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The use of plants for detoxification of heavy metals in polluted soils

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ABSTRACT

Phytoremediation is an environmentally friendly biotechnological approach, which reduces contaminants concentrations without causing any secondary effluent impact in the recipient environment. Plants uptake is one of the major pathways by which potentially toxic elements from the contaminated soils enter the food chain. In this study, three experimental fields were designed. The objective of this research was to determine the phytoremediation efficiency of common beans (*Phaseolus vulgaris*) and Garland daisy *(Chrysanthemum coronarium)* flowering plant in field experiments. The bioavailability of the heavy metals (Cd, Cu, Cr, Ni, Pb and Zn) in contaminated soils were assessed by analyzing roots, stem tissues, seeds, flowers and leaves of the plants. Analysis of the data revealed that, the uptake of heavy metals in plant species significantly increased in contaminated soils when compared with the control soil. The pH $_{(water)}$ of the experimental soils was 7.4 and that of the control soil was 6.8. The organic carbon percentages of the experimental soil and the control soil were 9.5% and 8.4% respectively.

KEYWORDS

Heavy metals;
Sewage sludge;
Common beans (Phaseolus vulgaris);
Garland *daisy (Chrysanthemum coronarium)* and
polluted soils and
phytoremediation.

INTRODUCTION

Industrial activities cause fast and considerable degradation of soils. Domestic sewage, industrial effluents and other man made activities are the main sources of pollutants, which release the heavy metals into the environment[12, 15]. Sewage sludge utilization in agriculture is likely to increase in future years. Sewage contains considerable amount of nutrients like N and P. It may also contain high concentrations of potentially toxic elements such as Cu, Cd, Ni, Cr, Pb, Hg etc. Sewage application to agricultural land is commonly recognized as a nutrient resource[9]. The contamination of soil with heavy metals continues to be a greater concern because of their persistence in soils[24, 2]. Heavy metals have the highest impact on organisms, and can be absorbed by organisms very easily. Therefore, bioavailability is one of the keys to understanding the chemistry of heavy metals in soils[25, 2].

Environmental management of soils contaminated with heavy metals requires a wide knowledge of their spatial distribution and mobility. After the application of sewage sludge, the soil will gradually establish new biochemical equilibrium due to the decomposition of sludge amended organic matter and, in many cases, acidification of the soil[20]. Consequently, the availability of sludge borne heavy elements may change after the biodegradation of sewage sludge in soils[20, 26]. Plants have high capabilities of accumulating heavy metals. Plants uptake is one of the major pathways by which the heavy metals enter the food chain[4, 5]. The ability to select species of plants that either are resistant to heavy metals, or can accumulate great amounts of them, can certainly facilitate reclamation of contaminated soil. Plants due to their high sensitivity to heavy metals seem to provide good indicators of environmental pollution. Hence, the phytoremediation technology is an alternative method for assessing the relative pollution level in soil contaminated with toxic heavy metals[11, 8, 18]. The aim of this investigation was to analyze the influence of heavy metals pollution of soil using selected plant species.

MATERIALS & METHODS

Field studies

The phytoremediation studies were carried out using field experimental model and three experimental sites were designed with the area covering 2 m long and 4 m wide. The selected area soil sample was gray and loomy in nature. Field – I served as control and fields – II and III served as experimental fields.

Common beans (*Phaseolus vulgaris*) and **Garland daisy** *(Chrysanthemum coronarium)* flowering plants were used as bioindicators for evaluation of soil pollution. The soils were pretreated with combined heavy metal salts solution of Cd, Cu, Cr, Ni and Zn in nitrate form in equal proportion. The ambient air temperature in the experimental field is ranged between 18 – 22 ^{0}C with the humidity of 65 ± 5%. During the harvesting period, all the experimental fields were applied with drinking water to avoid wilting. In all the fields, compost fertilizer was applied one time during the middle of the harvesting period to maintain the fertility of the soil.

Chemical analysis

Soil sample analysis

The soil samples were air-dried, crushed to pass through a 1mm sieve and stored in plastic bags for further analysis. Soil pH was determined using 1:5 soil/water ratio, organic carbon was measured using the standard procedures described in literature[19] and soluble forms of heavy metals (Cd, Cu, Cr, Ni, Pb and Zn) were extracted by using 2 M HNO_3 and determined using AAS[1].

Plant sample analysis

Plant samples such as stem tissues, seeds, roots, flowers and leaves were collected and dried at 65 – 70 ^{0}C for 48h, weighed and ground to pass through a 60 – mesh sieve and stored in a decicator for further analysis. 1.0 g each sample was incinerated in muffle furnace at 500 ^{0}C. The residue was dissolved in hot 10 ml of dilute aqua – regia (1:3 v/v) and filtered using Whatman filter paper No. 541. The filtrates were made up to 25 ml by adding double distilled water and the heavy metal contents were analyzed using FAAS (Simadzu, AA 6200). The concentration of the metals was expressed as mg/kg dry weight[14].

Statistical analysis

Heavy metal concentrations in soil samples and different parts of the experimental plant species were analyzed using the general descriptive statistics component of SAS program.

RESULTS & DISCUSSION

The availability of heavy metals in the soil provides a valuable means of studying the soil – plant relationships of the potentially toxic metals. The soil profile of the experimental field soils were determined and reported in the TABLE 1. The soil pH was 7.4, which indicates that, the soil was slightly alkaline in nature. The percent clay in the soil was less than the sand. The rate of cation ion exchange capacity of the soil was good. The selected soil type was very much suitable to cultivate the crop and flowering plants. The quality of the water applied in control as well as experimental fields was pre-

TABLE 1 : Physico-chemical characteristics of the soil

Texture	Soil separate (%)			pH	OM (%)	CEC (cmol/Kg)	FMC (%)
	Sand	Silt	Clay				
Clay loam	52.3	11.5	36.2	7.4	8.4	6.3	16.5

TABLE 2 : The quality of water applied in fields

Parameters	Values (ppm)	Parameters	Values (ppm)
pH	7.8	Sulphate	435
EC (μS/cm)	1637	Nitrate	0.9
TDS	1085	Phosphate	1.05
Total Hardness	460	Dissolved Oxygen	4.2
Total alkalinity	110	Trace elements:	
Calcium	73.5	Cd	0.02
Magnesium	44.6	Cu	0.8
Sodium	28	Cr	0.03
Potassium	14	Ni	0.06
Iron	0.8	Pb	0.02
Chloride	340	Zn	1.25

Note: pH value has no units.

sented in the TABLE 2. The values of water quality parameters suggest that, the water was suitable for any type of crop plants and does not contain any harmful chemical parameters. Heavy metals such as Zn, Cu, Cr, Cd, Ni and Pb are potential bioaccumulative toxins of the food production system, as soils tend to act as long-term sinks via sorption[20]. The concentration of the selected heavy metals (Cd, Cu, Cr, Ni, Pb and Zn) in the control field and the experimental fields was reported in the Figure 3. The amount of heavy metals present in the soil profile was very much significant. Trace amount of all heavy metals is very essential for plant growth. Heavy metals stimulate various biochemical metabolisms in the plant. However, higher levels of heavy metals in the soil excert phytotoxicity in plants and ultimately influence the plant growth and yields.

In the present study, Common beans (*Phaseolus vulgaris*) and **Garland daisy** *(Chrysanthemum coronarium)* flowering plants were cultivated in chemically contaminated and unpolluted soil to evaluate the phytoextraction capabilities of the experimental plants. The phytoaccumulation of most of the heavy metals in roots of the plants was very much significant than in the other parts of the plants.

Cadmium (Cd)

Cadmium was detected in all plant parts of the experimental plant species. The lowest and median concentrations of Cd were generally found in leaves and seeds of the common beans and seed in garland daisy. The concentrations of Cd in roots of both plant species are significantly higher. Cadmium disperses to most roots and shoot tissues, but can be confined to the meristem[13]. Mobilization of cadmium can also occur as results of formation of complexes with the organic matter of the contaminated soils. This process can have an effect on the uptake and movement of the metal in the roots and shoots of the plant[16, 17].

Few studies have reported typical cadmium concentrations up to 10 mg/kg of forages and alfalfa up to 0.64 mg/kg[23] grown in fields near industrial zinc plating sites, where urban sludge has been used as fertilizer and where silt from industrial areas has been deposited. Cadmium is generally more mobile in the soil and plant than other heavy metals, its concentration decreases in the order: root> stem tissues > leaves > seeds > flowers in the present studies Figure 1.

Copper (Cu)

Copper content was detected in all parts of the experimental plant species. The level of Cu in common beans is comparatively lower than in garland daisy species. Higher concentration of Cu was observed in garland daisy grown in experimental field – III. The level of Cu observed in the plant species is in the order of: root> stem tissues > leaves > seeds

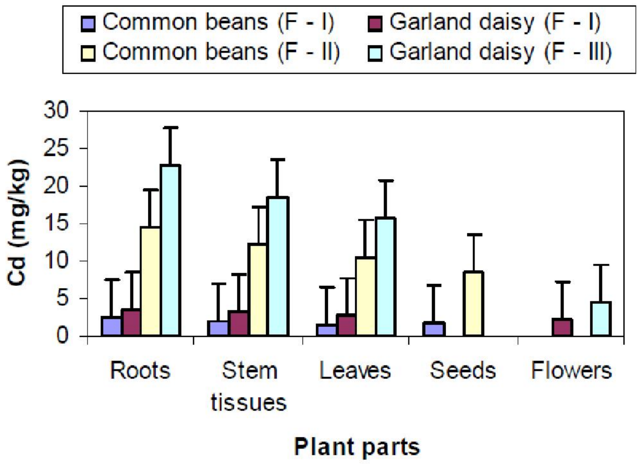

Figure 1 : Accumulation of Cd in parts of plants

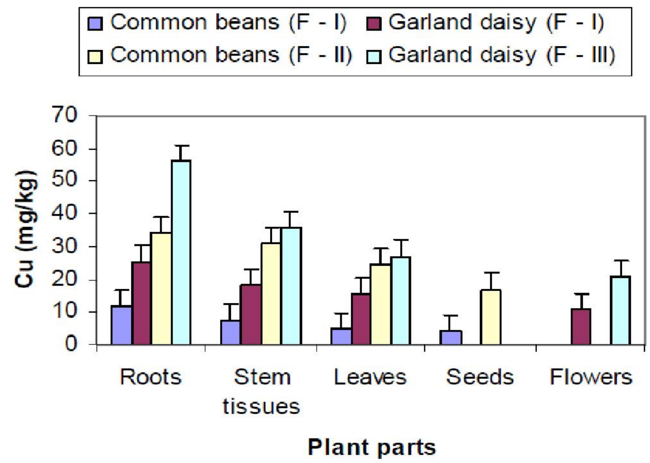

Figure 2 : Accumulation of Cu in parts of plants

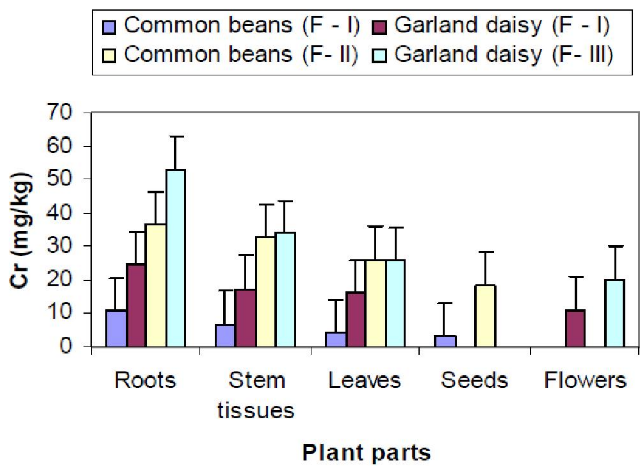

Figure 3 : Accumulation of Cr in parts of plants

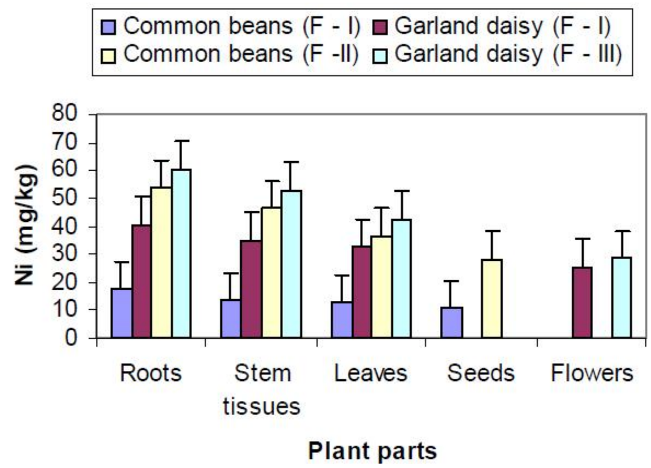

Figure 4 : Accumulation of Ni in parts of plants

> flowers in the present studies Figure 2. Mc Bride and Spiers planted corn in soils of varying Cu concentrations and reported the presence of a very limited Cu accumulation in plant tissue (< 35 mg/kg) [10].

Chromium (Cr)

Chromium is a phytotoxic element. The higher concentration of Cr was observed in roots of common beans and garland daisy species in control as well as experimental fields. The lowest level of Cr was found in seeds of common beans in unpolluted soil Figure 3. The lower level of Cr concentration was observed in corn silages grown in industrial effluent contaminated area in United States[4] and United Kingdom[7]. The level of Cr observed in the plant species is in the order of: root> stem tissues > leaves > seeds > flowers in the present studies Figure 3.

Nickel (Ni)

The concentrations of nickel were detected in all samples of the plant species. The mobility of Ni was comparatively higher than the other heavy metals in soils – plant interaction. The accumulation of Ni was higher in roots than other parts of plant species. Relatively garland daisy removed more Ni from soil matrix than common beans. The solubility factor Ni may influence the higher accumulation of Ni in plant species. Nickel has no known biochemical mechanisms in plant metabolism. Its removal is mandatory by cleaning contaminated soil system. The level of Ni observed in the plant species is in the order of: root> stem tissues > leaves > seeds > flowers in the present studies Figure 4.

Lead (Pb)

Concentrations of lead are extremely variable

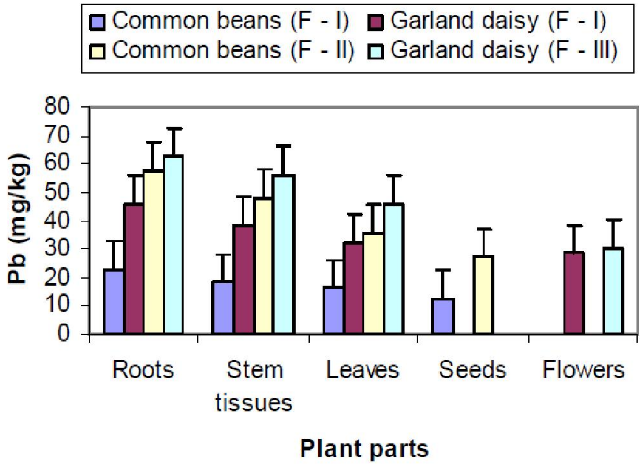

Figure 5 : Accumulation of Pb in parts of plants

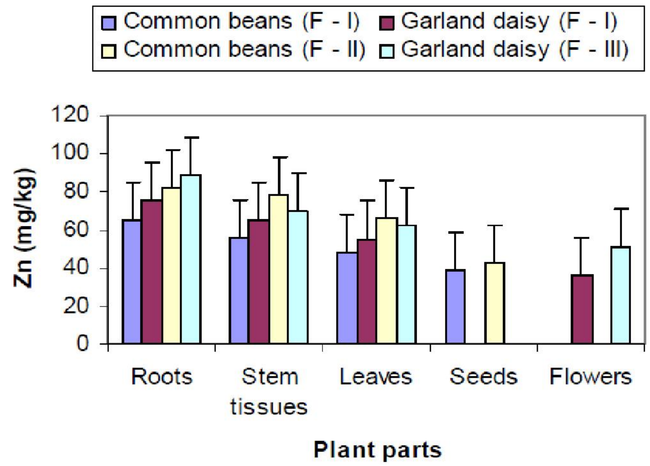

Figure 6 : Accumulation of Zn in parts of plants.

TABLE 3 : Selected heavy metal contents of the soil

Fields No	Heavy metals (mg/Kg)					
	Cd	Cu	Cr	Ni	Pb	Zn
F – I	5.85	80.4	44.6	48.9	52.6	212.6
F – II	56.7	130.6	90.8	98.8	105.6	253.4
F – III	58.6	135.8	92.6	101.3	108.2	255.2

F – I is Control, F – II & F – III are Experimental fields.

in all parts of the plant species. The amounts of Pb in all samples were higher than other elements. Normally roots were recorded for higher accumulation of Pb than any other parts of the plant species. Garland daisy absorbed relatively higher contents of Pb than common beans. Nicholson et al., have reported that, the concentration of Pb for corn silage was < 1 mg/kg in the United Kingdom[10]. The availability of Pb in soils is generally low. Plant species such as common beans and garland daisy have higher potential to remove Pb from soils receiving high application of contaminants via sewage sludge. The level of Pb observed in the plant species is in the order of: root> stem tissues > leaves > seeds > flowers in the present studies Figure 5.

Zinc (Zn)

The concentration of Zn in control and experimental soils were significantly higher. Higher concentration of Zn has been observed in all samples of the experimental plants. The accumulation of Zn in roots, stem tissues, leaves and seed were relatively higher than flower parts in garland daisy. Overall accumulation on Zn is much higher in garland daisy than common beans. High levels of Zn (300 mg/kg) have been found in the tissues of alfalfa grown in low pH and high Zn soil and results in a 20 to 90% yield reduction were observed[4]. Higher levels of Zn (400 mg/kg) were also reported in the tissues of corn plants grown on peat soil with high Zn content mobility, but extreme phytotoxic effects on yield were observed[7]. The level of Zn observed in the plant species is in the order of: root> stem tissues > leaves > seeds > flowers in the present studies Figure 6.

CONCLUSIONS

Phytoremediation of heavy metals contaminated soils are an emerging technology that aims to extract or inactivate toxic metals in soils. Soils contaminated with multiple heavy metals can present a difficult challenge to phytoremediation. This study demonstrated the promising potential for phytoextraction of heavy metals by common beans and garland daisy plants. These plants have several beneficial characteristics such as the ability to accumulate metals in their roots and stem tissues and an exceptionally high tolerance to heavy metals. These plants were hyperaccumulator to the heavy metals studied. The heavy metal accumulation in both plant species was strongly influenced by their concentration in soils and metal availability to plants. In this study, the amount of heavy metal accumulated in plant parts was in the order of Zn > Pb > Ni > Cr > Cu > Cd in roots, stem tissues, leaves, seed and flowers. The results indicate that, garland daisy has more accumulative power than common beans in contaminated soils. Hence, it was suggested that, garland daisy was much more suitable for phytoextraction of many toxic metals in contaminated soil environment.

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