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Phytoremediation of contaminated soil with cobalt and chromium

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ABSTRACT

A phytoremediation trial was made to study the use of different plant species to extract Co and Cr out of contaminated soils. Five plant species tested in this study namely, Panikum (*Panicum antidotal*), Napier grass (*Pennisetum purpureum*), Squash (*Cucurbita pepo*), Cotton (*Gossypium hirsutum*) and Sunflower (*Helianthus annuus*) were grown on two different polluted soil types (Mostorud Clayey soil, irrigated with contaminated water for more than 30 years and El-Gabal EL-Asfar sandy loam soil, subjected to sewage effluent irrigation for more than 50 years) in a complete randomized block experimental design. Calculation of recovery percentage based on Co and Cr removed from the soil by whole plant after cultivation ranged between 13.8 and 43.7% and 17.0 to 41.6% of total initial Co and Cr, respectively. However, the percentage of Co and Cr removed by plant shoots from the total Co and Cr -removed by whole plant varied between 30.7 and 43.1% and 29.9 to 36.5% of the removed Co and Cr, respectively, whereas the lowest values were observed in case of Panikum for Co and Cr. As expected plant roots exhibited higher Co and Cr accumulation than in shoots by 1.32–2.25 and 1.7–2.34 folds, respectively. Sunflower roots showed the highest Co and Cr accumulation followed by Panikum and Napier grass then cotton and the least Squash roots. It is worth to mention, that roots tend to accumulate 56.9 to 69.3% and 41.2 to 70.1% of Co and Cr accumulated in plant biomass respectively.

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1. Introduction

Heavy metal pollution of soil is a global problem; it will transport to the soil around the repository and pose a great threat to the ecosystem, agro-system and people's health (Frostick et al., 2008; Garba et al., 2012). Many of these trace elements are toxic even at very low concentrations because of their non-biodegradable nature, long biological half-life, and potential to accumulate inside the living bodies (Behbahaninia et al., 2009). Excessive deposits of heavy metals in agricultural soils may not only result in soil contamination but also lead to elevated heavy metal uptake by crop plants affecting quality and safety of foods (Muchuweti et al., 2006). Therefore, cleaning up of polluted soils is a subject of utmost concern to human beings. In addition, diffuse contamination of large areas causes particular difficulties, since most classical engineering technologies directed at soil decontamination traditionally involve excavation of soil, and thus are expensive, invasive, and pose a threat to the nutritional and microbial balance of soil (Begonia et al., 1998; Garcia et al., 2004; Huang and Cunningham, 1996; Shen et al., 2002). As chemical hazards, heavy metals can remain almost indefinitely in the soil environment, however, their availability to biota can change considerably depending on their chemical speciation in the soil. The adequate protection and restoration of the soil ecosystems, therefore, require the characterization and remediation of soils that are contaminated with heavy metals (Nouri et al., 2008; Nwachukwu et al., 2010). The release of toxic heavy metals such as Chromium (Cr) and Cobalt (Co) into the environment is a serious pollution problem affecting soil and water qualities, therefore presenting a direct hazard to human health. Ions of chromium and cadmium which are frequently present in the wastewaters can cause renal dysfunction as well as chronic alterations in the nervous system and gastrointestinal tract (Santosh et al., 2012). In order to overcome these problems, one of promising strategies for treating the large scale, low-level contamination is use of plants to extract metals from soil (Phytoextraction) (Abdel-Sabour, 2007).

Phytoextraction is an environmentally sound and cost-effective technology for cleaning up soils contaminated with toxic metals. This technique has repeatedly been suggested as a novel clean-up technology. It has the potential to provide cost effective (January 2006), renewable alternatives to previously used remediation techniques while preventing the loss of topsoil which occurs through the excavation process (Blaylock et al., 1997). As suggested by Robinson et al. (2000), a different approach lies in the use of plants which are fast growing, deep-rooted, easily propagated and accumulate the target metal, combined with an increase of the phytoavailability of the metals in soil (Felix, 1997). Research has focused, therefore, on crops such as maize (*Zea mays*), tobacco (*Nicotiana tabacum*), Indian mustard (*Brassica juncea*), oat (*Avena sativa*), barley (*Hordeum vulgare*), pea (*Pisum sativa*),

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poplar (*Populus* spp.) and sunflower (*Helianthus annuus*) (Chen and Cutright, 2001; Dickinson and Pulford, 2005; Liphadzi et al., 2003; Wenger et al., 2002). Unfortunately, the main disadvantage of the phytoremediation techniques is the long time required for cleanup of metal contaminated soils (Lucian et al., 2011).

The success of phytoextraction depends on the ability of plants to produce large amounts of biomass. The success of phytoextraction also, is primarily dependent upon the bioavailability of the contaminants of concern for plant uptake. In addition, plants must be tolerant to the target metals and be efficient to translocate metals from roots to the aboveground organs. The effectiveness of phytoextraction also depends upon site and metal species. However, the amount of metals extracted by plants is basically decided by (1) the metal concentration in dry plant tissues and (2) the total biomass of the plant. Certain varieties of high-biomass crops have been found to have the ability to clean up the contaminated soils. When phytoextraction is practiced, metal-accumulating plants are seeded or transplanted into metal polluted soil and are cultivated according to the established agricultural practices. The roots of established plants absorb metal elements from the soil and translocate them to the aboveground shoots where they accumulate. After sufficient plant growth and metal accumulation, the aboveground parts of the crop are harvested and removed from the contaminated site. This technology is applicable only to sites that contain low to moderate levels of metal pollution, because plant growth is not sustained in heavily polluted soils.

The aim of the present work is to investigate the potential and the engineered use of five plant species (Panikum (*Panicum antidotal*), Napier grass (*Pennisetum purpureum*), Squash (*Cucurbita pepo*), cotton (*Gossypium hirsutum*) and sunflower (*H. annuus*)) to extract Co and Cr from contaminated soils.

2. Materials and methods

2.1. Soil sampling preparation and analysis

Two soil samples were chosen from different contaminated locations at north greater Cairo, Egypt — to represent two different soil types (alluvial and sandy) as well as two different sources of contaminated wastewater (sewage and industrial effluent) as follows: (A) Clayey polluted soil from the Mostorud area (irrigated with contaminated water for more than 30 years due to direct discharge of industrial wastewater to irrigation water canals). (B) Sandy polluted soil from the El-Gabal El-Asfar farm (subjected to sewage effluent irrigation for more than 50 years). Surface soil samples were collected (*i.e.* 0–20 cm). The samples were air-dried, crushed to pass a 2.0 mm sieve and then analyzed for main physical and chemical properties.

Soil texture was determined by the Bouyoucos hydrometer method. The moisture content of soil was calculated by the weight difference before and after drying at 105 °C to a constant weight. The pH and electrical conductivity (EC) were measured after mixing samples vigorously 20 min at 1: 2.5 solid: deionized water ratio using digital meters (Elico, Model LI-120) with a combination pH electrode and a 1-cm platinum conductivity cell respectively. Cation exchange capacity (CEC) was determined after extraction with ammonium acetate at pH 7.0 and the organic carbon was determined by using the Walkley–Black method (Jackson, 1973). Available Co and Cr were determined by the DTPA method according to Lindsay and Norvell (1978). For total soil Co and Cr determinations, 0.5 g of dried soil was digested with 4 ml of concentrated sulfuric acid (~7 min) and subsequently with 10 ml of a H_2O_2 solution (50% w/w in H_2O) at 440 °C (~12 min). Then, the digest was diluted to 100 ml with deionized water. Total Co and Cr contents were determined by using an inductively coupled plasma (ICP) technique. Table 1 shows some physical and chemical properties of the tested soil samples. Table 2 shows Co and Cr total contents and extractable DTPA of heavy metals (mg/kg) in studied soil.

Table 1
Some physical and chemical Properties of the investigated soils.

Soil prosperities	Mostorud	El-Gabal El-Asfar
Soil separates, %		
Sand	31.49	79.83
Silt	24.31	0.84
Clay	44.20	19.33
pH*	6.74	6.91
EC**, dS/m	8.43	1.23
CaCO3 (%)	1.60	0.70
OM (%)	7.99	6.17
CEC, mmol/100 g^{-1} soil	37.44	13.26
Soluble ions, mmol$_c$/L^{-1}		
Ca^{++}	34.7	3.5
Mg^{++}	24.1	2.4
Na^{+}	22.9	5.2
K^{+}	2.6	1.2
SO_4^{-}	62.4	2.0
HCO_3^{-}	4.4	6.3
Cl^{-}	17.5	4.0

CEC, cation exchange capacity; EC, electrical conductivity; OM, organic matter.
* In the soil water suspension(1: 2.5).
** In the extract of saturated soil paste.

2.2. Experimental setup

A pot experiment was carried out to investigate the potential use of plants to extract Co and Cr from polluted soils. Five kg of each air-dried surface soil sample (0–20 cm) were packed in plastic containers (20 cm internal diameter and 20 cm height) with three replicates. The 5 plant species were grown on each tested soil and arranged in a complete randomized block experimental design. The tested plant species were in this study namely, Panikum (*P. antidotal*), Napier grass (*P. purpureum*), Squash (*C. pepo*), Cotton (*G. hirsutum*), and Sunflower (*H. annuus*). Nitrogen and phosphorus fertilizer doses were applied to each soil before the cultivation of the plants at the recommended rates. Ten seeds per pot were planted. After 7 days, the seedlings were thinned to 5 plants/pot. The soils were irrigated to maintain soil moisture at about 80% of the soil field capacity during the 2 month (8 weeks) growth period of the experiment. To prevent loss of nutrients and trace elements out of the pots, plastic trays were placed under each pot and the leachates collected were put back in the respective pots.

Plant shoots were harvested after 60 days (8 weeks) by cutting the stems approximately 2 cm above the soil surface. The roots were collected, sieved to get rid of soil particles and washed with running water and distilled water. Another soil sample was taken for total Co and Cr content analyses. Plant samples (shoots and roots) were dried at 60 °C to a constant weight, grounded into fine powder, sieved with a 2 mm wire mesh. 0.5 g of the powdered samples was digested with 4 ml of concentrated sulfuric acid (~7 min) and subsequently with 10 ml of a H_2O_2 solution and analyzed for Co and Cr concentrations using an inductively coupled plasma (ICP) technique.

Table 2
Initial total content and extractable DTPA of heavy metals, mg kg^{-1}, in investigated soils.

Heavy metals	Samples location	
	Mostorud	El-Gabal
Total content (mg $^{-1}$)		
Co	146	83
Cr	213	148
Extractable content (mg kg^{-1})		
Co	0.9	1.4
Cr	3.8	5.4