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Biomass and chemical amendments for enhanced phytoremediation of mixed contaminated soils

Reshma A. Chirakkara*, Krishna R. Reddy

University of Illinois at Chicago, Department of Civil and Materials Engineering, 842 West Taylor Street, Chicago, IL 60607, United States

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ABSTRACT

Pot experiments were conducted to investigate the impact of biomass amendments (biochar, compost and nutrient solution) and chemical amendments (Ethylenediaminetetraacetic acid (EDTA) and Igepal CA-720) on the phytoremediation of soil co-contaminated with organic and metal contaminants by *Helianthus annuus* (sunflower) and *Avena sativa* (oat plant). Mixed contaminated soil was prepared by mixing clean soil with naphthalene, phenanthrene, lead (Pb), cadmium (Cd), and chromium (Cr). To study the biomass amendments, soil was amended with biochar, compost, or a nutrient solution. To study chemical amendments, plants raised in contaminated soils were amended with a solution of EDTA, Igepal CA-720 or both. The combination of biomass and chemical amendments were studied by treating composted soil with either EDTA or Igepal CA-720. The results showed that the biochar and compost amendments improved the growth characteristics and biomass of the plants. Growth improvement was best observed for sunflower plants in composted soil. Average maximum plant height of sunflower in contaminated soil was increased by 115% with the addition of compost. Cd and Pb removal was best in the presence of biochar and compost amendments, but Cr removal was unaffected by the use of amendments. The best removal rate was observed for Pb by oat plant in compost amended soil, with average final Pb concentration decreased by 57.8% with the addition of compost to soil. Nutrient solution amendment did not improve the removal of the metal contamination from the soil. The overall growth and biomass were less for plants grown in soil that was treated with chemical amendments. A combination of compost and chemical amendments also did not provide positive results on the plant growth or contaminant dissipation. Polycyclic aromatic hydrocarbon (PAH) degradation improved in the presence of all of the amendments studied. The results suggest that biochar and compost amendments can improve the plant growth characteristics and enhance phytoremediation of mixed contaminated soils.

1. Introduction

Phytoremediation is a green, sustainable remedial option that can be adopted to remediate soil that is contaminated with a mixture of organic and metal contaminants (Reddy and Chirakkara, 2013). Phytoremediation is the use of plants to degrade (phytodegradation), extract (phytoextraction), and contain or immobilize (phytostabilization) contaminants from soil and water (Sharma and Reddy, 2004). The capability of the plants to uptake contaminants, survive in contaminated soil and the low bioavailability of the contaminants in the soil are some of the limiting factors that influence phytoremediation efficiency. Phytoremediation can be enhanced either by increasing the capability of contaminant uptake by the plant or amending the soil to increase the bioavailability of the contaminants. Plant uptake of contaminants can also be increased by the use of transgenic plants (Bhargava and Srivastava, 2014) or the inoculation of engineered entophytic bacteria (Bell et al., 2014).

By improving the growth of the plants, their water and nutrient uptake will be increased, which leads to increased contaminant uptake. Plant uptake of contaminants will also be affected by ion competition at the soil and plant level (Pilon-Smits, 2005). The addition of organic matter to the soil can improve the soil and increase the plant biomass in phytoremediation (Masciandaro et al., 2013). Biochar can immobilize metals in the soil through the surface sorption of the metals and also improve the biological activity in the soil (Beesley et al., 2011; Paz-Ferreiro et al., 2014). It can release essential nutrients that are beneficial for plant growth (Uchimiya et al., 2010). The biochar amendment of the soil can improve its water holding capacity and porosity and improve the soil structure to promote better plant growth (Karhu et al., 2011).

* Corresponding author.
E-mail addresses: reshmaac@gmail.com (R.A. Chirakkara), kreddy@uic.edu (K.R. Reddy).

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These properties make biochar a suitable option to amend soil in order to enhance phytoremediation. Only a limited number of researchers have addressed the combination of biochar application and phytoremediation for the remediation of metal contaminated soils (Karami et al., 2011; Fellet et al., 2014).

The addition of compost to the soil can improve plant growth as well as increase soil microbial activity (Ghanem et al., 2013). Compost is expected to immobilize the metal contaminants in the soil, thus plant germination and growth are expected to improve in composted soil (Alvarenga et al., 2014). A number of researchers in the past decade have examined the combination of phytoremediation with a compost application to the soil (Parrish et al., 2005; Wang et al., 2012; Clemente et al., 2006; Karami et al., 2011). Most of these studies concentrate on the enhanced biodegradation of organic compounds using the combined method. Vouillamoz and Milke (2001) showed that composting can improve plant growth and organic contaminant degradation by ryegrass (*Lolium perenne*).

Nutrient solutions were applied to the soil to improve the growth of plants for phytoremediation (Ahammed et al., 2013; Batty and Anslow, 2008). Even though NPK fertilizer application is expected to improve remediation due to improved plant biomass, there are instances of reduced concentration of metals in plants produced in fertilized soils due to increased yield (Chigbo et al., 2013). Even in that case, the total removal of metals from the soil was higher in fertilized than unfertilized soil. Most of the existing studies that involve nutrient applications do not concentrate on the effect of nutrient application on phytoremediation. In the present study, different soil treatments are compared, with and without nutrient application, to investigate the specific effect of nutrient solution in the growth and phytoremediation efficiency of plants.

The bioavailability of metals can decrease in the presence of organic contaminants and become a limiting factor in the phytoremediation of mixed contaminated soils (Batty and Dolan, 2013). Due to the low bioavailability of metals, the accumulation of metals by plants is less in the presence of organic contaminants (Chen et al., 2004; Kobyłecka and Skiba, 2008). The addition of chelating agents or surfactants to the soil can increase the metal bioavailability by desorbing it from the particle surfaces or by complex formation.

Research shows that the mobility of metals in the soil can be considerably increased by the addition of chelating agents. A number of natural and synthetic chelating agents are available, although their effectiveness varies with plant and soil types. The chelating agent used in the present study- EDTA is commonly used for increasing plant metal uptake of metals (Zaier et al., 2014; Huang et al., 1997).

Surfactants are the other group of chemicals that can assist in increasing the water solubility of contaminants, so they can be more easily accumulated by plants (Noordman et al., 2002; Mudler et al., 1998). These are biodegradable soil amendments for enhancing the bioavailability of the contaminants (Agnello et al., 2014). Most of the phytoremediation studies involving surfactants are conducted on soil contaminated solely with organic contaminants (Gao et al., 2007, 2008; Cheng et al., 2008). There are also instances where surfactants were used to improve the bio availability of metal contaminants (Ramamurthy and Memarian, 2012). Use of surfactants in co-contaminated soils can improve both phytoextraction and phytodegradation (Sun et al., 2013). Igepal CA-720, used in the present study, is a non-ionic surfactant used in previous studies where it was effective in removing phenanthrene from soils co-contaminated with nickel and phenanthrene (Khodadoust et al., 2004; Maturi et al., 2009).

Immobilization of the contaminants by biomass amendments can reduce phytoextraction efficienly (Karami et al., 2011). This can be overcome by supplementing the soil with chelating agents or surfactants after the plants have germinated and are established. To test this effect, the present study includes treatments where EDTA or Igepal CA-720 was applied periodically to composted soil, after the plants were established in the soil.

Naphthalene, phenanthrene, Pb, Cd, and Cr are the most common contaminants discovered at many mixed contaminated sites, such as abandoned industrial sites. The existing studies on enhanced phytoremediation do not address the typical contaminants of current interest. Of the existing studies that involve biochar and compost amendments, all were completed on soils contaminated with either metals or organic contaminants, not both although sites are likely to be co-contaminated. Some studies discuss the usage of compost, chelating agents or surfactants for enhancement of phytoremediation (Walker et al., 2003; Yang et al., 2005; Cheng et al., 2008). But, they do not consider the usage of a chelating agent or surfactant in the composted soil. The objective of this study is to fill some of the missed areas of research by comparing the germination rate, growth rate and phytoremediation efficiencies of *Avena sativa* (Oat plant) and *Helianthus annuus* (sunflower) in soils contaminated with a mixture of organic contaminants (naphthalene and phenanthrene) and heavy metals (Pb, Cd, Cr), and to investigate the possibilities of enhanced phytoremediation through the application of biomass amendments, chemical amendments, or a combination of both.

2. Materials and methods

2.1. Soil used

Gray silty clay, which represents typical Chicago glacial till, collected from Chicago area was selected for the pot experiments. Selected properties of the soil are presented in Table 1.

2.2. Soil spiking procedure

The clean control soil required for the pot experiment was prepared by mixing the soil with 15% tap water. Mixed contaminated soil was prepared by spiking the soil with naphthalene, phenanthrene, Pb, Cd, and Cr. For that, a measured amount of naphthalene and phenanthrene were dissolved in hexane using a magnetic stirrer, and once dissolved it was then mixed into a measured quantity of soil to produce a final concentration of 50 mg/kg naphthalene and 100 mg/kg phenanthrene in the soil. The mixed soil dried in a fume hood for 3–4 days. To ensure uniformity, the drying soil was mixed daily. After that, $PbCl_2$, $K_2Cr_2O_7$ and $CdCl_2 \cdot ½ H_2O$ were measured to produce a final concentration of 500 mg/kg Pb, 200 mg/kg Cr and 50 mg/kg Cd. These chemicals were mixed in water (to get approximate water content of 15% in soil) for 1 h using the magnetic stirrer before being added to the soil that was previously spiked with naphthalene and phenanthrene. The soil was again mixed well to ensure that the contaminant distribution was uniform.

Table 1
Properties of soil used for the experiments.

Property	ASTM Standards	Value
Soil organic content	ASTM D 2974	2.4%
Specific gravity	ASTM D 854	2.7
Water holding capacity	ASTM D 2980	46.4%
Liquid limit	ASTM D 4318	32.7%
Plastic limit	ASTM D 4318	19.1%
Plasticity index	ASTM D 4318	13.6%
Clay (<0.002 mm)	ASTM D 422	41%
Silt (0.002–0.05 mm)	ASTM D 422	43%
Sand (0.05–2 mm)	ASTM D 422	14.2%
USCS Classification		CL
USDA Classification		Silty clay