Science of the Total Environment 625 (2018) 320–335

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Biochar application for the remediation of salt-affected soils: Challenges and opportunities

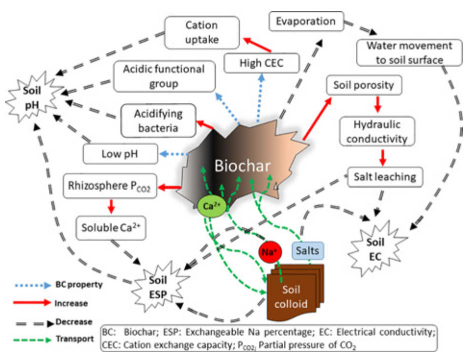
Saifullah [a,b,*], Saad Dahlawi [a,b], Asif Naeem [c], Zed Rengel [d], Ravi Naidu [e,f]

[a] *Department of Environmental Health, College of Public Health, Imam Abdulrahman Bin Faisal University, Dammam, Saudi Arabia*
[b] *Institute of Research and Medical Consultations, Imam Abdulrahman Bin Faisal University, Dammam, Saudi Arabia*
[c] *Nuclear Institute of Agriculture and Biology, Jhang Road, Faisalabad, Pakistan*
[d] *School of Agriculture and Environment, The University of Western Australia, Perth, Australia*
[e] *Global Centre for Environmental Remediation, Faculty of Science, The University of Newcastle, Australia*
[f] *Cooperative Research Centre for Contamination Assessment and Remediation of Environment (CRC CARE), The University of Newcastle, Australia*

HIGHLIGHTS

- Use of biochar for the reclamation of salt-affected lands has been reviewed.
- Biochar can reclaim salt-affected soils, but the effects are dependent on biochar properties.
- Interactions between biochar and soil properties need further evaluation.
- Sustainable and profitable use of salt-affected soils by applying biochar is emphasized.
- Low-cost methods for producing biochar are urgently needed.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 21 November 2017
Received in revised form 21 December 2017
Accepted 21 December 2017
Available online xxxx

Editor: F Frederic Coulon

Keywords:
Biochar
Salt-affected soils
Nutrient availability
Salt leaching
Plant growth

ABSTRACT

Soil salinization and sodification are two commonly occurring major threats to soil productivity in arable croplands. Salt-affected soils are found in >100 countries, and their distribution is extensive and widespread in arid and semi-arid regions of the world. In order to meet the challenges of global food security, it is imperative to bring barren salt-affected soils under cultivation. Various inorganic and organic amendments are used to reclaim the salt-affected lands. The selection of a sustainable ameliorant is largely determined by the site-specific geographical and soil physicochemical parameters. 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. However, some studies have also found an increase in soil salinity and sodicity 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 and sodicity. Moreover, there is relatively limited information on the long-term behavior of salt-affected soils subjected to biochar applications. The main objective of the present paper was to review, analyze and discuss the recent studies investigating a role of biochar in improving soil properties and plant growth in salt-affected soils. This review emphasizes that using biochar as an organic amendment for sustainable

Abbreviations: AEC, anion exchange capacity; CEC, cation exchange capacity; DDL, diffuse double layer; ESP, exchangeable sodium percentage; DOC, dissolved organic carbon; EC_e, electrical conductivity of soil saturated paste extract; SAR, sodium adsorption ratio.

* Corresponding author at: Department of Environmental Health, College of Public Health, Imam Abdulrahman Bin Faisal University, Dammam, Saudi Arabia.
E-mail address: smferoz@uod.edu.sa (Saifullah).

https://doi.org/10.1016/j.scitotenv.2017.12.257

and profitable use of salt-affected soils would not be practicable as long as low-cost methods for the production of biochar are not devised.

Contents

1. Introduction . . . 321
2. What makes biochar a suitable amendment for salt-affected soils? . . . 322
3. Effect of biochar on soil properties . . . 322
 3.1. Effect of biochar on nutrient status of salt-affected soils . . . 322
  3.1.1. Effect of biochar on macronutrient availability in salt-affected soils . . . 323
  3.1.2. Effect of biochar on micronutrients in salt-affected soils . . . 324
 3.2. Role of biochar in improving physical properties of salt-affected soils . . . 324
 3.3. Role of biochar in improving chemical properties of salt-affected soils . . . 326
  3.3.1. Biochar impact on soil electrical conductivity of salt-affected soils . . . 326
  3.3.2. Biochar impact on pH, SAR and ESP of salt-affected soils . . . 327
 3.4. Role of biochar in altering biological properties of soils. . . . 328
4. Effect of biochar on plant growth, physiology and biochemical process in salt-affected soils . . . 328
5. Knowledge gaps and suggested research themes in BIOCHAR use for salt-affected soils . . . 331
6. Conclusions . . . 331
References . . . 332

1. Introduction

Soil salinization and sodification are two major threats to soil productivity in arable croplands worldwide (Mahmoodabadi et al., 2013). Soils having high amounts of soluble salts (saline soils) or exchangeable sodium (sodic soils) or both (saline-sodic) adversely affect the growth of most crop plants and are collectively called salt-affected soils (Ghassemi et al., 1995; Soil Science Society of America, 1997). Salt-affected soils are widespread in arid and semi-arid regions of Asia, Australia, Africa and South America (Kovda, 1971; Szabolcs, 1889; Rengasamy, 2006). According to Tóth et al. (2008), the total area of salt-affected soil is about 1 billion hectares and is likely to expand worldwide in the future due to poor management of land and water resources and unprecedented regional and global climate change and variability (Wong et al., 2010).

Salt-affected soils may be saline, saline-sodic or sodic. However, from the management and reclamation point of view, salt-affected soils are grouped into two classes only: (i) saline and (ii) saline-sodic and sodic soils (Qadir et al., 2000; Qadir et al., 2007). Excessive concentrations of soluble salts and/or exchangeable sodium (Na) on cation exchange sites in soil cause poor and patchy crop stands, with uneven and stunted growth, thus reducing the yield (Francois et al., 1986). 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). Salt-affected soils can be used successfully for crop production following measures aimed at removal of soluble salts and/or exchangeable Na (reclamation of salt-affected soils) or minimizing the adverse impacts of salts on plants (management of salt-affected soils).

Saline soils are easy to reclaim because the problem lies with the excessive amounts of soluble salts that can be removed from the soil profile, providing good-quality water is available and there is no hindrance to movement of water from the soil (good internal drainage). For reclamation of saline-sodic and sodic soils, there is a need to remove excessive amounts of exchangeable Na from the cation exchange sites using other cations such as calcium (Ca) followed by leaching the replaced Na from the soil profile with the application of good-quality water. Gypsum is widely accepted as a significant source of Ca^{2+} to replace exchangeable Na from saline-sodic and sodic soils (Oster et al., 1999; Ghafoor et al., 2001) and it works equally well in calcareous as well as non-calcareous soils. Other chemical reclamation strategies include application of acids or acid-forming compounds that solubilize native calcite (calcareous soils only) and supply the required Ca to remove Na from the cation exchange sites (Gupta and Abrol, 1990). Even though all of the above mentioned strategies may work well, it is generally thought that selection of a sustainable reclamation technique is largely determined by the site-specific geographical and soil physicochemical parameters (Seenivasan et al., 2015).

Application of organic amendments such as farm manure, poultry manure, compost and pressmud could be effective in improving plant growth through their beneficial impacts on physical, chemical, nutritional and biological properties of saline, saline-sodic and sodic soils (Srivastava et al., 2016; Yaduvanshi and Swarup, 2005; Oo et al., 2015). In saline soils, organic amendments provide essential nutrients (Lax et al., 1994; Qadir et al., 2001), and help increase the leaching/washing of salts out of the soil by: (1) improving and maintaining soil porosity and thus improving water movement in soil (Tejada et al., 2008; Jalali and Ranjbar, 2009), and (2) enhancing root vigor and growth that in turn improves soil structure and creates water channels to increase water movement in soils (Qadir and Oster, 2004; Tejada et al., 2006; Clark et al., 2007; Walker and Bernal, 2008; Lakhdar et al., 2009; Wang et al., 2014; Xie et al., 2017). Similarly, growing salt-tolerant plants and improving fertilizer, sowing and irrigation practices have also been claimed to decrease salt stress and improve plant yield in saline soils (Qadir et al., 2007).

Application of organic amendments to saline-sodic and/or sodic soils could produce beneficial impacts on plant growth by improving soil properties, especially physiochemical ones (Singh et al., 2016; Fan et al., 2016). Organic amendments can increase the dissolution of native calcite ($CaCO_3$) minerals via increased formation of carbonic acid in the soil profile (Kumar and Singh, 2003; Qadir et al., 2007). Such dissolution could release Ca in soil solution to facilitate the removal of Na from the cation exchange sites (Li and Keren, 2009; Srivastava et al., 2016; Yaduvanshi, 2017). In addition, organic amendments help improve the binding of the small particles in saline-sodic and sodic soils to form large water-stable aggregates (Muyen and Wrigley, 2016; Zhu et al., 2016). Furthermore, the large-sized individual particles of these organic materials create channels in otherwise poorly structured saline–sodic and/or sodic soils and thus help improve the soil permeability and leach Na from the soil profile (Lakhdar et al., 2009).