Biochar for the Remediation of Soils Contaminated with Potentially Toxic Elements

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Potentially Toxic Elements in Contaminated Soils

Soil contamination as a result of anthropogenic activities is a widespread problem globally, but can also have natural causes. Intensive industrial activities, inadequate waste disposal, mining, spills, along with diffuse contamination through atmospheric deposition and agriculture activities, can load soils with excessive amounts of potentially toxic elements (PTEs). These not only represent a threat to the environment but may also be taken up by plants and transferred into the food chain becoming a potential threat to human health[1,2]. Those of most concern include arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb), and zinc (Zn)[3,4].

Potentially toxic elements in soils are partitioned into a number of binding phases, incorporated in the solid phase, bound to the surface of the solid phase, bound to ligands in solution, and as free ions in solution (Figure 1). Only the free ions in soil solution are bioavailable and can be taken up by organisms.

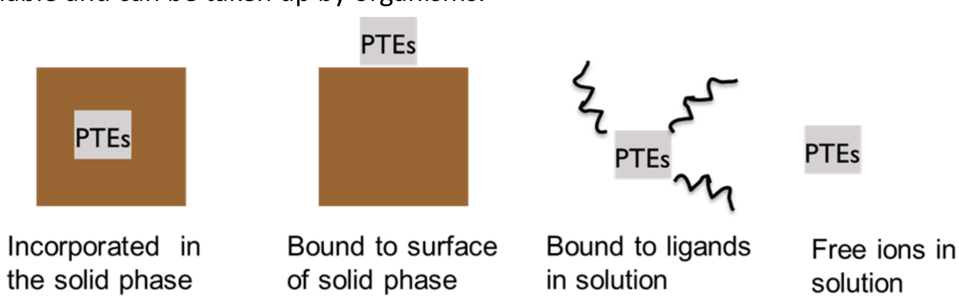

Figure 1. Partitioning of potentially toxic elements (PTEs) in soils.

Since PTEs cannot be broken down and an isolation of receptors is not possible in practical terms, the only viable option to break the source-pathway-receptor linkage is to disrupt the connection between the PTEs and the organism receptor (Figure 2). It is the manipulation of bioavailability rather than that of the absolute concentration in soils that is important to consider in terms of the application of remedial amendments to soils.

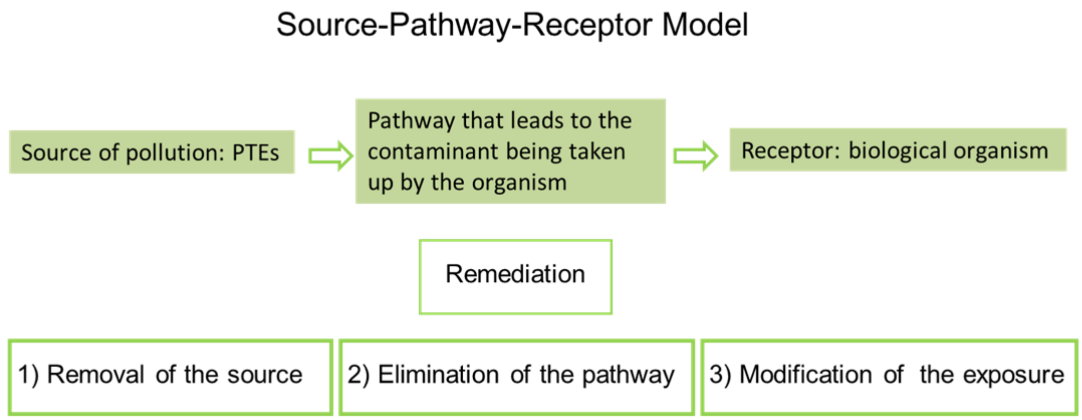

Figure 2. The source-pathway-receptor model and remediation options

Soil amendments, including biochar, are often applied to contaminated soils to immobilize potentially toxic elements thus reducing the risk of being taken up by organisms (e.g., acting on the pathway that leads to the contaminant being immobilized).

Biochar as a Remedial Amendment

- Most biochars have a greater surface area, and after aging can also have a greater cation exchange capacity than some soils, and are thus capable of increasing the retention of cationic PTEs in soil (Figure 3). Furthermore, by raising soil pH, biochars can also further enhance the immobilization of PTEs on soil minerals and organic matter.
- Biochars may also retain PTEs through more specific types of surface interactions (e.g., ligand exchange), and precipitation and redox reactions (Figure 3). Changes in pH caused by biochar will also influence these reactions.

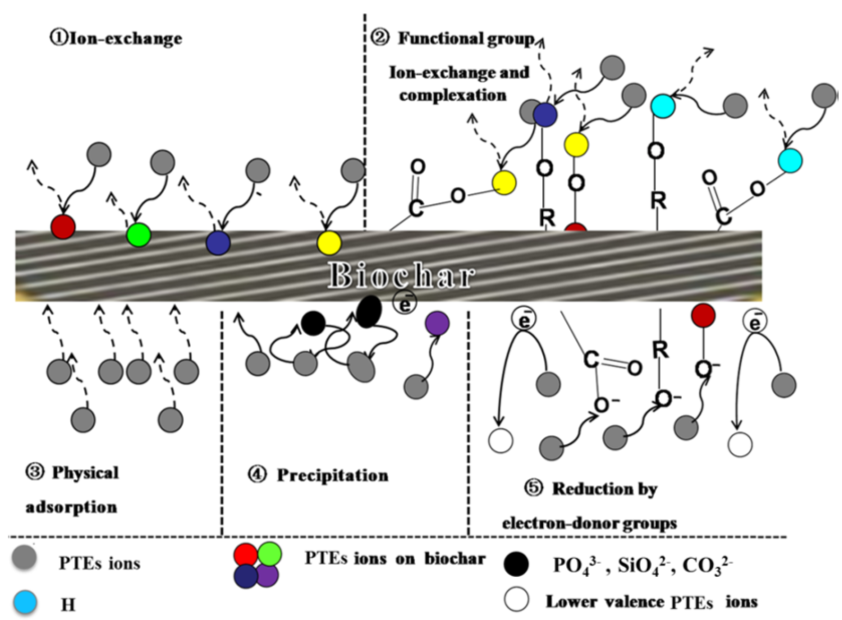

Figure 3. Diagrammatic representation of the possible adsorption mechanisms of potentially toxic elements (PTEs) on biochar (Zhang and Wang, unpublished)

- Biochar can assist re-vegetation in some contaminated soils by reducing phytotoxicity.
- Even though previous studies have demonstrated that biochars can be used as amendments to remediate PTEs-polluted soils, most of these studies were based on laboratory rather than field experiments. It is important to consider the biogeochemistry of the soils and geography of the site before biochar is applied for remediation purposes. A cost-benefit analysis may also be required to ensure other available amendments are not equally or more suitable than biochars.
- A tentative flow chart (Figure 4) may help identify the type of biochar to be used for the remediation of soil contaminated by a specific type of PTE. However, a good general understanding of retention mechanisms is needed prior to wide-scale deployment of biochar for remediation.

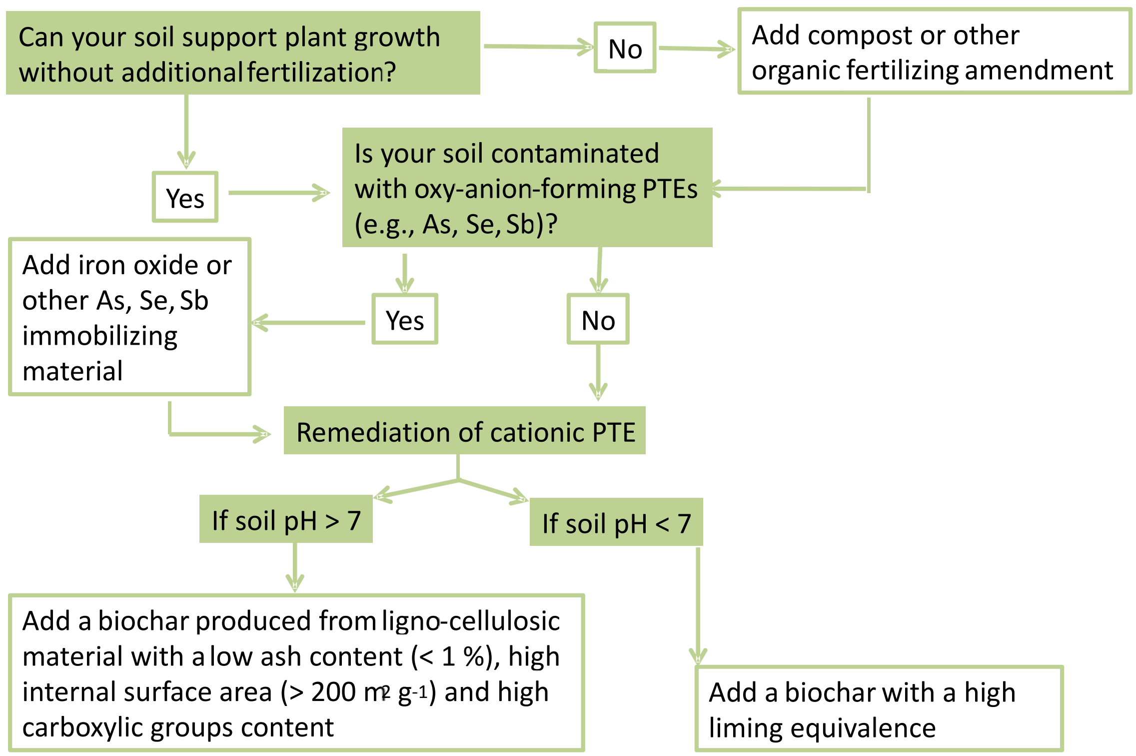

Figure 4. Tentative decision tree for soil remediation with biochar based on Beesley et al. (2011)[5] and modified by Camps Arbestain (unpublished).

Efficacy of Biochar to Reduce PTEs Mobility and Bioavailability

Numerous studies have shown that biochar application is effective in PTEs immobilization, thereby reducing the bioavailability and phytotoxicity of PTEs (Table 1). However, the effect of biochar on PTEs bioavailability varies with the types of biochar as well as with each PTE (Figure 4). Therefore, specific biochars need to be selected for specific purposes of remediation.

Table 1. Recent research on the effects of biochar application on the mobility and bioavailability of PTEs in soils

PTEs	Production temperature	Feedstock material	Effect	Reference
Cd	Not available	Bamboo	Removal of extractable Cd by 79.6% within 12 days.	6
Cd	450°C	Cotton stalks	Cadmium content of edible part and roots of *Brassica chinensis* were reduced by 49.43% to 68.29 %, and 64.14% to 77.66 %, respectively.	7
As	400°C	Hardwood	Significant reduction of As in the foliage of *Miscanthus*.	8
As, Cd, Cu, Zn	450°C	Hardwood	Reduction of Cd in soil pore water by 10 fold; Cd and Zn concentrations reduced by 300 and 45 fold respectively in column leaching tests.	9, 10
Cd, Cu, Pb	550°C	Chicken manure and green waste	Significant reduction of Cd uptake by Indian mustard.	11
Cd	500°C	Quail litter	Reduction of the concentration of Cd in physic nut (*Jatropha curcas* L.); reduction increased at increasing application rates.	12
Cu, Pb, Cd	Not available	Rice straw	Significant reduction in concentration of free Cu, Pb and Cd in contaminated soils.	13
Cr	550°C	Chicken manure	Enhanced reduction of Cr(VI) to Cr(III) in soil.	14
Cu, Pb, Cd	350°C	Peanut and canola straws	Increase in the adsorption of Cu, Pb and Cd by the soil amended with biochar.	15
Cd, Cu, Pb, Zn	750°C	Rice straw and bamboo	Decrease in concentration of extractable Cd, Cu, Pb and Zn.	16
Cd, Cu, Pb, Zn	500°C and 750°C	Rice straw and bamboo	Rice straw biochar was more effective than bamboo biochar in decreasing extractable PTEs in soil.	17

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