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How to decontaminate soil using garden cress: A case study

L. F. Pures[1,*], M. Ihlam[2]

[1] *Department of Soil, University of Ponta Grossa, PR, Brasil*
[2]*National Fertilizer Development Center, Islamabad, Pakistan*

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ABSTRACT

In this paper phytoremediation of lead from soil by garden cress is investigated according to randomized complete block design. Phytoremediation is an environmental friendly method for large-scale cleanup of contaminated water and soil. Every plant sample has been put in pots containing five kg of surface soil (0 to 10 cm). The experiment consisted of four treatments, including 0 (control, T1), 75 (T2), 150 (T3) and 300 (T4) mg.Kg-1 lead added to the soil samples. After 30 days, in the Lepidium sativum L. under the treatments, the concentration of extractable lead (ppm) in roots under T1, T2, T3 and T4 were 0.00, 14.01, 27.69, and 52.62, respectively. And the concentration of extractable lead (ppm) in shoots under T1, T2, T3 and T4 were 0.00, 6.92, 13.11, and 20.25, respectively. The evidences provided by this experiment indicated that the Lepidium sativum L. was capable of accumulating the lead preferentially from soil. This result also showed that the maximum remediation of lead was in T4 by Lepidium sativum L., and the potential of Lepidium sativum L. for phytoremediation increased with increasing lead concentration to 300 (ppm).

1. Introduction

One of the major problems the industrialized world is facing today is the contamination of soil, groundwater, sediments, surface water and air with hazardous and toxic chemicals (Achal et al., 2011). The presence of heavy metals in the environment has brought about a number of environmental problems (Yeneneh et al., 2011). In recent times, the occurrence of metal contaminants especially the heavy metals in excess of natural loads has become a problem of increasing concern. This situation has arisen as a result of the rapid growth of population, increased urbanization and expansion of industrial activities, exploration and exploitation of natural resources, extension of irrigation and other modern agricultural practices as well as the lack of environmental regulations (Ndimele and Jimoh, 2011).

Bioremediation is one of the most economical alternatives for soil and aquifer restoration. This technique includes phytoremediation which uses the capacity of certain plant species to survive in environments contaminated with heavy metals and organic substances while extracting, accumulating and immobilizing or transforming the contaminants by altering its molecular structure. Phytoremediation has become a topical research field in the last decade as it is safe and potentially cheap compared to traditional remediation techniques (Cruz-Landero et al., 2010).

Garbisu and Alkorta (2001) reviewed one phytoremediation category, phytoextraction, for its ability to remove heavy metals from soil using its ability to uptake metals, which are essential for plant growth (Fe, Mn, Zn, Cu, Mg, Mo and Ni) (Quoted by Cho-Ruk et al., 2006).

1.1. Heavy Metals

Strictly speaking, heavy metals are defined as those with higher density than 5 mg mL-1 but the collective term now includes arsenic, cadmium, chromium, copper, lead, nickel, molybdenum, vanadium and zinc. Some interest also exists in aluminum, cobalt, strontium and other rare metals. Physiologic roles are known for iron (haemmoeties of hemoglobin and cytochromes), copper (amine oxidases, dopamine hydrolase and collagen synthesis), manganese (super-oxide dismutase), and

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[*] Corresponding author.
E-mail address: L.F.Pires@gmail.com (L. F. Pires)

zinc (protein synthesis, stabilization of DNA and RNA) with low requirements of chromium (glucose homeostasis). Other heavy metal ions are not believed to be essential to health even in trace amounts (Suruchi and Khanna, 2011).

Absorption and accumulation of heavy metals in plants are influenced by many factors, including: Concentration of heavy metals in soil, composition and intensity of atmospheric deposition, including precipitations, phase of plant vegetation. To all of these, can be added other sources generated by agricultural technologies such as: irrigation with wastewater, the administration of organic and mineral fertilizers with the load of heavy metals, or application of pesticides, which contain in their structure such as chemical elements (Atlabachew et al., 2011).

1.2. Lead (Pb)

The primary processes influencing the fate of lead in soil include adsorption, ion exchange, precipitation, and complexion with sobbed organic matter. These processes limit the amount of lead that can be transported into the surface water or groundwater. The relatively volatile organ lead compound tetra methyl lead may form in anaerobic sediments as a result of alkylation by microorganisms (Evanko and Dzombak, 1997).

Heavy metals when present at an elevated level in soil are absorbed by the root system, accumulate in different parts of plants, reduce their growth and impair metabolism (Seregin and Ivanov, 2001). Among heavy metals, Pb is the major contaminant of soil. Lead absorption by roots from soil occurs via the plasma membrane, probably involving cationic channels such as calcium channels. Lead absorption is regulated by pH, cation exchange capacity of soil, organic matter contents, type of plant species as well as by exudation and physicochemical parameters (Kibria et al., 2010).

1.3. Plants metal taking up and transportation

Soluble metals can enter into the root symplast by crossing the plasma membrane of the root endodermal cells, or they can enter the root apoplast through the space between cells. While it is possible for solutes to travel up through the plant by apoplastic flow, the more efficient method of moving up the plant is through the vasculature of the plant, called the xylem. To enter the xylem, solutes must cross the Casparian strip, a waxy coating, which is impermeable to solutes, unless they pass through the cells of the endodermis. Therefore, to enter the xylem, metals must cross a membrane, probably through the action of a membrane pump or channel. Once loaded into the xylem, the flow of the xylem sap will transport the metal to the leaves, where it must be loaded into the cells of the leaf, again crossing a membrane. The cell types where the metals are deposited vary between hyperaccumulator species. For example, T. caerulescens was found to have more Zn in its epidermis than in its mesophyll, while A. halleri preferentially accumulates its Zn in its mesophyll cells instead of its epidermal cells (Peer et al., 2005).

1.4. Contaminated Soil

Soil consists of a mixture of weathered minerals and varying amounts of organic matter. Most lead that is released to the environment is retained in the soil. Sources of heavy metal contaminants in soils include metalliferous mining and smelting, metallurgical industries, sewage sludge treatment, warfare and military training, waste disposal sites, agricultural fertilizers and electronic industries (Padmavathiamma and Li, 2007).

1.5. Phytoremediation

Phytoremediation is an emerging technology, environmental friendly method for large-scale cleanup of contaminated water and soil (Jayashree et al., 2011). Phytoremediation is a developing technology that can potentially address the problems of contaminated agricultural land or more intensely polluted areas affected by urban or industrial activities. Three main strategies currently exist to phytoextract inorganic substances from soils using plants:(1) use of natural hyper accumulators; (2) enhancement of element uptake of high biomass species by chemical additions to soil and plants; and (3) phytovolatilization of elements, which often involves alteration of their chemical form within the plant prior to volatilization to the atmosphere. It is important to select an appropriate pioneer plant species for successful site reclamation and in phytoremediation efforts to ensure a self-sustainable vegetative cover (Mojiri, 2011).

Cho-Ruk et al. (2006) investigated perennial plants in the phytoremediation of Lead-contaminated soils. Their results showed that A. philaxeroides had the ability to extract an approximately 1.3-1.8 times greater amount than P. grandiflora and S. procumbens.

Chehregani et al. (2009) studied phytoremediation of heavy-metal-polluted soils: Screening for new accumulator plants in Angouran mine (Iran) and evaluation of removal ability, the study showed that the amounts of heavy metals in the root, leave and shoot portions of N. mucronata varied significantly but all the concentrations were more than natural soils. The results indicated N. mucronata is an effective accumulator plant for phytoremediation of heavy-metals polluted soils.

1.6. Types of Phytoremediation Technology

The five different plant-based technologies of phytoremediation, each having a different mechanism of action for remediating metal-polluted soil, sediment or water (Table 1): (1) **Phytoextraction**: Plants absorb metals from soil through the root system and translocate them to harvestable shoots where they accumulate. Hyperaccumulators mostly used this process to extract metals from the contaminated site. The recoveries of the extracted metals are also possible through harvesting the plants appropriately. (2) **Phytovolatilization**: Plants used to extract certain metals from soil and then release them into the atmosphere by volatilization.

(3) **Phytostabilization**: In this process, the plant roots and microbial interactions can immobilized organic and some inorganic contaminants by binding them to soil particles and as a result reduce migration of contaminants to grown water. (4) **Phytofiltration**: Phytofiltration is the use of plants roots (rhizofiltration) or seedlings (blastofiltration) to absorb or adsorb pollutants, mainly metals, from water and aqueous waste Streams (Sarma, 2011). (5) **Phytotransformation**: Phytotransformation refers to the uptake of organic and nutrient contaminants from soil and groundwater and the subsequent transformation by plants. Phytotransformation depends on the direct uptake of contaminants from soil water and the accumulation of metabolites in plant tissue. For environmental application, it is important that the metabolites which accumulate in vegetation be non-toxic or at least significantly less toxic than the parent compound (Schnoor, 1997).

Table 1. Phytoremediation includes the following processes and mechanisms of contaminant removal (Ghosh and Singh, 2005)

No.	Process	Mechanism	Contaminant
1	Phytoextraction	Hyper-accumulation	Inorganics
2	Phytovolatilization	Volatilization by leaves	Organics/Inorganics
3	Phytostabilisation	Complexion	Inorganics
4	Rhizofiltration	Rhizosphere accumulation	Organics/Inorganics
5	Phytotransformation	Degradation in plant	Organics

1.7. Lepidium sativum L

The Lepidium sativum L. (family-Brassicaceae) is a native shrub. The Lepidium sativum (L.) seeds contain volatile essential aromatic oils, active principle and fatty oils and carbohydrate, protein, fatty acid, Vitamin: β-carotene, riboflavin, and niacin, and ascorbic acid, Flavonoids, Isothiocynates glycoside2. The Lepidium sativum L. seeds are used as aperients, diuretic, good anti-inflammatory, demulcent, aphrodisiac, carminative, galactagogue, antiasthematic, antiscorbutic, and stimulant (Yadav et al., 2010). Some literature (Khodaverdiloo and Homai, 2008; Khodaverdiloo et al., 2008) reported; Lepidium sativum L is an accumulator plant that can be used for phytoremediation.

The aim of this study was to investigate the phytoextraction of lead from soil by Lepidium sativum L.

2. Materials and methods

2.1. Sample preparation

A study was carried out to investigate the phytoremediation of lead from soil by Lepidium sativum L. according to randomized complete block design. Every Lepidium sativum L. plant was put in pots containing 5 Kg of surface soil (0 to 10 cm). The experiment consisted of four treatments including 0 (control, T1), 75 (T2), 150 (T3) and 300 (T4) mg Kg-1 lead added to the soil samples. After 30 days, the samples were taken for testing. The plant tissues were prepared for laboratory analysis by Wet Digestion method (Campbell and Plank, 1998). Soil samples were air dried in a greenhouse at a temperature between 25ºC and 30ºC and sifted through a 2-mm mesh sieve for preparation of soil samples (Mojiri and Amirossadat, 2011).

2.2. Laboratory determinations

Soil reaction (pH) and electrical conductivity (EC) were measured on 1:1 extract (Soil: Water). Heavy metals in soil and plant samples were carried out by DTPA in accordance the Standard Methods (APHA, 1998). Soil properties are shown in Table 2.

Table 2: Soil Properties

pH	EC ($dS.m^{-1}$)	Clay (%)	Sand (%)	TN (%)	P ($me.L^{-1}$)	Fe (ppm)	Pb (ppm)
7.03	1.04	11.9	45.2	0.06	11.6	2.08	0.0

2.3. Statistical analysis

Descriptive statistical analysis including mean comparison using Duncan's Multiple Range Test (DMRT) (in 0.05 level) was conducted using SPSS software.

3. Results and discussion

Tables 3 and 4 have shown comparing the means of treatments in soil and Lepidium sativum L., respectively.

Table 3: Comparing the Means of Treatments in Soil

Treatments	Pb (ppm)
T1	0.00a
T2	45.03b
T3	82.78c
T4	155.92d

3.1. Lead concentration in soil

According to Table 3, The Pb (ppm) concentration was in soil under T1, T2, T3 and T4 after 30 days in order of 0.00, 45.03, 82.78 and 155.92, respectively.

According to Table 3, it was clear that the concentration of Pb significantly decreased in the planted soil after 30 days cultures. The most decreasing Pb was in soil under T4 by 48%. The decreasing of Pb (ppm) was in soil under T2, T3 and T4 in order of 29.97, 67.22 and 144.08.

3.2. Lead concentration in Lepidium sativum L

The biggest challenge to effective phytoremediation of Pb is its extremely low solubility, as only ~0.1% of soil Pb is available for extraction. Efforts at phytoremediation of Pb have concentrated on using soil amendments like EDTA to increase the available Pb uptake. Addition of chelators does increase the solubility and uptake, but the amount Pb transferred to shoots is still low in comparison to the amount of Pb in the soil, and increases the likelihood that the mobilized Pb-EDTA will leach out of the soil and contaminate groundwater (Peer et al., 2005).

According to Table 4, The Pb (ppm) concentration was in roots under T1, T2, T3 and T4 after 30 days in order of 0.00, 14.01, 27.69 and 52.62, respectively. The Pb (ppm) concentration was in shoots under T1, T2, T3 and T4 after 30 days in order of 0.00, 6.92, 13.11 and 20.25, respectively.

Accumulation of lead in roots is higher than in shoots. This result showed that the root of Lepidium sativum L. is more active than shoot to phytoremediation of lead. This is in line with finding of Mojiri (2011) and Xiao et al. (2008). According to Table 2 and 3, increasing soil contamination to 300 (ppm) increased phytoremediation of lead from soil by *Lepidium sativum* L.

As a plant-based technology, the success of phytoextraction is inherently dependent on several plant characteristics, the two most important being the ability to accumulate large quantities of biomass rapidly and the capacity to accumulate large quantities of environmentally important metals in the shoot tissue (Padmavathiamma and Li, 2007).

Khodaverdi and Homai (2008) investigated modeling of phytoremediation of soil contaminated with cadmium and lead. Their results showed that the increasing soil contamination with Pb increased phytoremediation of Pb from soil by *Barbarea verna* and *Spinacia Oleracea* L. but increasing soil contamination with Cd did not change phytoremediation of cadmium from soil by *Barbarea verna* and *Spinacia Oleracea* L.

Table 4: Comparing the Means of Treatments in Lepidium sativum L

Treatments	Root/ Pb (ppm)	Shoot/ Pb (ppm)
T1	0.00a	0.00a
T2	14.01b	6.92b
T3	27.69c	13.11c
T4	52.62d	20.25d

Paz-Alberto et al. (2007) investigated phytoextraction of lead-contaminanted soil using vetivergrass (*Vetiveria zizanioides* L.), cogon grass (*Imperata cylindrica* L.) and caraboa grass (*Paspalum conjugatum* L.). Their result showed that levels of Pb among the three grass (shoots + roots) did not vary significantly with the amount of Pb added (75 and 150 mg/kg) to the soil. Vetivergrass yielded the highest biomass; it has also the greatest amount of Pb absorbed (roots + shoots). This can be attributed to the highly extensive root system of vetivergrass with the presence of the enormous amount of root hairs. The present study indicated that vetivergrass possessed many beneficial characteristics to uptake Pb from contaminated soil. It was the most tolerant and could grow in soil contaminated with high Pb concentration. Cogon grass and carabao grass are also potential phytoremediators since they can absorb the small amount of Pb in soils, although cogongrass is more tolerant to Pb-contaminated soil compared with carabaograss. The important implication of our findings is that vetivergrass can be used for phytoextraction on sites contaminated with high levels of heavy metals, particularly Pb.

4. Conclusion

Contaminated soils and waters pose a major environmental and human health problem, which may be partially solved by the emerging phytoremediation technology. This result showed that the *Lepidium sativum* L is an effective accumulator plant for phytoremediation of lead polluted soils. The maximum remediation of lead was in T4 Lepidium sativum L., and the potential of Lepidium sativum L. for phytoremediation increased with increasing lead concentration to 300 (ppm). Accumulation of lead in roots was more important than in shoots.

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