Pedosphere **27**(6): 991–1014, 2017
doi:10.1016/S1002-0160(17)60490-9
ISSN 1002-0160/CN 32-1315/P

Published by Elsevier B.V. and Science Press

PEDOSPHERE

www.elsevier.com/locate/pedosphere

Use of Biochar as an Amendment for Remediation of Heavy Metal-Contaminated Soils: Prospects and Challenges

Altaf Hussain LAHORI[1], GUO Zhanyu[1], ZHANG Zengqiang[1,*], LI Ronghua[1], Amanullah MAHAR[2], Mukesh Kumar AWASTHI[1,3], SHEN Feng[1], Tanveer Ali SIAL[1], Farhana KUMBHAR[4], WANG Ping[1] and JIANG Shuncheng[1]

[1] *College of Natural Resources and Environment, Northwest A&F University, Yangling 712100 (China)*
[2] *Centre for Environmental Sciences, University of Sindh, Jamshoro 76080 (Pakistan)*
[3] *Department of Biotechnology, Amicable Knowledge Solution University, Satna 485001 (India)*
[4] *College of Agronomy, Northwest A&F University, Yangling 712100 (China)*

(Received August 1, 2017; revised November 14, 2017)

ABSTRACT

Biochar (BC), known as the new black gold, is a stable, novel carbonaceous by-product that is synthesized through pyrolysis of biological materials in the absence of O_2. Recently, an emerging interest in the application of BC as a robust soil amendment has given rise to a broad research area in science and technology. It is considered a promising remediation option for heavy metal (HM)-contaminated soils to reduce HM bioavailability to plants. Remediation efficacy of BC depends on the porosity, composition, pyrolysis temperature, feedstock, and residence time of pyrolysis. This review article aimed to present an overview of BC use in the immobilization of HMs, *i.e.*, Cd, As, Pb, Zn, Ni, Cu, Mn, Cr, and Sb, in contaminated soils. The remaining uncertain factors, including the specific soil HM immobilization mechanisms, long-term beneficial effects, and potential environmental risks associated with BC application are analyzed. Future research must be conducted to ensure that the management of environmental pollution is in accord with ecological sustainability and adaptation of the black gold biotechnology on a commercial basis for immobilization of HMs in contaminated soils.

Key Words: additives, environmental pollution, feedstock, immobilization, pyrolysis temperature, remediation efficacy

Citation: Lahori A H, Guo Z Y, Zhang Z Q, Li R H, Mahar A, Awasthi M K, Shen F, Sial T A, Kumbhar F, Wang P, Jiang S C. 2017. Use of biochar as an amendment for remediation of heavy metal-contaminated soils: Prospects and challenges. *Pedosphere*. **27**(6): 991–1014.

INTRODUCTION

Anthropogenic human activities and natural mineralization of rocks and minerals are primarily responsible for pollution of soils by the excessive release of heavy metals (HMs) (Fig. 1) (Mahar *et al.*, 2016a; Lahori *et al.*, 2017a,b; Zhang *et al.*, 2017). Heavy metal contamination of soils and its management are a challenging issue worldwide primarily because soil HMs do not rapidly mineralize into other forms, and their persistence in the environment causes numerous adverse effects on the soil ecosystem and agricultural productivity, and also pollutes underground water reserves, resulting in serious health problems for living organisms (Muchuweti *et al.*, 2006; Anawar *et al.*, 2015; Ali *et al.*, 2017a). Although several traditional methods have been used to remediate HM-contaminated soils, each method has several drawbacks, *i.e.*, poor feasiblity, unsustainablity, prohibitive cost, and environmentality disruption (Zwonitzer *et al.*, 2003; Cao *et al.*, 2004). Recently, the use of biochar (BC) has been considered as an economically feasible approach for remediation of HM-contaminated soils with its extraordinary efficacy and applicability because of its porous structure and large surface area and the dominance of micro-pores (Cao *et al.*, 2011; Ahmad *et al.*, 2014b). Biochar is the carbon-rich end product of thermal degradation of organic biomass in the absence of oxygen (Klinar, 2016). Using the words "biochar + soil + heavy metal + immobilization" or "biochar + additives + soil + heavy metals + immobilization" as the topic in database searches of indexed journals returned a number of publications (according to ISI Web of Science™ from 2013 to 2017) that has been increasing (Figs. 2 and 3), indicating a growing interest in the scientific community in BC research. Numerous researchers have noted that different BCs have a diverse potential to reduce the bioavailability of HMs and their

*Corresponding author. E-mail: zhangzq58@126.com.

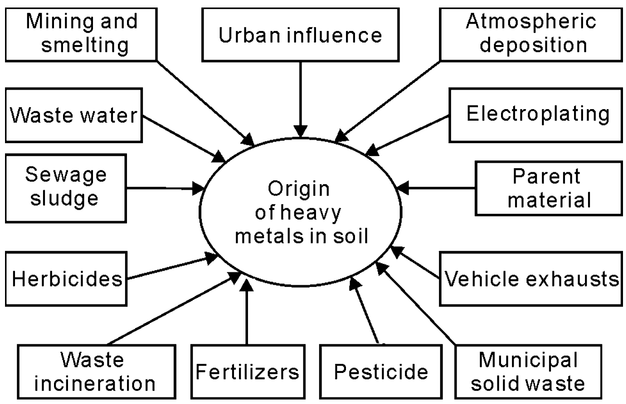

Fig. 1 Primary sources of heavy metals in polluted soil.

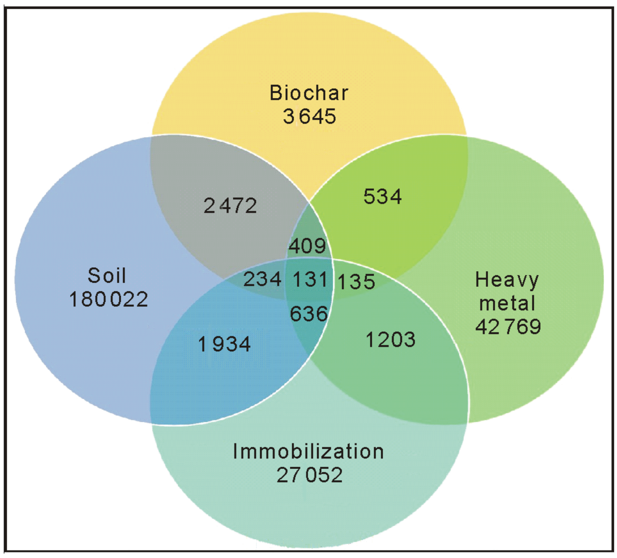

Fig. 2 Numbers of publications that included the words "biochar + soil + heavy metal + immobilization" in the topic of indexed journals (according to ISI Web of Science™ from 2013 to 2017).

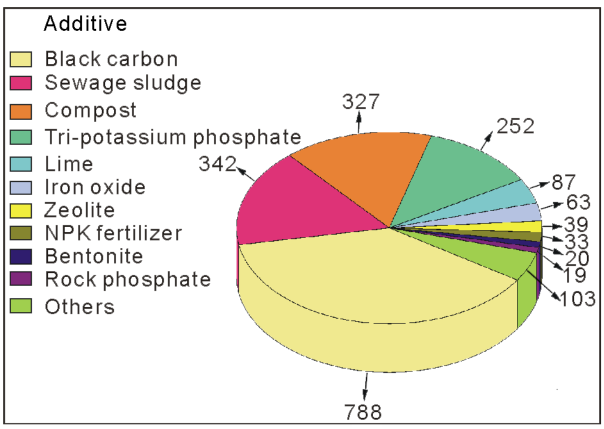

Fig. 3 Numbers of publications that include the words "biochar + additives + soil + heavy metals + immobilization" in the topic of indexed journals (according to ISI Web of Science™ from 2013 to 2017). The number of publications has been growing progressively.

uptake by plants, because of the eco-friendly remediation ability of BC (Ahmad *et al.*, 2016; Abbas *et al.*, 2017). Although BC is recognized for its use as a soil amendment, its production can be considered a management approach for dealing with large amounts of organic waste biomass, including domestic solids and semisolid waste, agriculture crop residues, yard waste, food waste, and industrial waste (Fellet *et al.*, 2014; Khan *et al.*, 2017; Kiran *et al.*, 2017). China alone produces approximately 30 million tons of sewage sludge annually, which accounts for a quarter of the overall organic waste (Sohi *et al.*, 2009; Cai *et al.*, 2016), while USA produces 6.2 million tons annually (Yu, 2011). Furthermore, China produces 22.76 million tons of soybean straw, 134.9 million tons of rice straw, 46.3 million tons of rice hull, and 3.14 million tons of peanut shells annually, with these amounts continuing to increase (Fytili and Zabaniotou, 2008; Wang *et al.*, 2010). Furthermore, the total agriculture biomass contribution from different seasonal crops and processing residues could reach 998 million tons dry biomass year^{-1} in China (Zhang *et al.*, 2008). However, BC production could be implemented as a cost effective and eco-friendly biotechnology for the utilization of organic fractions of agricultural waste biomass, because BC has the ability to absorb and immobilize both organic and inorganic pollutants in contaminated soils (Beesley and Dickinson, 2011; Mohan *et al.*, 2014). The micropores of BC are also responsible for the sorption of dissolved organic matter (DOM) and enhanced microbial activity, thus facilitating remediation of organic contaminants in soils (Kasozi *et al.*, 2010). Recently, Kołtowski *et al.* (2016) made preliminary calculations and observed that the cost of remediation using BC was several times cheaper compared to traditional methods, such as physical treatment, electrokinetic remediation, biological remediation, and phytoremediation. However, various countermeasures to remediate HM-polluted soils have been evaluated, including simultaneous use of organic manure, choice of crop genotypes with lower uptake of HMs, and agro-ecological engineering practices (Mahmoudand El-Kader, 2015). Therefore, the purpose of this review article was to present an overview of BC use as a soil amendment for remediation of HM-contaminated soil based on the data published in the past five years.

USE OF BIOCHAR AS A SOIL AMENDMENT FOR IMMOBILIZATION OF HEAVY METALS

In recent years, the fame of BC as a soil amendment has increased considerably because of its fundamental