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REVIEW ARTICLE **OPEN ACCESS**

Biochar Mitigates Soil Salinity: A review

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ABSTRACT
Salinity is one of the most limiting factors of environment which affect the productivity of agricultural crops. Most crops are perceptive to soil salinity which is caused by high concentration of salts in the soil. In order to meet the global challenges of food demands, it is important to bring saline soils under cultivation. A recent concept of "biochar"is gaining considerable attention in enhancing various physico-chemical and biological properties under saline soil conditions. Biochar improves soil structure, increase pH, and augmented soil aeration and moisture content.Further extensive work is required for investigating the effect of various biochar amendments on different saline soils with different physico-chemical properties, different concentration of salinities at both laboratory and field scale. The main objective of the present review paper is to discuss the recent studies and investigations on the role of biochar in improving soil properties and plant growth in saline soils.
Key Words-Agriculture, Biochar, Environment, Soil, Salinity

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INTRODUCTION

Soil salinity is one of the main constraints present in irrigated agricultural lands world-wide. In India about 8.6 mha of land area is affected by soil salinity [28] and it is increasing every year as a result of secondary salinization. In India, the problem of salinity is found in the states of Uttar Pradesh, Gujarat, West Bengal, Rajasthan, Punjab, Maharashtra, Haryana, Orissa, Delhi, Kerala and Tamilnadu[18]. Almost 2.8 million hectares of salt-affected soils are present within the Indo-Gangetic alluvial plain occupying parts of Punjab, Haryana, Uttar Pradesh, Delhi, Bihar and Rajasthan states [2]. At least 20% of all irrigated lands are salt affected with some estimates being as high as 50% (by year 2050) whereas the world's population continues to rise, the total land area under irrigation appears to have levelled off [14, 18].
Most crops are sensitive to salinity caused by high concentration of salts in the soil. The soluble salts that occur in soils are found in various proportions of the cations sodium, calcium and magnesium, and the anions chloride and sulphate. The minor amounts of cation potassium and the anions bicarbonate, carbonate and nitrate are also present. A saline soil is generally defined as one in which the electrical conductivity of the saturation extract in the root zone exceeds 4 dS m^{-1} (approximately 40 mMNaCl) at 25 °C and has an exchangeable sodium of 15% [26]. Salinization associated with agriculture occurs when salts build up in the root zone, either because the soil is intrinsically saline, or because the drainage of water from the sub-soil is not sufficient to prevent saline water rising into the root zone. This problem is very common in arid and semi-arid regions where leaching of salt is poor due to lower rainfall; where there are strongly saline sub-soils formed from marine deposits or where irrigation changes water tables and salt flow; also due to excessive evapotranspiration in these regions, the secondary salinization is becoming important factor for salinity [35].
All soils contain some water-soluble salts. Plants absorb essential nutrients in the form of soluble salts, but excessive accumulation strongly suppresses the plant growth. Salinity not only decreases the agricultural production of most crops but also effects soil physicochemical properties, and ecological balance of the particular region. The impacts of salinity mainly include the low agricultural productivity, low economic returns and soil erosions [13]. Salinity effects are the results of complex interactions among morphological, physiological, molecular and biochemical processes including seed germination, plant

growth, and water and nutrient uptake[34]. Soil salinity causes ion toxicity, osmotic stress, nutrient (N, Ca, K, P, Fe, Zn) deficiency and oxidative stress on plants, and therefore limits water uptake from soil. Soil salinity significantly reduces plant phosphorus (P) uptake because phosphate ions precipitate with Caions [6,7]. Some elements (sodium, chlorine, and boron) have specific toxic effects on plants. Excessive accumulation of sodium in cell walls can rapidly lead to osmotic stress and cell death [25]. Salinity also affects photosynthesis mainly through a reduction in leaf area, chlorophyll content and stomatal conductance. Salinity adversely affects reproductive development of seed and does not allow seed to germinate by inhabiting micro-sporogenesis and stamen filament elongation, enhancing programed cell death in some tissue types, ovule abortion and senescence of fertilized embryos[32].

In order to meet the global challenges for food demands, it is important to bring the saline soils suitable for cultivation. There is wide variety of methods has been developed and applied in order to control soil salinization in the agricultural lands but they have major disadvantages also. These methods include the application of chemical amendments (cause secondary chemical soil pollution), planting salt-tolerant plants (time consuming), leaching irrigation (shift salinity from shallow to deep soil) etc [20]. Thus there is need to develop a simple and nearly natural method to mitigate effect of salinity in soil and boom the agricultural production. The selection of most sustainable amendment is largely determined by the geographical and physicochemical parameters of soil of particular region. Recently, biochar has attracted considerable attention as a soil amendment. Biochar is a carbon-rich solid obtained by heating biomass, such as wood or manure with a little or no oxygen, that can be applied to soil for both agricultural production and carbon sequestration. Application of biochar in saline soil addition effectively reduces the amount of soil evaporation, thus decreasing the amount of salinity transferred from the deep soils or groundwater to shallow soils via water transportation [1,37]. Also, as biochar possess strong adsorbing ability and have super-large surface area, thus have significant potential for adsorbing the active soil salt ions such as Na^+, K^+,Ca^{2+}, and then reduces the amount of salt in both soil and solution [3,16].An emerging concept of this knowledge shows that biochar is effective in improving physical, chemical and biological properties of salt-affected soils.

The present paper reviews recent studies and investigations on the role of biochar in improving soil physical, chemical, biological properties and enhancing plant growth in saline soils. This review emphasizes sustainable and profitable use of saline soils for agriculture by amending the salt-affected soils with biochar.

EFFECT OF BIOCHAR ON PROPERTIES OF SALINE SOIL AND PLANT GROWTHS

Considerable evidence from pot and field studies suggests that biochar addition helps to improve plant growth in saline-soil by compensating the decreased uptake of excess ion by plants. Recent studies have confirmed a positive impact on physical, chemical and biological properties of saline-soils by biochar. Biochar enhances the growth and development of soil organisms in salt-affected soils by improving aggregate formation, improving water retention, releasing nutrients in soil for microbes, and providing a rich source of carbon for microbes [8].

Walker and Bernal [36] studied the use of biochar of chicken litter to improve the chemical properties of a saline soil and reported the increase in both cation exchange capacity (CEC) and soluble and exchangeable K^+, thus K^+ competes with Na^+ in terms of adsorption limiting their entry into exchange places. Similar observations were also given by Fernandes *et al.*, [12] with the biochar produced from a poultry litter. They reported increased electrical conductivity, pH, Na and K, as well as sodium content and sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP).

Salinity is a major stress threatening crop production in dry lands. An experiment was conducted by Lashari *et al.*, [19]to assess the potential of a biochar product to alleviate salt-stress to a maize crop in a saline soil. The soil was amended with compost at 12t/haof wheat straw biochar and poultry manure compost and a diluted pyroligneous solution at 0.15t/ha. While soil salinity decreased, there were large increases in leaf area index, plant performance, and maize grain yield, with a considerable decrease in leaf electrolyte leakage when grown in amendments. Maize leaf sap nitrogen, phosphorus and potassium increased while sodium and chloride decreased, leaf bioactivity related to osmotic stress was improved following the treatments. With the amendment, microbial biomass carbon and nitrogen, and bacterial gene abundance were significantly and greatly increased in both bulk and rhizosphere samples. Two single bands belonging respectively to Alphaproteo-bacteria and Deltaproteo-bacteria were emerged in the amended soil. Activities of urease, invertase and phosphatase in both bulk soils and rhizosphere soils were also found increased. Likewise, Akhtar *et al.*, [4]while studying the growth, physiology and yield of potato in salinity stress observed the significant reductions of shoot biomass, root length and volume, tuber yield, photosynthetic rate, stomatal conductance, midday leaf water potential, but increased abscisic acid (ABA) concentration in both leaf and xylem sap. They reported that application of biochar mitigates the salinity stress by adsorbing Na^+, which results in decreased Na^+, Na^+/K^+ ratio and increased K^+ content in xylem of potato plant. Incorporation of biochar increased shoot biomass, root length and volume, tuber yield, photosynthetic rate, stomatal conductance, midday leaf water potential, and decreased ABA concentration in the leaf and xylem sap.The reclamation potential of biochar, biosolids and green-waste composts applied to a saline-sodic soil was evaluated by Chaganti *et al*., [9]. Results showed that leaching with moderate SAR water was effective in reducing the soil salinity, irrespective of amendment application. They also observed higher leachate losses of cations with biochar and compost treated soils. Improvements in soil aggregate stability and saturated hydraulic conductivity were prominent in compost treated soils. After leaching, soil analyses indicated that organic amendments lowered significantly more soil EC, ESP and SAR than that of the control soils and saturated the exchange complex with Ca^{2+}. Soil pH was significantly reduced and CEC was significantly increased in only compost treated soils. Although individual organic amendment applications proved to be significant enough to remediate a saline-sodic soil, combined applications of gypsum and organic amendments were more effective in improving soil properties directly related to sodium removal including sodium leaching, hydraulic conductivity, ESP, and SAR, and therefore could have a supplementary benefit of accelerating the reclamation process.

Yue *et al*.,[38] derived the biochars from rice (*Oryza sativa* L.) straw (RSB), sunflower (*Helianthus annuus*) straw (SSB), and cow manure (CMB) and added to saline soil at Hetao region in China. Among these three biochars, sunflower straw showed highest potential amendment which led to much lower contents of the most detrimental ions of both sodium (Na^+) and bicarbonate ($HCO^-{}_3$) in the soil.

Under the salinity stress, biochar mitigates the negative effects of salt ions and improves plant growth and productivity. A research was carried out by Kanwal*et al*., [15] to study the effect of 1% and 2% of biochar application on wheat seed germination and growth under the salinity-stress conditions. They reported improved germination and growth of wheat (2% biochar level being more effective), increased root and shoot length (up to 23% and11%, respectively), increased leaf water potential and osmotic potential, decreased proline content and soluble sugar (51% and 27%, respectively),decreased superoxide dismutase activity (15.3%). An emerging pool of research and investigations shows that biochar addition is effective in improving physical, chemical and biological properties of salt-affected soils. However, some contrary findings are also observed that application of biochar at high rates increases soil salinity. Al-Wabel *et al*., [5] inferred that applications of high quantity of decomposable organic amendment in saline-stress soil is neither economically feasible nor environmentally friendly (increased CO_2 emission). It has been reported by researchers that organic amendments at elevated rates have high content of Na, K and NH_4that can increase soil salinity and thus leads to structural breakdown and inhibition of plant growth [10, 23].

In some experiments manures and biochars were compared for their efficiency to deal with salinity stress. Dugdug *et al*., [11] conducted a research at local farm in Alberta, Canada on saline-sodic and non-saline soils. Biochar were produced from wheat straw, hardwood, and willow wood. They reported that Willow wood biochar showed the highest phosphorus (P) sorption followed by hardwood and wheat straw biochars. In the leachates of hardwood biochar amended saline-sodic soils the electrical conductivity was found decreased with increasing biochar application rate. They also observed that application of biochar increases movement of water through the soil and in this way prevent the waterlogging of the saline-sodic soil. Separate application of biochar and manure increased nutrient availability. Biochar application also increased nutrient concentrations in the plant tissue, but not shown by manure application. The crop when applied with both biochar and manure to the saline-sodic soil showed the highest survival rate, nutrients, dry biomass, and production. The interactive effects of rice husk biochar, straw biochar and cow manure on rice growth and salt-affected soil were studied by Nguyen *et al*.,[27]. They observed that addition of both rice-husk and straw biochar significantly increased rice growth, whereas the combination of individual biochar with manure did not report such positive effect. Application of biocharin soil also showed higher cation exchange capacity (CEC) (28.8 to 29.0 $cmol_c$/kg) than the control (25.6 $cmol_c$/kg), but manure addition did not showed effect. Thus biochar addition enhanced rice growth by enhancing nutrient availabilities such as P and K and also CEC.

Conjuctive irrigation along with the biochar application has been reported to reduce the soil salinity. Mingyi *et al*., [4] designed experiment using biochar and conjunctive irrigation with brackish water at salt-affected lands at coastal areas of Eastern China. In the experiment sweet corn (*Z. mays* L. saccharate) was grown in a coastal saline soil amended with biochar. They reported that biochar application improved sweet corn photosynthetic performance and mitigated oxidative damage as well as salt stress, further resulted in higher production and marketable value. They also observed removal out ofmore salts due to biochar after leaching and thus reduced the salinity of the soil profile during conjunctive irrigation.

Biochar also reduced Na^+ adsorption ratio (25.7% to 32.6%) under saline water irrigation. Likewise Rekaby *et al*., [29]assess the influences of biochar (BC) on barely growth under saline conditions. The biochar treatment enhanced soil organic matter by 55.2% and dry biomass by 15.4% compared to control. The study conducted by Rezaie *et al*., [31] also reported the similar results with different irrigation levels and different quantity of biochar produced from wheat straw under non-oxygen conditions. They reported that the concentration of sodium, potassium and calcium, electrical conductivity and sodium absorption ratio in the 0-10 cm layer with the application of the highest level of biochar (75Mgha^{-1}) increased by 1.1 and 143.8, 2.2, 2.1 and 0.8 times in comparison with no biochar application. They observed higher concentration of ions,electrical conductivity and Na^+ absorption ratio at upper soil profile(0-10 cm) than deeper soil profile (10-20cm). This is because of the effect of biochar application which had resulted in higher evaporation as well as increased water holding capacity in top layer of soil. Increase in both EC and pH with increasing rate of rice-biochar application were studied by Singh *et al*., [33].At all salinity levels, NO_3^--N concentrations increase with increasing incubation time and biochar rates, whereas NH_4^+-N concentrations were greater on day 14 than day 56 of incubation. They concluded that application of higher rates of rice-residue biochar (2-4%) will be more effective in reducing the adverse effects of salinity on soil properties.

Many recent studies have reported for decrease in the soil pH after the biochar application [17, 21].Biochar application decrease the saline soil pH is due to an increase in acidic functional groups released during the oxidation of biochar [22]. More recently similar observations were also reported in a experiment conducted byRezaei and Razzaghi [30] to investigate the effect of four levels of biochar (0, 25, 50 and 75 t/ha) and four saline irrigation levels (0.5, 5, 7 and 9 dS m^{-1}, the mixture of 50% NaCl and 50% $CaCl_2$ solution on molar basis) on growth and yield of wheat. They reported that in each salinity level, increasing biochar level significantly reduced the dry weight of straw and grain yield. Increasing the amount of salinity in each biochar level also reduced the dry weight of wheat straw and grain yield. Increasing salinity up to 5 dS m^{-1} in each biochar level increased water use efficiency, while increasing salinity over 5 dSm^{-1} reduced the water use efficiency. Further, increasing biochar to 25 t/ha in each level of salinity also enhanced water use efficiency, while it was reduced by increasing biochar levels. As the produced biochar had a saturated electrical conductivity of 1 dS m^{-1}, which increased the soil salinity by applying more biochar, it also negatively affected the yield and water use efficiency especially at higher levels of biochar application. They concluded that application of appropriate biochar levels (25 t/ha) will enhance water use efficiency.

CONCLUSIONS AND RECOMMENDATIONS

Soil salinization is one of the major threats to soil productivity in farming croplands. The covering area of saline stress regions is very extensive and widespread in arid and semi-arid regions of the world. In order to meet the global challenges of food demands, it is important to bring barren salt-affected soils under the cultivation. There are various inorganic and organic amendments that can be used for the reclamation of the salt-affected lands. The selection of a most sustainable and suitable amendment is largely determined by the geographical and physicochemical parameters of particular salt affected land. Recently, the most novel organic and natural amendment i.e. biochar is gaining considerable attention to overcome this problem. An emerging concept of biochar knowledge and related research shows that this amendment is effective in improving physical, chemical and biological properties and also facilitates the leaching of salts from the rooting zone. Application of biochar improves soil quality including soil pH, water holding capacity and infiltration, and fertilization use efficiency by plant. Improvement in all these parameters resulted in enhanced plant growth and yield in salt-affected soils. However, some studies have revealed that increased rate of biochar application may increase in soil salinity. The raw material used to produce the biochar is the key factor that determines its effectiveness as an organic soil conditioner. Current data on salinization affected soils with biochar are inconsistent and it is difficult to compare the existing studies in the literature with each other. This is probably due to the large variation between the biochar composition and the diversity of soils used in the different studies. Yet, there is relatively limited information and research work on the long-term behavior of salt-affected soils amended with biochar applications. Therefore, further more extensive and elaborated work is required for investigating the effect of biochar on different saline soils with different physico-chemical properties and different concentration of salinities at both laboratory and field scale.

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