The Potential of *Chrysanthemum* and *Pelargonium* for Phytoextraction of Lead - Contaminated Soils

W. S. Abdullah [1] ***and S. M. Sarem*** [1]

Department of Civil Engineering, Jordan University of Science and Technology, Irbid, Jordan

ABSTRACT

Phytoremediation is a set of technologies that uses plants to clean up contaminated soils and groundwater. Phytoremediation is environmentally friendly, successful and cost-effective compared to other *in situ* methods such as the electrokinetic method. In this work, two local plant species, *Chrysanthemum* and *Pelargonium*, were examined for their ability to uptake lead from lead contaminated soils (1000 ppm). Additionally, two types of soils were used for the phytoremediation study. The first soil was a silty clay soil, and the second was a carefully designed mixture of commercially available peat moss (33%), peyrlaite (16%), sand (16%), clay (17%) and organic "manure" fertilizer (18%). Commercially available pots as well as especially designed and manufactured pots were used for the phytoremediation experiments. *Chrysanthemum* showed greater potential for lead accumulation than *Pelargonium*. *Chrysanthemum* reduced lead from about1000 ppm to about 276 ppm in the soil in five months only. Most of the lead was found in the roots of the plant (73%), while 11%, 9% and 7% was found in the stems, leaves and flowers, respectively. *Pelargonium*, however, was not as effective as *Chrysanthemum*. *Pelargonium* reduced lead concentrations from about 1400 ppm to about 900 ppm.

KEYWORDS: Phytoremediation, Phytoextraction, Lead, *Pelargonium, Chrysanthemum.*

INTRODUCTION

Phytoremediation is the process of using plants to extract pollutants from contaminated soils as well as groundwater. Phytoextraction, also known as phytoaccumulation, refers to the uptake and translocation of metal contaminants in soils by plant roots into other parts of the plants.

The major aspects of significance of the phytoremediation technology are: low operational cost, *in situ* application, not requiring excavations or use of machinery, being less disruptive, large scale clean-up operations, high public acceptance due to the pleasant visual nature of plants. This technology is cost-effective and environmentally friendly. Many plant species have been successful in absorbing contaminants such as lead, cadmium, chromium, arsenic and various radionuclides from soils (Baker et al., 2000; Chrysafopoulou et al., 2005; Marchiol et al., 2004). Garbisu and Alkorta (2001) reviewed the competence of plants (using the phytoextraction process) to remove pollutants from soils.

Heavy metals cannot be destroyed biologically but are only transformed from one oxidation state or organic complex to another. The most common heavy metal contaminants are: Ni, Cd, Cr, Cu, Hg, Pb, Co and Zn. Contamination results from industrial activities such as mining, smelting of metalliferous ores, electroplating, gas exhaust, energy and fuel production, fertilizer and pesticide application and generation of municipal wastes.

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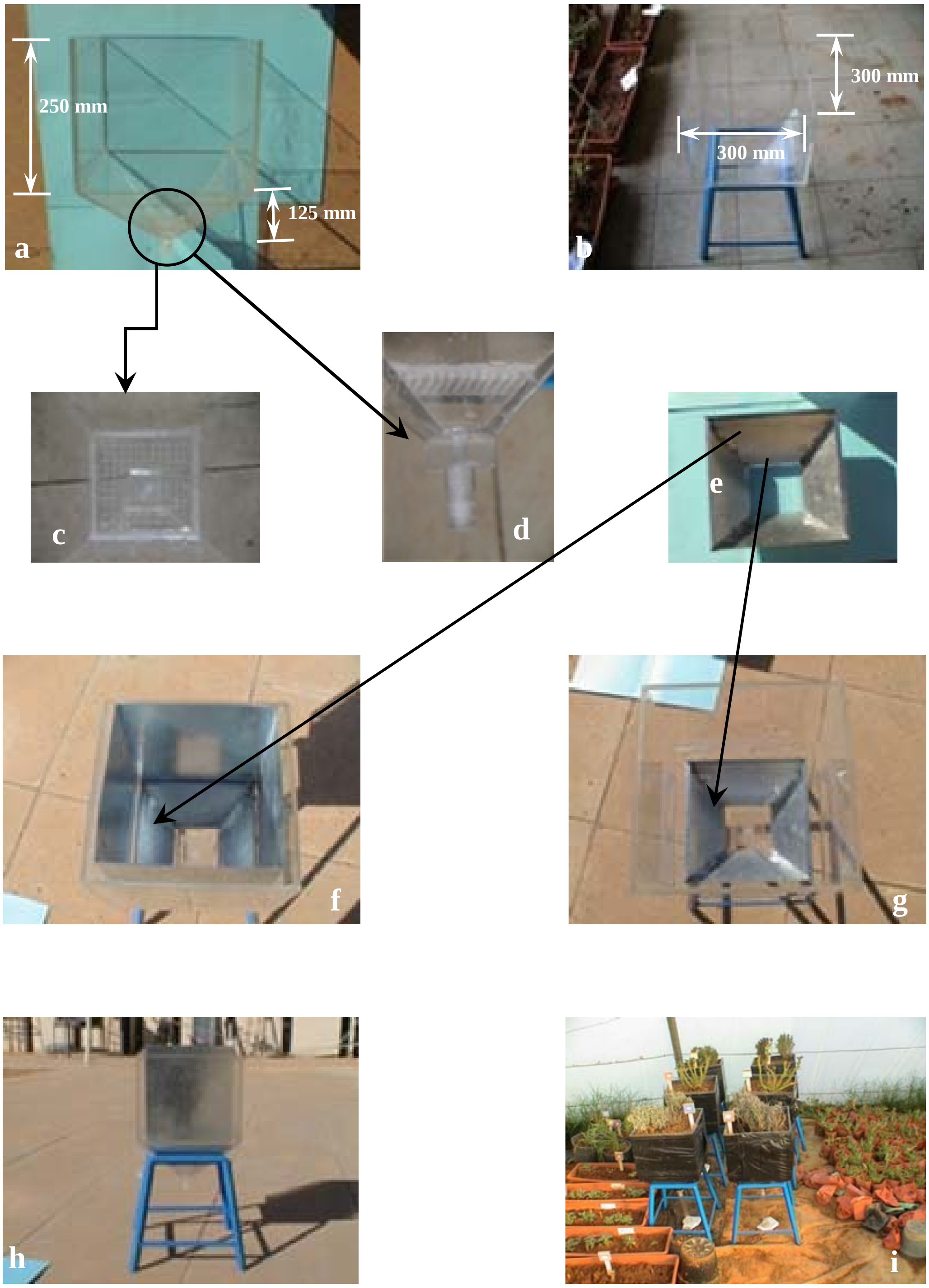

Figure 1: Designed pots; (a) soil compartment, (b) pot with carrier frame (c) perforated platter (d) filtration system, (e), (f), (g) and (h) galvanized steel components, (i) planted pots (Sarem, 2006)

In soils, metals may be found; (1) in soil water as free metal ions and soluble metal complexes; (2) as exchangeable cations adsorbed on clay mineral surfaces to satisfy electrical neutrality; (3) bound to soil organic matter; and (4) precipitated such as oxides, hydroxides and carbonates.

For phytoextraction to function, contaminants must be bioavailable (ready to be absorbed by roots). Bioavailability depends on metal solubility in soil solution. Only metal ions in soil water and in exchangeable positions are readily available for plant uptake. Some metals, such as Zn and Cd, occur primarily in exchangeable form; i.e. readily bioavailable form. Others, such as Pb, occur as precipitates; a considerably less bioavailable form. Therefore, Pb is very difficult to remove. The capacity of a soil to adsorb Pb increases with increasing pH, cation exchange capacity, organic carbon content, soil/water ratio and phosphate levels (United States Environmental Protection Agency, 1992).

Indian mustard (*B. juncea*) has been used for the phytoremediation of lead and other metals (Huang et al., 1997). Chen et al. (2000) studied the effects of different concentrations of Pb on the uptake and accumulation of this element by the roots and shoots of *B. juncea*. Their results showed that *B. juncea* has a considerable ability to remove Pb and accumulate it. However, *B. juncea* transported and concentrated only a small amount of Pb in shoots.

SCOPE OF THE WORK

The scope of the present work covers evaluating the competence of *Pelargonium* and *Chrysanthemum* to clean up grounds contaminated with lead using the phytoextraction process.

MATERIALS AND METHODS

The parameters investigated in this work were: type of plant, type of soil and type of planting pots.

Types of Plants Used

Two types of plants were used for the experimentation; they were *Pelargonium* and *Chrysanthemum*. *Chrysanthemum* was planted in a silty clay soil obtained from the "JUST" campus site. *Pelargonium* was planted in a well designed mixture of sand, clay, peat moss, peyrlaite and organic fertilizer.

Soil Preparations

The first soil was obtained from the Jordan University of Science and Technology "JUST" campus site. Roots and other foreign materials were removed, and then the soil was air-dried and sieved on sieve #4. Prepared soil was spiked with the contaminant, then mixed thoroughly before planting (Sarem, 2006).

The second soil was a well designed mixture of peat, peyrlaite, sand, clayey soil taken from JUST campus site and organic fertilizer. It was prepared with the following proportions (by volume): 33%, 16%, 16%, 17% and 18%, respectively. The peat was a leaves' substrate and was imported from Novagro Company of Finland.

Planting Pots

The first type of pot was designed to provide the plants with favourable living, growing and thriving conditions. The pots were manufactured at the Workshop of the Jordan University of Science and Technology. The pots were made of plexiglas (8 mm thick) in pyramidal shape, with 300mm by 300mm dimensions of the base, 250mm depth and 125mm height of the pyramidal shape (Fig. 1). Each pot was provided with a filtration system consisting of: a filter paper perforated plexiglas disk tightly fixed to the inner edges of the pot, a small compartment to collect excess water and a 30 mm long open valve connected to a graduated cylinder (Fig.1, c and d). The size of each pot was made sufficiently large to easily accommodate to the root system of the examined plants. To enable good drainage conditions, the designed pots were provided with an approximately 40 mm thick sand layer surrounding the potting soil. This was done by using a galvanized steel system to separate the potting soil and the edges of the plexiglas pots (Fig.1, e, f, g and h). The potting soil was first placed inside the galvanized steel, next the sand was poured to fill the space between the pot and the galvanized steel and finally the galvanized steel system was pulled out to establish contact between the sand and the potting soil (Sarem, 2006).

The second type of pot consisted of commercial type pots usually used for house plants: 200 mm wide, 600 mm long and 200 mm deep.

Lead Contaminant

Lead contaminant was obtained from lead nitrate $Pb(NO_3)_2$. As previously mentioned, the two types of soils were air-dried and sieved on sieve # 4. The contaminant was dissolved in water, and the water/contaminant mixture was added to the air-dried soil and thoroughly mixed to ensure a homogeneous distribution of the contaminant within the soil matrix.

UP-KEEPING OF PLANTS

Constant up-keeping was conducted throughout the experiment period. Plants were regularly irrigated at a frequency of once per week. A spring pump was used to spray trace elements on the leaves of the plants twice per week. A small shovel was used to plough up the soil surface. The period of all experiments was five months. The plants were left to grow in a greenhouse environment for the first two months, and then they were taken out to grow up in the nursery of JUST Agricultural Services for three more months. In the nursery, continuous caring was done including (a) Irrigation with tap water to maintain the moisture content of soil at about 55-65%, (b) Leaf fertilizing by spraying leaves with trace elements and humic acid. The components of the trace elements were: nitrogen, phosphorous, K_2O, amino acids and other nutrients. Concentration of sprayed humic acid was 2 ml/L and for the trace elements the concentration was 1 g/L. Leaf fertilizing was used to achieve two goals; the first was to provide the plants with nutrients through leaves in order to get quick results, especially within the first weeks of plantation. The second goal, however, was to reduce the percentage of fertilizers that are applied directly to the soil. Fertilizers directly applied to the soil may negatively influence the bioavailability of the contaminants. Fertilizers are composed of different anions and cations such as phosphate anions and potassium cations. Anions may combine with lead or nickel cations to form stable complexes and become hard to uptake by the plants' roots. Increasing salinity is a second negative effect of the fertilizers that are directly applied to the soil causing growth retardation of the plants and thus low contaminant uptake by the plants. Leaf fertilizing started at the first day of planting and lasted to the end of the experiment period at a frequency of twice per week (Sarem, 2006).

MEASURING CONTAMINANT CONCENTRATION

At the end of the experiments, the plants were removed from the soil and separated into 4 parts; roots, stems, leaves and flowers. The spiked soil was sampled at three locations; top, middle and bottom of the pot. Extraction and contaminant concentrations were measured in the soil as well as the various parts of the plants used. The contaminant was extracted from the soil and from each part of the plant by using the 1M HNO_3 solution method.

EXPERIMENTAL RESULTS

Chrysanthemum was planted in “JUST” campus site soil. Three experiments were run using *Chrysanthemum*.

1. Two identical experiments with 1000 ppm by dry mass of Pb.
2. One experiment was conducted with no contaminant (control test).

Chrysanthemum planted in lead spiked “JUST” soil showed no dissimilarity with *Chrysanthemum* planted in the same soil but with no lead contaminants (Fig. 2 and Fig. 3). This matter is attributed to the very low solubility of lead compounds.

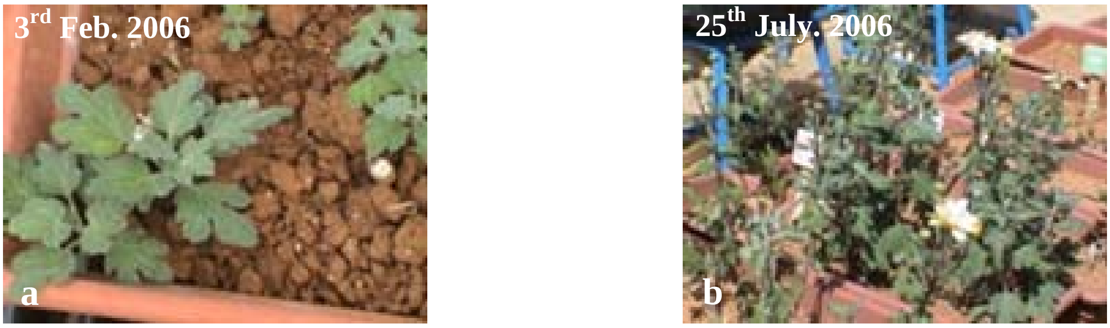

Figure 2: *Chrysanthemum* planted in "JUST" soil with no contaminant (Sarem, 2006)

Figure 3: *Chrysanthemum* planted in "JUST" soil with 1000 ppm lead (Sarem, 2006)

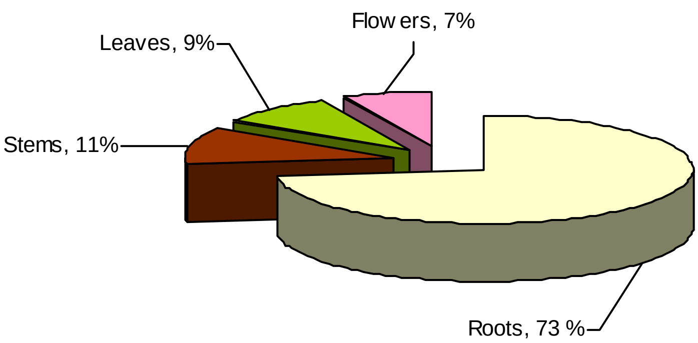

Figure 4: Lead concentration at various parts of *Chrysanthemum*

Table 1: Pb concentration in ppm *versus* depth for *Chrysanthemum*

Initial (ppm)	Top (ppm)	Middle (ppm)	Bottom (ppm)
993	872	543	212

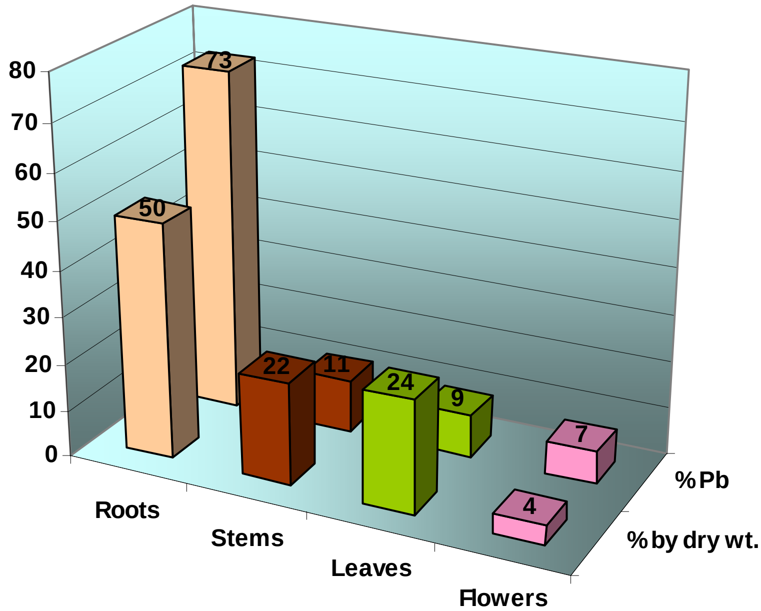

Figure 5: Lead concentration at the various parts of *Chrysanthemum* and percentage of dry weight of each part of *Chrysanthemum* to dry weight of the whole plant

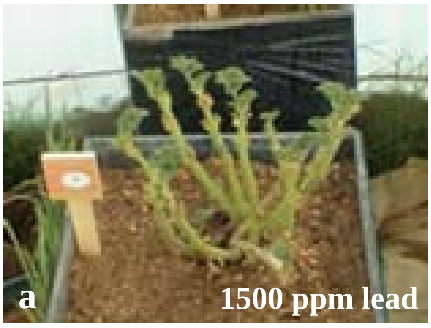

Figure 6: *Pelargonium*, (a) 1st month, (b) 5th month (Sarem, 2006)

The plants, after five months, were taken out of the soil. Each plant was separated into its main parts; stems, leaves, roots and flowers. Each part of the plant was dried and the moisture content was determined. The contaminant was extracted from each part of the plant by using a 1M HNO_3 solution. The roots have accumulated about 73% by dry mass of the lead (Fig. 4 and Fig. 5). The remaining 28% of the contaminants was nearly evenly distributed in the stems, leaves and flowers (Fig. 4 and Fig. 5).

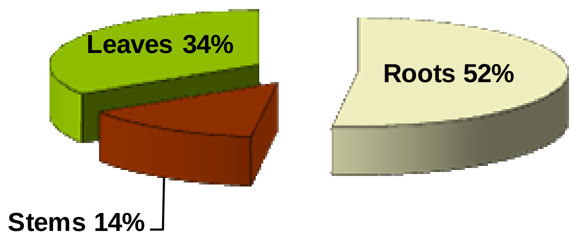

Figure 7: Lead concentration at various parts of *Pelargonium*

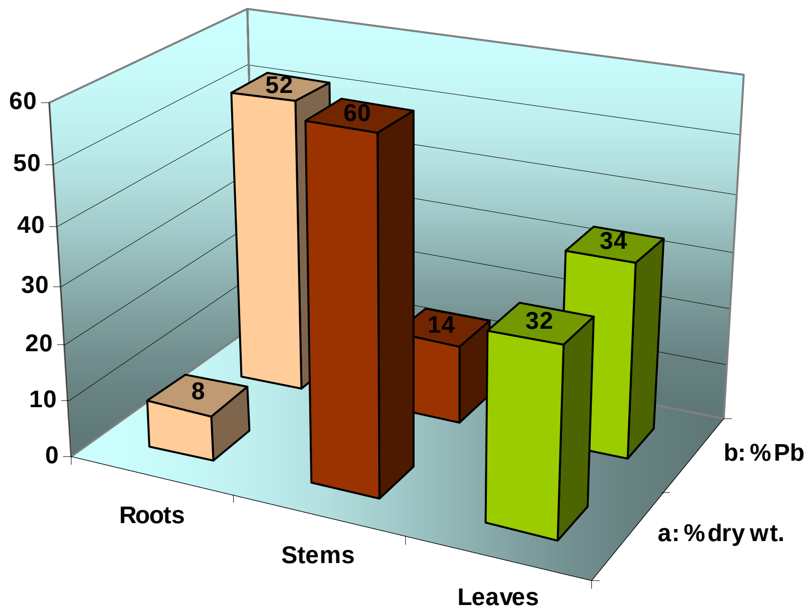

Figure 8: Lead concentration at the various parts of *Pelargonium* and percentage of dry weight of each part of *Pelargonium* to dry weight of the whole plant

As for the contaminant concentration in the soil, the lower part of the soil experienced higher reduction in the contaminant concentration (Table 1). This matter is attributed to the high root density at the bottom of the pot, and since the roots extracted the major part of the contaminant, the nearer the soil to the root system the higher the reduction in the contaminant (Sarem, 2006).

Pelargonium (Grandiflorum) was planted in the mixture of peat, peyrlaite, sand, clay and organic fertilizer. Two identical experiments were conducted with the soil mixture spiked with 1500 ppm lead by dry mass.

For the first month, there was almost no growth for *Pelargonium* planted in lead spiked soil (Fig. 6a); however, growth rate improved after that (Fig. 6b).

At the end of the test period, the plants were taken out of the soil and separated into their main parts; stems, leaves and roots. Each part of the plant was dried and the moisture content was determined. The contaminant was extracted from each part of the plant by using a 1M HNO_3 solution. The roots have accumulated about 52% by dry mass of the lead (Fig. 7 and Fig. 8). The remaining 48% of the contaminants was distributed in the stems and leaves; 14% and 34%, respectively (Fig. 7 and Fig. 8).

Table 2 shows lead concentration at the three sampled locations in the soil (Sarem, 2006).

Table 2: Pb concentration in ppm *versus* depth of *Pelargonium*

Initial (ppm)	Top (ppm)	Middle (ppm)	Bottom (ppm)
1367	1210	879	989

SUMMARY AND CONCLUSIONS

Chrysanthemum and *Pelargonium* were used to remedy lead spiked silty clay soil and well prepared mixture of commercially available peat moss (33%), peyrlaite (16%), sand (16%), clay (17%) and organic "manure" fertilizer (18%). Based on the results of the study, the following conclusions are drawn:

1. *Chrysanthemum* demonstrated an excellent ability to extract lead from contaminated soils. *Chrysanthemum* reduced lead (in the root zone) from about 1000 ppm by dry mass of soil to about 212 ppm. This means about 80% reduction in contaminant concentration in the soil, only in about five months.
2. Most of the extracted lead (over 80%) was found in the roots of the *Chrysanthemum.*
3. *Pelargonium* (Grandiflorum) has shown little ability to extract lead from contaminated soils; about 6% in the root zone.
4. Tolerance of *Pelargonium* to the presence of lead was lower than that of *Chrysanthemum*. *Pelargonium* growth rate was modest when used to extract lead from contaminated soils.

REFERENCES

Baker, A.J.M., McGarth, R.D., Reeves, R.D. and Smith, J.A.C. 2000. Metal hyperaccumulator plants: A review of the ecology and physiology of a biochemical resource for phyroremidiation of metal-polluted soils. Phytoremediation of contaminated soil and water. Lewis Publ., Boca Raton, FL., By Terry, N. and Banuelos, G. (Eds.): 85-107.

Chen, Z. S., Lee, G. J. and Liu, J. C. 2000. The effects of chemical remediation treatments on the extractability and speciation of cadmium and lead in contaminated soils. *Chemosphere,* (41): 235-242.

Chrysafopoulou, E., Kadokova, J. and Kalogerakis, N. 2005. A whole-plant mathematical model for the phytoextravtion of lead (Pb) by mazie, *Environ. Intl.*, (31): 255-262.

Garbisu, C. and Alkorta, I. 2001. Phytoextraction: a cost-effective plant-based technology for the removal of metals from the environment. *Bioresource Technol.*, (777): 229-236.

Huang, J.W.W., Chen, J.J., Berti, W.R. and Cunningham, S.D. 1997. Phytoremediation of lead-contaminated soils: Role of synthetic chelates in lead phytoextraction. *Environmental Science and Technology,* (31): 800-805.

Marchiol, L., Assolari, S., Sacco, P. and Zerbi, G. 2004. Phytoremediation of heavy metal metals by canola (*Brassica napus*) and radish (*Raphanus sativus*) grown on multicontaminated soil. *Environ. Poll*., (132): 21-27.

Sarem, S. M. 2006. Electroremediation and phytoremediation of saturated and unsaturated contaminated soils. Thesis submitted in partial fulfillment of the requirements of the degree of M.Sc. in Civil Engineering, Jordan University of Science and Technology, Irbid, Jordan.

United States Environmental Protection Agency. 1992. Selection of control technologies for remediation of lead battery recycling sites. EPA/540/S-92/011. US Environmental Protection Agency, Office of Emergency and Remedial Response, Washington, DC, USA.