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Remediation of Heavy Metal-Contaminated Soil by Ornamental Plant Zinnia (*Zinnia elegance* L.)

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Phytoremediation potential of ornamental plant Zinnia (*Zinnia elegance*) was assessed for contaminated soil with heavy metals (lead and chromium). Plants were grown in pots having soils with different levels of metal contamination *i.e.* T1 (10 ppm), T2 (20 ppm), T3 (30 ppm), T4 (40 ppm), T5 (50 ppm), T6 (60 ppm) and T7 (70 ppm). Plants were also grown in pots with uncontaminated soil as control treatment (T0). After pot study (6 weeks), plants were harvested, different physical parameters were measured and plant samples were prepared for chemical analysis. Soil was collected from the pots to prepare representative soil samples for chemical analysis. Atomic absorption spectrophotometer was used to measure concentration of heavy metals in plants and soil. The results indicated that plants grown in lead contaminated soils were healthier as compared to the plants grown in chromium-contaminated soils. The fresh and dry weight, bioconcentration factor and translocation factor were also higher in the lead-contaminated soils. The results indicated that the remediation capacity of *Z. elegance* is better for lead contamination. Therefore, this plant can be used for soil remediation contaminated with lead.

Keywords: Soil contamination, Heavy metals, Phytoremediation, Soil pollution.

INTRODUCTION

There are different causes of soil contamination or mobilization of toxic elements and heavy metals in soils, which include application of agrochemicals, discharge of untreated wastewater, use of untreated municipal waste water for irrigation, soil acidification, *etc*. [1-3]. The long-term usage of wastewater makes these metals to accumulate in soil and increases the absorption and accumulation by the plants. Contamination of soil with heavy metals like lead and chromium is a serious problem in Pakistan. Most of the industries have given least or no attention to the control and management of industrial waste water due to improper guidelines and management systems. So in many areas of developing countries like Pakistan this untreated waste water is directly used for irrigation of crops [4].

The chronic exposure of heavy metals plays a significant role in causing tumorigenesis, moreover the studies reveal that it is not necessary that the heavy metal should accumulate in a high concentration in the human body to induce tumorigenesis. Chromium(VI) is potential lungs, liver and kidney cancer producer; DNA damages, whereas the exposure of lead with blood stream affects the soft tissues and mineralizes the tissues. Lead, mercury, chromium and cadmium are the most important heavy metal pollutants. Most of the heavy metals have toxic effect on human neutrophils [5]. In children the lead exposure affects their growth metabolism and in severe cases the central nervous system [6].

Phytoremediation is an emerging natural technique used for removal of heavy metals from soil. It is comparatively cost efficient and natural as compared to other soil purification techniques. The selection of ideal plant species for phytoremediation depends upon the ability of plant for extracting heavy metals, their ability to tolerate higher concentrations of heavy metals, harvesting and availability. Some plants have ability to uptake and absorb heavy metals from soil along with other nutrients. These are known as hyperaccumulators. Phytoextraction, is a phenomenon in which the contaminants are taken up by the roots of plants and translocated and accumulated by shoot or other above ground biomass like stem, leaves and fruits [7,8]. Phytoremediation is also known as green technology, which is used to clean waste water and remove contaminations from soil. This technology gains its popularity as it is cost effective, environmental friendly and adds aesthetic value to the area. Secondly this technique is equally applicable for removal of organic and inorganic pollutants from soil, air and water.

EXPERIMENTAL

Soil preparation for pot experiment and soil characterization: Normal soil was collected from the field for the pot experiment. The collected soil samples were prepared for pot experiments and soil characterization by air drying under shade, crushing of air dried samples by hammer, sieving of crushed soil samples (mesh size 2 mm) to remove stones, wood particles, *etc*. and mixing thoroughly to make the samples homogeneous for experiment.

Representative sample was taken for characterization of basic properties. Soil properties were determined by different methods; particle size distribution by hydrometer method [9], soil texture by textural triangle [10], soil bulk density by core method [11], soil pH by pH meter, electronic conductivity by EC meter [12], cation exchange capacity (CEC) by ammonium acetate method [13] and soil organic carbon and organic matter by wet oxidation or Walkley-Black method [14].

Preparation of pots and development of contamination: The prepared soil samples were used for filling pots. Earthen pots (having 45.72 cm height and 30.48 cm diameter) were prepared. These pots were lined with polythene bags to avoid leaching. All pots were filled with the same calculated quantity (6 kg) of prepared soil.

The calculated amounts of lead acetate and potassium chromate were dissolved in water to develop the required level of contamination. The prepared solutions of heavy metals were applied to the soils in pots to develop contamination of lead and chromium. The prepared solutions were applied slowly to avoid overflow from the pots. After solution application, pots were left for a few days and then equal amount of water was applied to pots for uniform contamination of heavy metals in the soil in the pots.

Plants species and experimental design: Phytoremediation study was conducted using on an ornamental plants in pots. A summer ornamental plant was selected for the experimentation *i.e. Zinnia elegance*. It is a wide spread plant, which is easily available and it grows very easily. This species is tolerant to heavy metals (lead and chromium). The experiment was consisted of 48 pots (1 ornamental plant × 2 heavy metals × 8 treatments × 3 replications).

Seedlings transplantation: Healthy seedlings, having the same height, were transplanted in each pot. After transplantation, small quantity of water was applied to each pot for irrigation. The *Zinnia elegance* were grown on contaminated soils till flowering (42 days). All the ornamental plants were harvested. Soil was also removed from all the pots after experiment.

Experimental variables: The fresh weight was measured after washing plant thoroughly firstly with tap water and then distilled water to remove soil and other dirt particles. The plants were first dried in air and then oven dried at 120 °C over night to remove all the moisture and dry weight was measured by the balance. The moisture content in the plants was calculated after measuring the fresh and dry weight of the plants. Concentration of heavy metals in plants and soil samples were measured by an atomic absorption spectrophotometer (AAS). Translocation factor (TF) is the ratio of how much the plant body has translocated the heavy metals in its vegetative part from the roots. Bioconcentration factor (BCF) and translocation factor (TF) are the key elements for the evaluation and selection of plants for phytoremediation purposes [15]. Equations used for calculation of parameters are as under:

$$\text{Moisture content (\%)} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Fresh weight}} \times 100$$

$$\text{BCF} = \frac{\text{Conc. of heavy metal in plants}}{\text{Conc. of heavy metal in soil}}$$

$$\text{TF} = \frac{\text{Conc. of heavy metal in shoot}}{\text{Conc. of heavy metal in root}}$$

$$\text{Removal (\%)} = \frac{\text{Amount of heavy metal in plant}}{\text{Total amount of heavy metal in soil}} \times 100$$

RESULTS AND DISCUSSION

After transplantation, seedlings' growth was monitored on regular basis for the physical parameters like number of flowers, plant biomass, colour and other factors. It was observed that plants with chromium concentrations were much healthier and flower rate was higher as compared to lead concentrations. In higher contamination levels, the flowering rate decreased and plants showed stunted growth for both lead and chromium-contaminated soils.

Height of plants in contaminated soils: Height of *Zinnia elegance* was measured in seven levels of lead and chromium contaminations (10, 20, 30, 40, 50, 60 and 70 ppm). The average plant height in the control treatment was 15.50 cm. It was noted that plant height increased with increase in Cr-concentration till T3 (30 ppm). In T4 (40 ppm), T5(50 ppm) and T6 (60 ppm) the average height of plants decreased as compared to T3 (30 ppm) plants. It is also noteworthy from the results that the biomass of plants T1 (10 ppm), T2 (20 ppm) and T3 (30 ppm) was much greater as compared to the control treatment (0 ppm). The plants were lush green and quite healthier as compared to the higher concentrations *i.e.* T4 (40 ppm) and T5 (50 ppm). The plants of T6 (60 ppm) showed stunted growth, very low rate of flowering. These plants died in the 3rd week after transplantation. The plant height in different treatments of chromium is shown in Fig. 1. The seedlings grown in Cr-contaminated soil in T7 (70 ppm) didn't show any growth so the results were not measured for this level of contamination.

Height of *Zinnia elegance* in lead contaminated soils (10, 20, 30, 40, 50, 60 and 70 ppm) increased till T4 (40 ppm), while plant height decreased in T5 (26.9 cm) and T6 (24.6 cm). A stunted plant growth was observed in T7 (70 ppm) which indicates that there was no further growth in these plants. The stunted growth of plants has been observed at higher concentrations of lead by a study [16]. Plant height decreases with increase in concentration of heavy metals [17].

Fresh and dry weight of plants in contaminated soils: The fresh weight in chromium contaminated *Zinnia elegance* at T0 (control plants) was about 17.23 g which increased in T1 (10 ppm) and T2 (20 ppm). In concentrations above T2, the fresh weight of *Zinnia elegance* decreased. The lowest fresh

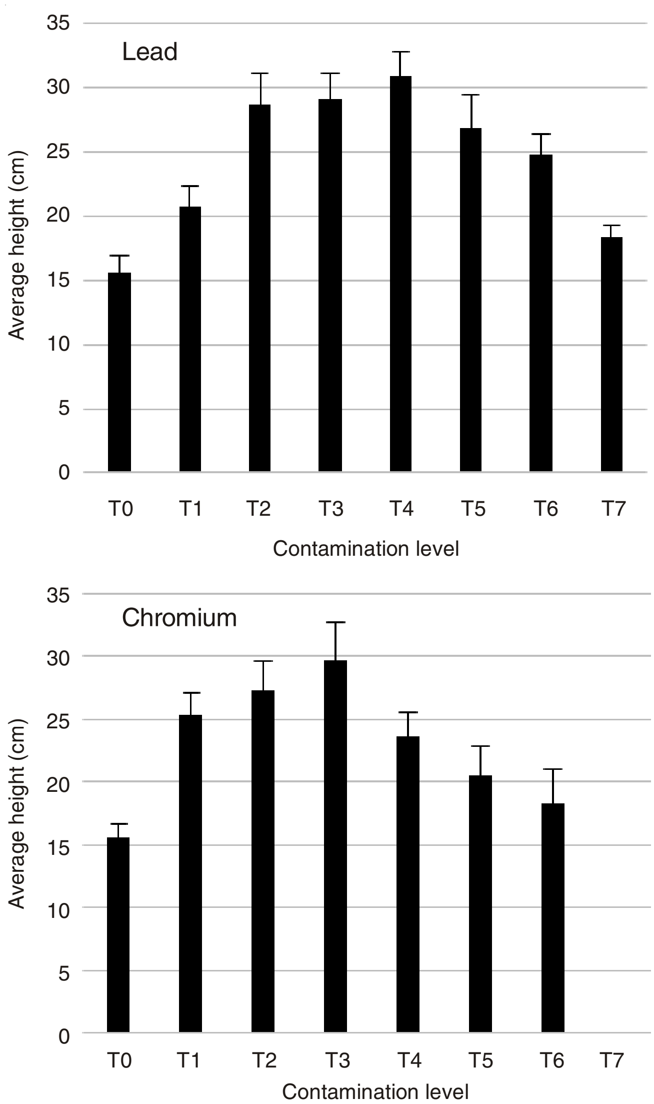

Fig. 1. Average height (cm) of *Zinnia elegance*

weight of plant was observed in T6 *i.e.* 6 g. The results indicated that after few days of experimentation, the plants in higher levels of Cr-contamination (70 ppm) started to wither and died within 10 days, whereas, in lead concentration the plants showed resistance against the heavy metal and survived. However these plants also had stunted growth and later had no flower production. The dry weight of *Zinnia elegance* at T0 control plants was about 4 g. It increased to 4.3 g in T1 (10 g) and decreased in higher concentrations *i.e.* T2 (3.4 g), T3 (2.53 g), T4 (2.3 g), T5 (1.64 g) and T6 (1.21 g). It was observed that the seedlings of *Zinnia elegance* in higher levels of Cr-concentration (70 ppm) showed inconsistent growth and withered within 10 days of plantation. A research reported by Maqsood [18] on rice plants grown in pots indicated that roots were more sensitive to chromium. The greater concentrations of chromium proved more lethal than that of lower Cr levels. The overall adverse effect of Cr on growth and development of plants may result in a serious impairment of uptake of mineral nutrients and water leading to deficiency in the shoot [19]. The fresh and dry weight of chromium treated *Zinnia elegance* is presented in Fig. 2.

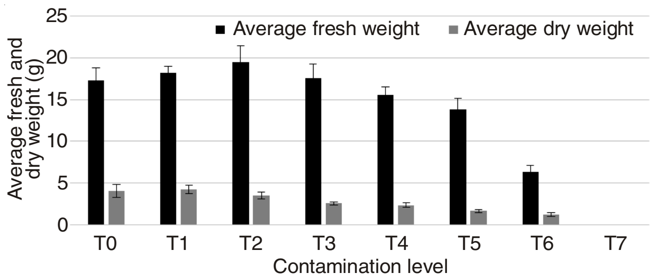

Fig. 2. Average fresh and dry weight of chromium treated *Zinnia elegance*

The average fresh and dry weight of plants in lead contaminated soil is presented Fig. 3. In control treatment (T0) fresh weight was about 15 g. In T1 (10 ppm), T2 (20 ppm) and T3 (30 ppm) the fresh weight of plants decreased but remained almost constant *i.e.* 12.5, 13 and 12.9 g, respectively. In T4 (40 ppm) and T5 (50 ppm) the fresh weight of *Zinnia elegance* dropped to about 10 g. In T6, T7, T8 and T9 the fresh weight again decreased and became lowest in T9 *i.e.* 4 g. Moreover it can also be noted that the flowering rate of plants in higher levels of contamination was lower as compared to plants grown in low levels of contamination. The dry weight of *Zinnia elegance* in control plants is about 4 g. It decreased to 3.1 g in T1 (10 ppm), remained almost the same from T2 (3.5 g) to T4 (3.2 g). At T5 the dry weight decreased to 1.2 g. T6 showed an irregular increase in dry weight that was about 1.7 g. The dry weight of plants at T0 control plants was about 2.7 g. It decreased to 1 g in T1 (10 ppm), remained almost the same for T2. In T3 and T4 there was an increase in dry weight *i.e.* 1.5 and 1.7 g. At T5 the dry weight decreased to 1.2 g. T6 showed an irregular increase in dry weight that was about 1.7 g. In T7, T8 and T9 the dry weight was almost constant at 2 g.

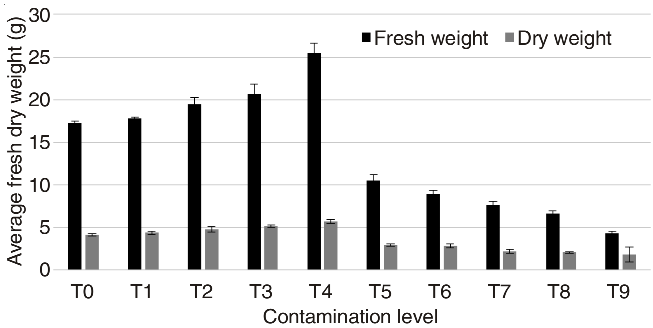

Fig. 3. Average fresh and dry weight of lead contaminated *Zinnia elegance*

Concentration of heavy metals in plants: The uptake of heavy metals in biomass was calculated in each organ of the plants. The plant species which accumulate very high concentrations of metals in their body parts above ground are known as hyper accumulators. The concentration of lead in *Zinnia elegance* increased with increase in concentration of metal in soil. Fig. 4 shows average concentration of heavy metals in plants. The results indicate that heavy metal uptake increased with increase in lead and chromium levels in soil.

Bioconcentration factor (BCF): The bioconcentration factor for chromium in *Zinnia elegance* increased with increase in contamination level reaching maximum in T3 (1.5) and it decreased for higher contamination levels (T4, T5 and T6) but remained higher than 1. The bioconcentration factor of

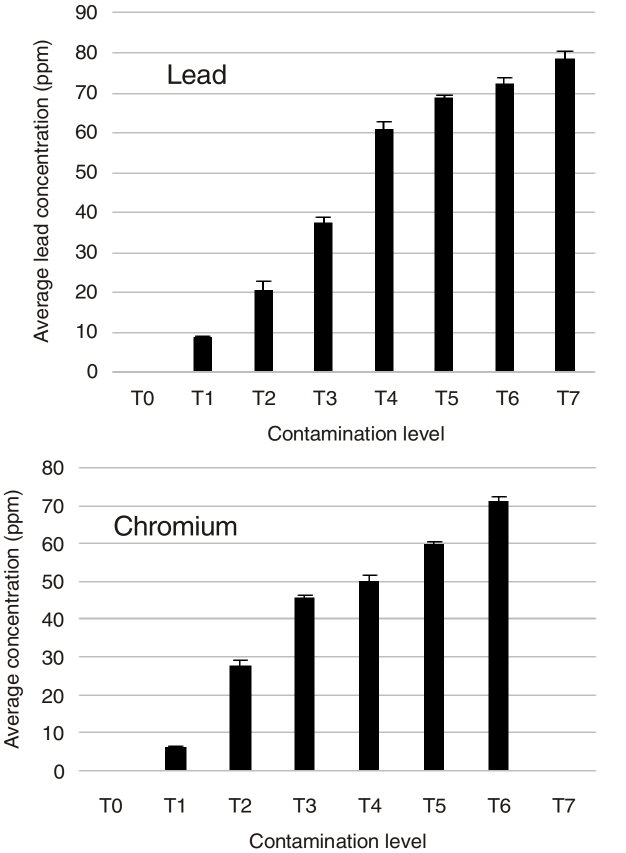

Fig. 4. Concentration of heavy metal (lead and chromium) uptake by *Zinnia elegance*

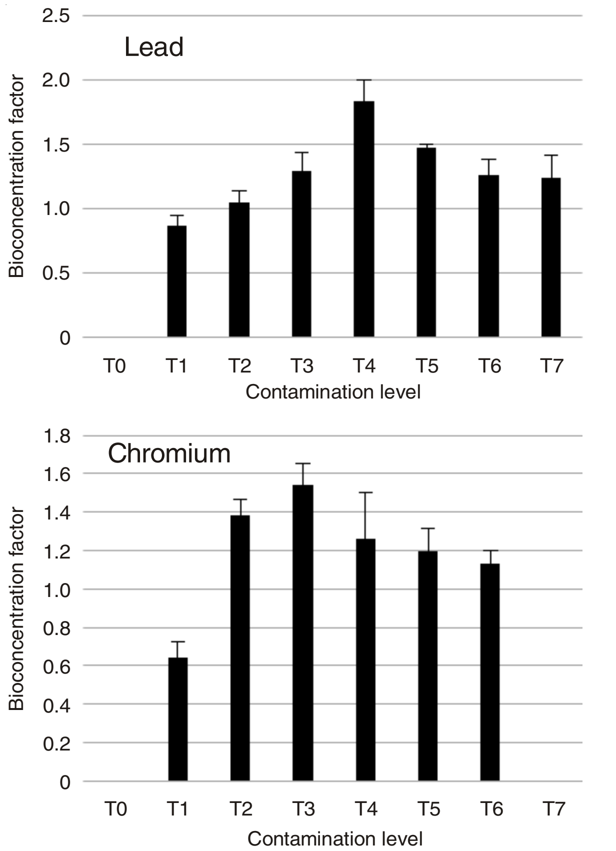

Fig. 5. Bioconcentration factor of lead and chromium treated *Zinnia elegance*

lead and chromium is presented in Fig. 5. The bioconcentration factor for lead increased with increase in contamination level reaching maximum in T4 (1.8) and in higher treatment levels (T4, T5 and T6) it decreased but remained above 1. Bioconcentration factor was not calculated for T7 as seedlings withered within 10 days of plantation. Yoon *et al.* [7] stated that the plants for which the bioconcentration factor and translocation factor is measured to be more than one (*i.e.* translocation factor and bioconcentration factor > 1) can be used in phytoextraction of heavy metals.

Translocation factor (TF): The translocation factor measures the rate of the heavy metal transported from roots to above ground parts of the plants like leaves, shoot and flowers. The translocation rate as illustrated in Fig. 6 shows that the translocation factor for chromium was higher as compared to that of lead. Bioconcentration factor and translocation factor are the key elements for the evaluation and selection of plants for phytoremediation purposes [15].

The translocation factor for lead in *Zinnia elegance* increased with increase in concentration. In T4 the translocation factor was highest *i.e.* 1.8. In high levels of lead (T5, T6 and T7) the translocation factor decreased. The translocation Factor calculated for chromium treatments increased with increase in chromium levels. The highest translocation factor was measured in T4 *i.e.* 1.1. In higher level of chromium treatments (T5 and T6) the translocation factor remained below 1.0.

The plants with bioconcentration factor greater than one and translocation factor less than one (bioconcentration factor > 1 and translocation factor < 1) have the potential for phyto-stabilization [7].

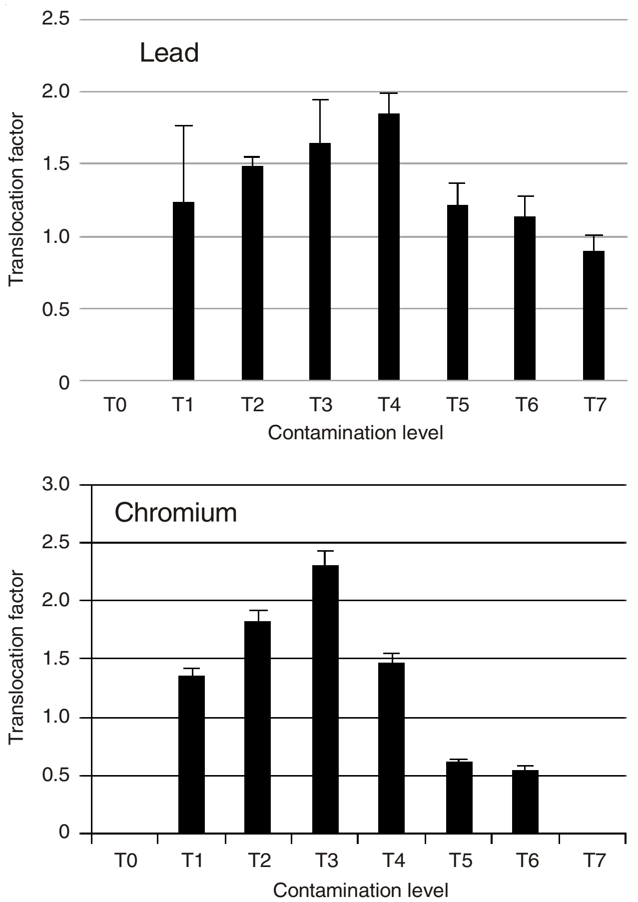

Fig. 6. Translocation factor of chromium and lead contaminated *Zinnia elegance*

Conclusion

The phytoremediation potential for an ornamental plant (*Zinnia elegance*) was assessed in different levels of contaminations of lead and chromium. The fresh and dry weight of *Zinnia elegance* was highest in 30 ppm of lead and 20 ppm of chromium. The maximum bioaccumulation factor was 1.8 for lead- and 1.5 for chromium-contaminated soils. Overall, translocation factor was higher than 1 in both heavy metal-contaminated soils. Therefore, *Zinnia elegance* plant can be used for remediation of lead- and chromium-contaminated soils. Using ornamental plants for phytoremediation will not only remove heavy metals from soils but will also enhance the aesthetic value of the area.

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