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Immobilization of Lead and Cadmium in Contaminated Soil Using Amendments: A Review

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ABSTRACT

Since the inception of industrial revolution, metal refining plants using pyrometallurgical processes have generated the prodigious emissions of lead (Pb) and cadmium (Cd). As the core target of such pollutants, a large number of soils are nowadays contaminated over widespread areas, posing a great threat to public health worldwide. Unlike organic pollutants, Pb and Cd do not undergo chemical or microbial breakdown and stay likely in site for longer duration after their release. Immobilization is an *in-situ* remediation technique that uses cost-effective soil amendments to reduce Pb and Cd availability in the contaminated soils. The Pb and Cd contamination in the soil environment is reviewed with focus on source enrichment, speciation and associated health risks, and immobilization options using various soil amendments. Commonly applied and emerging cost-effective soil amendments for Pb and Cd immobilization include phosphate compounds, liming, animal manure, biosolids, metal oxides, and biochar. These immobilizing agents could reduce the transfer of metal pollutants or residues to food web (plant uptake and leaching to subsurface water) and their long-term sustainability in heavy metal fixation needs further assessment.

Key Words: bioavailability, biochar, biosolids, heavy metal, public health, remediation, soil extraction

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INTRODUCTION

The contamination of land resources is a major worldwide concern as urban sprawl and industrial units are continuously rising and leaving negative ecological footprints on the natural environment (Wong and Li, 2004). Lead (Pb)- and cadmium (Cd)-contaminated soils are a global environmental concern that results not only in human health and ecological hazards, but also in huge economic implications with respect to reclamation and restoration costs (Semenzin *et al.*, 2007). Since the last few decades, the distribution and mobility of heavy metals in various soils have been documented. While few heavy metals are essential for living organisms in trace quantities, most are hazardous in high concentrations. Among the later, Cd and Pb, which are naturally present in soils, can accumulate in humans and cause serious health problems (Ok *et al.*, 2004).

Various unsustainable waste disposal practices have resulted in significant accumulation of a diverse range of toxic heavy metals including Cd and Pb. The contamination of toxic metals in food chain depends upon the source, dosage, rate, and magnitude of plant metal uptake, physico-chemical properties of soil, and the extent of absorption by animals (Adriano, 2001). Worldwide public now becomes vocal on the detrimental health implications to humans and the natural environment (Marshall, 2001). On a historical note in human health, metal toxicity has gained significant attention as a result of serial poisoning at a large scale; *i.e.*, a huge number of human poisoning tragic cases of Minamata disease due to consumption of contaminated fish by toxic metals were recorded, in Minamata Bay in Japan in the late 1950s (Knopf and König, 2010).

Many countries have recorded excessive Pb and Cd concentrations in their soils. Significant negative effects of Pb and Cd on human health have been noted in China, India, and Bangladesh with an alarming large number of populations at risk from toxic metals (Bhattacharya *et al.*, 2012). Cadmium is a serious concern for Australia and New Zealand, where it accumulates in offal of grazing animals and makes it unsuitable for human usage (Loganathan *et al.*, 2008). Likewise, Pb in soils resulting from unsustainable use as a compo-

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nent of herbicides and fungicides during urban development of horticultural sites is also an increasing concern there (Pietrzak and Uren, 2011).

Toxic heavy metals do not undertake chemical and microbial degradation and their total concentrations usually do not change due to their persistent nature after being released into the environment (Adriano *et al.*, 2004). As a result, the scientific community focuses immensely on the development of soil remediation technologies as global masses are increasingly vocal on the animal and human health implications resulting from contaminated soils. Soil remediation technologies are of special attention since conventional soil reclamation practices, *i.e.*, landfilling and excavation, are often very expansive and environmentally unfeasible, as compared to alternative options. Many soil amendment based-technologies such as soil immobilization/solidification are cost effective and less environmentally disruptive (Mulligan *et al.*, 2001; Kumpiene *et al.*, 2008).

Unlike organic pollutants which can be destroyed, heavy metals impair their toxicity and mobility by triggering the important immobilization process, *i.e.*, (ad)sorption, precipitation, complexation, and redox reactions, in the process of soil remediation (Adriano *et al.*, 2004). In addition, biological and chemical stabilization of toxic heavy metals using organic (*i.e.*, biosolids) and inorganic amendments (*i.e.*, phosphate compounds and lime) are suitable options to minimize metal bioavailability (Park *et al.*, 2011a). In the urban environment, as more localized toxic heavy metals are found, the process of metal stabilization including chemical washing and phytoextraction has been applied for remediation. For safe disposal of toxic metals from urban soil, phytoextraction process and the subsequent recovery are considered for commercial and research implications (Robinson *et al.*, 2009). However, when phytoextraction is ineffective, alternate options, *i.e.*, *in-situ* immobilization, are considered as important part of environmental management (Fig. 1). Both organic and inorganic soil amendments are components of remediation techniques applied to manage contaminated soils.

The immobilization of Pb and Cd in contaminated soils depends upon the local availability and financial implications of soil amendments. Therefore, the main question to be answered here in this review is that what types of amendments have been commonly employed and are emerging as cost-effective technologies to immobilize Pb and Cd in contaminated soils by significantly decreasing bioavailability of these metals.

SOURCES OF ENRICHMENT IN SOIL

Soil functions as a final sink for heavy metal contamination in terrestrial ecosystems. Both anthropogenic and pedogenic sources contribute to heavy metal loads in the soil environment. Most toxic trace elements are naturally present in the parent material of soil, mainly in forms that are not readily bioavailable for plant absorption or uptake as compared to those of pedogenic contribution by anthropogenic sources which have extreme bioavailability (Naidu *et al.*, 1996; Lamb *et al.*, 2009). Anthropogenic activities such as manufacturing industrial processes, usage of phosphorus (P) fertilizers, and disposal of domestic and industrial wastes are the main sources of toxic heavy metals

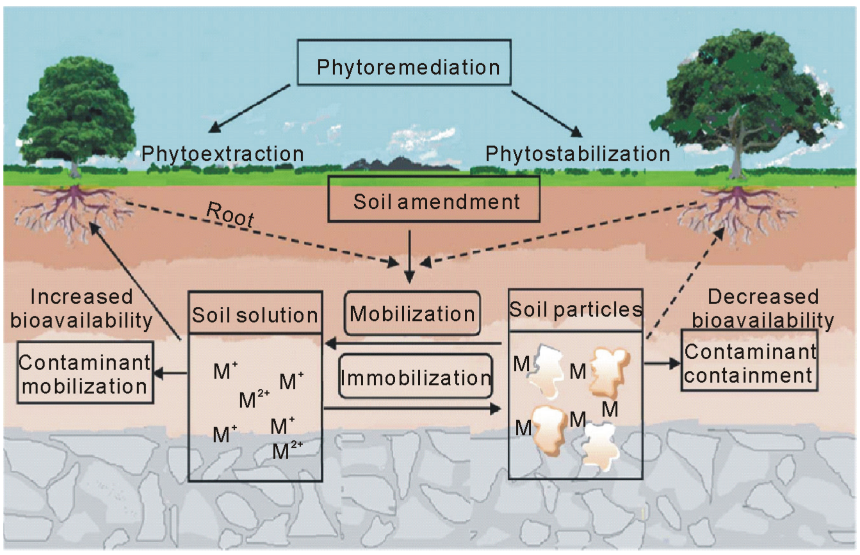

Fig. 1 Illustrative diagram showing the relationship between immobilization, bioavailability and remediation of toxic heavy metals (Bolan *et al.*, 2014). M = metal.