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Review on utilization of biochar for metal-contaminated soil and sediment remediation

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ABSTRACT

Biochar is a carbon-neutral or even carbon-negative material produced through thermal decomposition of plant- and animal-based biomass under oxygen-limited conditions. Recently, there has been an increasing interest in the application of biochar as an adsorbent, soil ameliorant and climate mitigation approach in many types of applications. Metal-contaminated soil remediation using biochar has been intensively investigated in small-scale and pilot-scale trials with obtained beneficial results and multifaceted effects. But so far, the study and application of biochar in contaminated sediment management has been very limited, and this is also a worldwide problem. Nonetheless, there is reason to believe that the same multiple benefits can also be realized with these sediments due to similar mechanisms for stabilizing contaminants. This paper provides a review on current biochar properties and its use as a sorbent/amendment for metal-contaminated soil/sediment remediation and its effect on plant growth, fauna habits as well as microorganism communities. In addition, the use of biochar as a potential strategy for contaminated sediment management is also discussed, especially as regards *in-situ* planning. Finally, we highlight the possibility of biochar application as an effective amendment and propose further research directions to ensure the safe and sustainable use of biochar as an amendment for remediation of contaminated soil and sediment.

Contents

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Introduction

Soil and sediment contamination by heavy metals

Due to some detrimental properties of heavy metals including mobility, non-decomposed, bioaccumulation and ecotoxicity, soil and sediments contaminated by metals have attracted much attention from concerned authorities (Bolan et al., 2014; Bastami et al., 2015), since they can pose a critical threat to the soil and aquatic environments. In recent years, high concentrations of metals such as As, Cd, Cu, Pb, and Zn in soils and sediments have often been reported in a number of countries. For example, significant negative impacts of metal pollutants on human health have been recorded in Bangladesh, India and China, and it is claimed that millions of people are potentially at risk from metal contamination (Bhattacharya et al., 2012; Bolan et al., 2014). In several cities of China, nearly all the measured concentrations of metals in urban soils, urban road dusts and agricultural soils are higher than their background values (Wei and Yang, 2010). Likewise, the situation in the aquatic benthic environment is also less than optimistic (Akcil et al., 2015; Yang et al., 2016; Zhang et al., 2016).

In terrestrial systems, soil is the major repository of chemical contaminants. The basic material requirements of human beings also largely depend on the yield of land farming and management for survival and development. Metals retained in the soil by sorption, precipitation and complexation can undergo a series of processes such as plant uptake, leaching, volatilization, redox and (de)methylation (Boening, 2000; Porter and Scheckel, 2004; Lu et al., 2011). Because the residence of these pollutants in the soil is almost permanent and they cannot be disintegrated through organic activity, they not only can lead to crop yield and quality problems, but can also endanger the health of human beings and animals through direct exposure and the food chain (Adriano et al., 2004; Park et al., 2011a; Bolan et al., 2014).

In aquatic ecosystems, sediments are the major sink and source of pollutants and they play an important role in both the environment and ecology (Zhang et al., 2014). Once metals enter an aquatic system, almost 90% of these pollutants deposit onto sediment surfaces (Zhang and Shan, 2008; Amin et al., 2009) as result of adsorption, precipitation, flocculation and incorporation into the lattice structures of minerals (Akcil et al., 2015; Laing et al., 2009; Lin et al., 2013). However, if the benthic and water environmental parameters change, bound metals can be released from sediments to become more mobile and bioavailable (Westerlund and Viklander, 2006; Atkinson et al., 2007).

Thus, it is important to improve contaminants' stability and reduce their bioavailability and migration ability in natural matrixes. Conventional management or remediation methods for soil and sediments can involve *in-* and/or *ex-situ* planning (Akcil et al., 2015). In fact, many treatment strategies proposed for the remediation of metal-contaminated sediments stem from techniques developed for soil management (Akcil et al., 2015). Once sediments are dredged from aquatic benthic environments and subjected to pretreatment such as dehydration, the subsequent treatment planning is very close to that for soil remediation (Fig. 1), including washing, thermal treatment, electrolytic processes, solidification/stabilization and so on (Mulligan et al., 2001; Gomes et al., 2013). The main aim of those actions is reducing the concentration of contaminants and decreasing their properties of mobility and bioavailability; the interaction between metal characteristics and their bioavailability is shown in Fig. 2 (Bolan et al., 2014). Nevertheless, the conditions for *in-situ* treatments may be different between soil and sediment, because the processes of contaminant transport and their geochemical behaviors can be more complicated in aquatic benthic conditions than in soil. The limitation of using soil remediation strategies on sediment management is the efficiency and feasibility of procedures conducted in benthic conditions. However, studies and applications can still learn from the methods and techniques developed from soil management.

As an alternative approach, sorbent amendments and stabilization strategies can strengthen contaminant binding both in *ex-* and *in-situ* remediation, likely promoting biogeochemical processes and potentially reducing ecological risks (Cornelissen et al., 2005; Millward et al., 2005). Several mineral-based materials have already been studied to remedy

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