp.*)	4.9	600	Nguyen &Lehmann 2009
Corn Stover residue (*Zea mays L.*)	5.9	350	Nguyen &Lehmann 2009
Corn Stover residue (*Zea mays L.*)	6.7	600	Nguyen &Lehmann 2009
Green waste	6.2	450	Chan *et al*. 2008
Canola straw	6.3	350	Yuan *et al*. 2011
Pea straw	6.3	350	Yuan *et al*. 2011
Soybean straw	6.3	350	Yuan *et al*. 2011
Peanut shells	8.3	400	Warnock *et al*. 2010
Peanut shells	8.2	430	Warnock *et al*. 2010
Peanut shells	8.3	360	Warnock *et al*. 2010

In addition Amini, (2015) stated a measureable reduce in pH of salt affected soil (pH=8.4) with the addition of acidic biochar (pH=3.1) compared to alkaline biochar (pH=8.2). Hence, the difference between pH values of biochar and soil may be the main reason for soil pH change (Liu and Zhang, 2012). For example, Wu *et al*. (2014) evaluated the impact of furfural and its biochar (pH = 4.5) on properties of salt-affected soils and recorded a considerable reduction in soil pH with biochar because of its low pH compared with that of the soil. Some studies show that biochar alkalinity depends on the temperature of pyrolysis and feedstock and the alkalinity of the biochar increases by increasing the temperature of pyrolysis as shown in Table 3. Another possible explanation for the pH decreases in biochar-amended soil could be the high cation exchange capacity of biochar that helped promote plant uptake of cations, resulting in H^+ release from roots to balance charges and also, the proliferation of acid producing soil microorganisms in biochar-amended soils may decrease soil pH (Fidel *et al*., 2017). Serkalem (2015) also observed a significant reduction in saline soil pH after biochar addition due to an increase in acidic functional groups released during oxidation of biochar (Liu and Zhang, 2012). Bekele *et al.* (2021) suggests that, sole and combined application of biochar and gypsum affected soil pH, with some inconsistency with increasing depth soil pH decreased. On surface soil the highest pH (8.24) was observed from control, while the lowest pH (7.60) was from 4 ton/ha Biochar + 100 % gypsum as shown Figure 2.



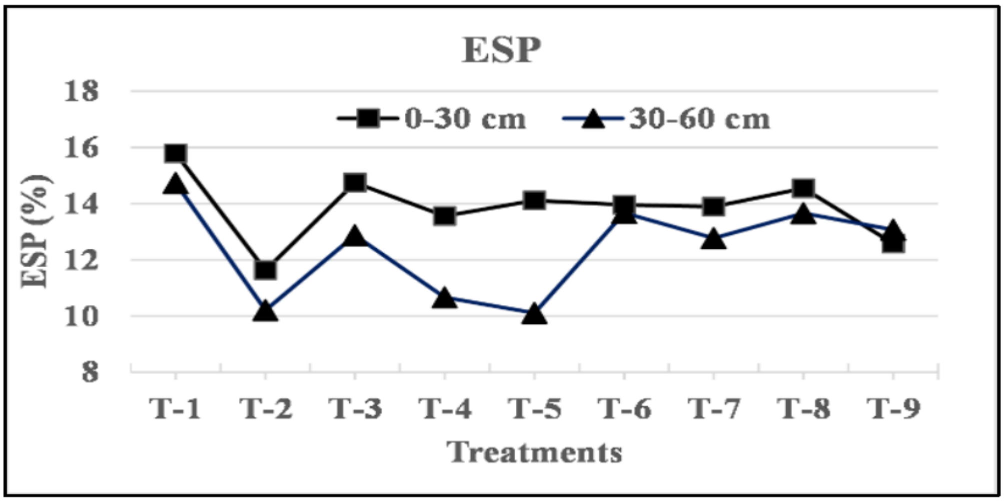
where, T1 -control, T2- 4t/ha biochar, T3- 8t/ha biochar, T4- 100 % gypsum, T5- 50% gypsum, T6- 4t/ha biochar + 50% gypsum, T7- 8t/ha biochar + 50% gypsum, T8- 4t/ha biochar + 100% gypsum and T9- 8t/ha biochar + 100% gypsum.

Figure 2. Effect of biochar and gypsum on soil pH with depth (Bekele *et al*., 2021).

Biochar impact on sodium Absorvation Ratio and exchangeable sodium percentage of salt-affected soils

Many recent studies have confirmed the beneficial impact of biochar on decreasing SAR/ESP of saline-sodic and sodic soils (Sun *et al*., 2017). A reduction in ESP due to biochar application may involve different mechanisms depending on the soil-plant biochar properties, e.g. (i) biochar application may increase surface charge density, potentially resulting in relatively more Ca than Na being adsorbed on the soil colloids, leading to lower ESP (Zheng *et al*., 2017), (ii) biochar may decrease ESP directly by providing exchangeable Ca to replace Na on the soil colloids (Chaganti *et al*., 2015), (iii) biochar as an organic amendment may increase partial pressure of CO_2 in the rhizosphere to mobilize Ca from calcareous soils for replacing Na from the soil colloids (Jalali and Ranjbar, 2009) and (iv) biochar-induced improvement in soil porosity may facilitate Na leaching from soil profile, reducing SAR and ESP (Di Lonardo *et al*., 2017).

As SAR values depend on the relative proportion of Na and Ca in soil solution, and the content of Na and Ca may vary with biochar types, the rate and types of biochar applied are the two most important factors in controlling the effect of biochar on sodium adsorption ratio of salt-affected soils (Zheng *et al*., 2017). High rates of biochar containing elevated level of Na may increase sodium adsorption ratio and/or exchangeable sodium percentage of soils and therefore, pre-testing biochar for Na content is recommended before application to soils (Sun *et al*., 2017). Given that study on biochar use to reclaim saline-sodic and sodic soils is at its infancy and most researches have been conducted in short-term laboratory incubation and greenhouse experiments (Luo *et al*., 2017), the mechanisms underlying exchangeable sodium percentage reduction are not only elusive but also controversial. For example, Luo *et al*. (2017) reported a significant reduction in exchangeable sodium percentage of sodic soils that was related to a corresponding increase in cation exchange capacity and OM content in biochar-amended soil. In contrast, other researchers (Lashari *et al*., 2015) reported substantial reductions in the ESP of biochar amended saline-sodic soil due to increasing supply of Ca and enhanced porosity, without any measurable effect of biochar on soil CEC. According to Teshome *et al*. (2021) Exchangeable sodium percentage was clearly influenced after application of biochar and gypsum. Plot that didn't received any treatment remain high ESP, however individual and synergetic effect of biochar and gypsum showed sodicity reduction and also with increasing depth ESP decreased as shown in figure 3.



Where , T1 -control, T2- 4t/ha biochar, T3- 8t/ha biochar, T4- 100 % gypsum, T5- 50% gypsum, T6- 4t/ha biochar + 50% gypsum, T7- 8t/ha biochar + 50% gypsum, T8- 4t/ha biochar + 100% gypsum and T9- 8t/ha biochar + 100% gypsum.

Figure 3. Effect of biochar and gypsum on soil ESP with depth (Bekele *et al*., 2021).

Effect of biochar in altering biological properties of soils

Soil microorganisms play vital functions in improving soil quality through their involvement in important soil processes such as decomposition of organic matter, nutrient transformation, soil aggregation, and structure development. Soil sodicity and salinity can negatively influence microbial growth, activity and diversity in numerous ways, including (i) decreased availability of water (Yan and Marschner, 2013), (ii) breakdown of soil aggregates and deteriorated soil structure that could lead to poor habitat for microbial growth and (iii) declining amounts of OM resulting in limited availability of energy substrates for microbes (Singh, 2015). Microbial biomass carbon is considered an indicator of any changes in soil organic carbon content and decomposition. Therefore, any processes and materials that alter carbon content in soil can influence biomass and activity of the microbial community.

Biochar can enhancer of the development and growth of soil organisms in salt-affected soils (Bhaduri *et al*., 2016) in different ways, including (i) improved aggregate formation in salt-affected soils (Jaafar *et al*., 2014), (ii) releasing nutrients in soil for microbes (Singh, 2015), (iii) reducing salinity and sodicity stress (Zheng *et al*., 2017) (iv) stimulating root exudation of dissolved organic carbon and nitrogen that are used in microbial metabolism and are the main constituents of microbial biomass (Li *et al*., 2017)and (vi) providing a rich source of carbon for microbes. However, many previous experiments have reported insignificant effects of biochar on microbial biomass C in non-saline (Zavalloni *et al*., 2011) and saline soils (Chaganti *et al*., 2015). Some studies even reported reduction in soil microbial biomass C with biochar application (Dempster *et al*., 2012).

Table 4. Summaries of potential biochar effects on different properties of salt-affected soil (Amini *et al*., 2016).

Soil salinity class	EC (dSm^{-1})	pH	ESP	SAR	Potential biochar effects
Potential biochar effects	>4.0	6–8	<15	<13	• Decreasing/increasing electrical conductivity (EC) depending on the nature of the applied biochar. • Improving plant establishment and growth and increasing crop yield
Saline-sodic soil	>4.0	>8	>15	>13	• increasing SOC stocks • .incresing or decreasing soil pH and SAR depending the nature and the source of biochar which affect the biochar pH • increasing the water holding capacity(WHC) hydraulic conductivity.(Ks)
Sodic soil	<4.0	>8	>15	>13	• Increasing total and aggregate associated SOC. • Increasing WHC & hydraulic conductivity (Ks) • Increasing microbial biomass carbon (MBC)

Effect of biochar on plant growth in salt-affected soils

Plant growth in salt-affected soils is challenged in different ways. Directly, plant growth could be stunted due to the presence of toxic levels of Cl, Na, and B in soil solution. Indirectly, plant growth may be reduced due to (i) decreased availability and uptake of plant essential nutrients due to the high concentration of elements such as Na and Mg, (ii) decreased availability of water to plants caused by high osmotic pressure of soil solution, (iii) poor root development and seedling emergence and inadequate availability of oxygen caused by Na-induced deterioration of soil physical properties, (iv) low levels of organic carbon in salt-affected soils, especially sodic soils, and (v) poor growth and activity of soil microbes responsible for organic matter turnover and nutrient cycling (Dahlawi *et al*., 2018).

Different laboratory and field studies showed that biochar addition to salt affected soils to a large extent improves salt stress and ameliorated plant growth directly through the release of essential macro- and micro-nutrients such as N, K, Ca, P and Zn in soil to support offset the adverse effects of salts (Drake *et al*., 2016). Because the accumulation of Na and impairment of K nutrition is a major characteristic of salt-stressed plants, improved K, Na ratio through enhancing K availability is considered a useful tool to increase plant growth under sodic and saline-sodic soils (Chakraborty *et al*., 2016). Biochar, depending upon feedstock, may increase potassium concentration in soils and such an increase in salt-affected soils to counteract the adverse effects of sodium is considered one of the major benefits associated with biochar application (Ali *et al*., 2017).

Biochar addition did not alter the concentration of exchangeable Na, Ca and Mg but it significantly increased the exchangeable potassium concentration to increase the potassium to sodium ratio in plants, which improved the plant salt tolerance and thus increased plant growth. Similarly, Lashari *et al*. (2015) stated a considerable increase in K and K/Na ratio in the leaf sap of corn under salt stress and an increasing supply of potassium was recommended as a major mechanism responsible for the alleviation of salt stress to plants. Not only by direct effects, biochar has also been shown to encourage plant growth in salt-affected soils because of many indirect benefits including (i) reduction in the availability and uptake of toxic salts such as sodium through adsorption onto biochar surfaces or physical entrapment of sodium in fine pores of biochars, or enhanced leaching from soil profile, (ii) improvement in chemical, physical and biological properties of salt affected soils (Sun *et al*., 2017), (iii) reduction in osmotic stress through improving water holding capacity and thus availability of water (Ali *et al*., 2017), (iv) improvement in stomatal density and conductance (Thomas *et al*., 2013) (v) lower production of phytohormones (Lashari *et al*., 2015), (vi) improvement in seed germination and (vii) the promotion of microbial activities and a bacterial community shift toward the beneficial taxa in the rhizosphere (Zheng *et al*., 2017).

Phytohramones such as abscisic acid are formed by plants under salinity stress (Duan *et al*., 2013). Abscisic acid is an indicator of the osmotic stress and acts as a long distance signal molecule to close stomata under water deficit conditions. It has been described that the strength of Abscisic acid signal is directly related to soil water status (Liu *et al*., 2017). Thus, decreased production of Abscisic acid could be attributed to a biochar-induced improvement in water availability to plants, which would result ultimately in increased stomata conductance. Additionally, enhanced availability of water and nutrients with biochar application under saline conditions could improve seed germination. A combined application of biochar with either chemical amendments (Hammer *et al*., 2014).

Evidence displays that, the biochar impact on the growth of plants in salt-affected soils is species dependent (Thomas *et al*., 2013). Biochar application significantly promoted the growth of salt-sensitive plant species; however, salt tolerant species did not show any growth improvement with biochar amendment (Zheng *et al*., 2017). In contrast, Luo *et al*. (2017) reported significant improvement in the growth of two salt-tolerant species, i.e. Sesbania pea (*Sesbania canabina*) and Seashore mallow (*Kosteletzkya virginica*) grown in biochar manure-compost amended salt-affected soils. In another study, Di Lonardo *et al*. (2017) reported no effect of a biochar based growth medium on salt-sensitive cherry laurel (*Prunus laurocerasus* L.) and salt-resistant phillyrea (*Phillyrea latifolia* L.); however, biochar addition limited salinity damage in cherry laurel. Drake *et al*. (2016) reported a significant increase in biomass of both salt-tolerant and salt-sensitive tree seedlings grown in biochar-amended saline-sodic soils.

Effects of biochar on improving crop production of Salt Affected Soils

In many cases, using of biochar and biochar with compost encourage the chemical and biophysical properties of the soil, as well as nutrient supply to plants (Akhtar *et al*., 2015). Biochar can also be used to reclaim depleted soils, making more agricultural land available, while increasing crop yields so that the need for expansion of agricultural land area decreases (Berihanu *et al***.**, 2017). Biochar soil amendment significantly enhanced plant growth and nutrition and improved the efficiency of N fertilizers (Yu *et al.*, 2019). Moreover, significant increases in root biomass, crop growth and yield have been observed following application of biochar to soil (Abiven *et al.*, 2015). wheat grain yield increased by 18% from the use of oil mallee biochar (Solaiman *et al.*, 2012) and peanut yield increased by 23% and 24% from the applications of biochar and co-composted biochar-compost (Agegnehu *et al.*, 2016).

Generally, averaged across many published scientific researches, biochar increases crop yields about 20% with application rates often exceeding 10 t ha^{-1}(Akhtar *et al.*, 2015). It has also been stated that applications of less than 5 t ha^{-1} can increase crop yields by over 50% in certain types of soils (Anwari *et al.*, 2020). Even highly productive agricultural lands contain patches of degraded soils that would benefit from biochar application (Schulz *et al.*, 2013). Responses will likely depend on the type and rate of amendment applied to soil as well as on soil characteristics such as soil C, CEC, pH and other components of soil fertility (Schulz *et al.*, 2013). Crop yield increases with biochar additions have, in most cases, been attributed to optimization of the availability of plant essential nutrients (Agegnehu *et al.*, 2016), increase in soil microbial biomass and activity (Wang *et al.*, 2016).

Cornelissen *et al.* (2013) stated that maize grain yield did not increase significantly in the first year following addition of 20 t biochar ha^{-1}, but increased by 28%, 30% and 140% relative to the control over the following 3 years, implying a longer term beneficial impact of biochar on yield and soil fertility. Yield responses of maize, cowpea and peanut to the applications of charred bark of Acacia mangium at the rate of 37 t ha^{-1} were only recorded at sites with less fertile soil, but a 200% increase was recorded on the less fertile soil when applied with fertilizer, which could be due to the increase in nitrogen and phosphorous availability (Yamato *et al.*, 2006). Solaiman *et al.* (2012) reported that the application of Oil Mallee biochar at the rate of 10 t ha^{-1} increased wheat seed germination from 93% to 98% in soil-less Petri-dish bioassay and by 9% on soil-based glasshouse bioassay, but decreased the germination of subterranean clover and mung bean. Application of biochar at the rate of 25t ha^{-1} and FYM at the rate of 5t ha^{-1} also resulted in improved maize growth and a decreased weed population at 30 and 60 days after sowing (Arif *et al.*, 2012). According to Nazar *et al.* (2018) okra pod yields decreased with the increasing salinity levels of the applied irrigation water but increased with increases in the Biochar amendment Figure 4. And other similar studies summarized in Figure 5, and Table 5.

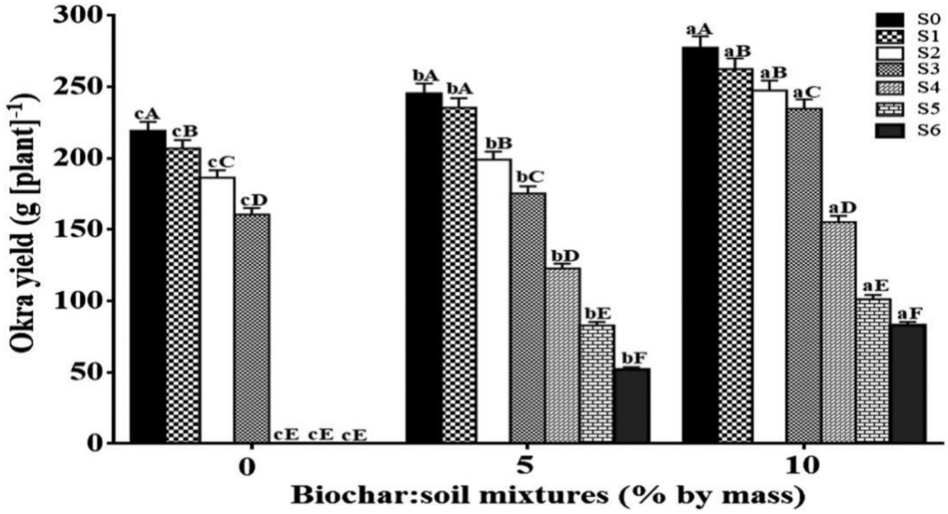
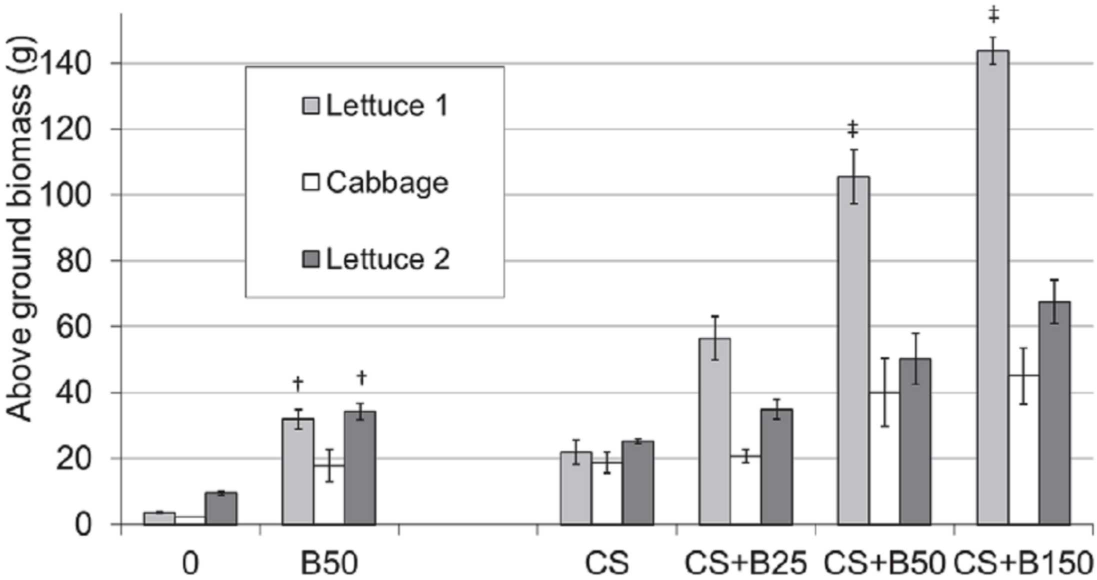


Figure 4. Okra pod yield as a function of the biochar amendment (BA) and water salinity treatments (S).

S0 to S6 represent salinities of 0.75, 1.0, 2.0, 4.0, 5.0, 6.0, and 7.0 dS m^{-1}. Letters above the bars that are the same indicate no significant differences among the BA (lowercase) or S (uppercase) treatments ($P < 0.05$) by least squares difference test (Nazar *et al.*, 2018).



Where: O= Unfertilized soil, B= rice-husk biochar, 25B, 50B and 150B were g/kg B, SC fertilized soil

Figure 5. Effect of rice husk biochar for above ground biomass of cabbage and lettuce (Carter *et al*. 2013)

Table 5. Summaries of responses of crops to different sources of biochar applications

Biochar source and application rate	Crop type	Crop response details	References
Coppiced trees (30, 60tha^{-1}), wood, wheat chaff (10 tha^{-1})	Wheat	Increase in seed germination by 4–9%; yield improvement by 30% and sustained yield for two consecutive seasons.	Solaiman *et al.*, 2012
Mango wood (0, 8, 16 t ha^{-1}), corn Stover (2.6–91tha^{-1})	Maize	Increase in biomass from 30–43% and yield by 22% due to improvements in soil pH, CEC, nutrient availability and water retention.	Rajkovich *et al.*, 2012
Citrus wood biochar (1,3 or 5% by volume in pots)	Pepper and Tomato	Increase in leaf area, canopy dry weight, number of nodes and yield .	Graber *et al*., 2010
Rice husk char (25,50, and 150 g kg^{-1})	Lettuce and Cabbage	Increase in biomass by 903% with biochar treatment, besides increase in soil Ca, Mg, and K.	Carter *et al*., 2013
Maize straw (20,30 and 40 t ha^{-1})	Choy Sum and Amaranth	Increase in yield by 28–48%, besides reduction in N_2O and CH_4 emissions	Jia *et al*., 2012

Conclusions

Biochar is a carbon-rich material produced by burning organic biomass under complete absence or partial absence of oxygen at temperatures(300-1000^{0}C) and intensive study is supporting biochar as an organic amendment for improving soil physical, biological and chemical properties, improving plant growth and crop production of salt-affected soils. Most researches show that biochar can increase nutrient availability in salt-affected soils through indirect and direct mechanisms. Many of studies have reported a considerable reduction in sodium adsorption ratio and exchangeable sodium percentage of sodic and saline-sodic soils and improvement in plant growth due to the sorption of Na salts by biochar; however, such data could be deceptive because saline sodic and sodic soils cannot be successfully reclaimed without removal of Na out of the soil profile. In general biochar addition did not alter the concentration of exchangeable Na, Ca and Mg but it significantly increased the exchangeable potassium concentration to increase the potassium to sodium ratio in plants, which improved the plant salt tolerance and thus increased plant growth. Clearly, intensive researches are still required to explore the processes by which biochar could influence plant growth in salt-affected soils. Such studies will not only help gain the potential benefits associated with biochar addition to soil, but will also aid in addressing minimizing trade-offs.

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