

Uptake and Removal Capability of Toxic Heavy Metals From the Industrial Discharge of Mobarakeh Steel Complex by Metal Accumulating Plants

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Introduction

Heavy metals are largely found in dispersed form in rock formations. Industrialization and urbanization have increased the anthropogenic contribution of heavy metals in the biosphere. Heavy metal pollution not only affects the production and the quality of crops, but also influences the quality of the atmosphere and water bodies, and threatens the health and life of human beings. Clean-up technologies have been developed for the removal of heavy metals but often these are expensive or have some environmentally deleterious consequences. Phytoremediation emerged in the early 1980s is an important technology for remediation of contaminated sites. One of the most promising phytoremediation technologies is phytoextraction using hyperaccumulators to remove heavy metals from contaminated soils. However, the known hyperaccumulator plants usually accumulate only a specific element and are usually small. Recently, most attention is focused to the plants that produce high biomass and are tolerant to the soils polluted with heavy metals.

T. caerulea was found to colonize areas with high Cd, Cu, Pb, and Zn present in soils due to mining. *M. chenopodiifolia* has good potential for absorbing Pb and Zn. *Eruca sativa* is tolerant to soil pollution with heavy metals and can accumulate Pb and Cd from contaminated soils. *B. napus* accumulated cadmium and zinc and translocated these elements into the harvestable parts of the plant. *S. nigrum* is often found in contaminated areas. It has previously been identified as a Cd hyperaccumulator. *H. annuus* is known for its high biomass yield. In addition, it is tolerant to soil pollution with heavy metals. *Z. mays* produce high biomass as well.

In this study, we studied the capability of stability, growth, and uptake of heavy metals by means of *T. caerulea*, *Z. mays*, *H. annuus*, *E. sativa*, *B. napus*, *S. nigrum*, and *M. chenopodiifolia* on the industrial discharge of Mobarakeh Steel Complex.

Materials and methods

Mobarakeh Steel Company is located 75 km south west of Isfahan, near the city of Mobarakeh, Isfahan Province, Iran. It is Iran's largest steel maker and one of the largest industrial complexes operating in Iran. Three type effluents (first and second type and galvanized unit) were taken from separated lagoons.

The pH of the soil was determined using a glass electrode after 10 g of soil had been stirred well in 30 ml distilled water in a beaker and allowed to stand for about 30 min. In the first experiment, pots (9 cm diameter) fill up with the first and second types and the galvanized unit effluents separately. The seeds of each plant (*T. caerulea*, *Z. mays*, *H. annuus*, *E. sativa*, *B. napus*, *S. nigrum* and *M. chenopodiifolia*) were then sown on the pots. The pots were irrigated with distilled water every three days for six weeks. The seedlings were irrigated with 100 ml nutrient solution containing 2.46 g/l KH₂PO₄, 4.72 g/l KNO₃, and 0.27 g/l Ca(NO₃)₂ every eight days instead of the distilled water. For the analysis of plant dry matter, the leaf materials were washed well with double-distilled water and dried at 70°C for 48 h. About 0.1 g of dry leaf sample was added to a 25 ml beaker and ashed in a muffle furnace for 6 h at 500°C. The ash was taken up in 10 ml 10% HNO₃ and the digest was finally made up to 50 ml in 10% HNO₃. The solutions were analyzed for elemental composition by AAS. All soil samples were air-dried and sieved to <2 mm. For the analysis of total elements, sub-samples of 4-5 g were ground to pass through a 80 mesh sieve and then oven-dried at 70°C. A further sub sample of 0.5 g was transferred to a Kjeldahl digestion tube for extraction with 10 ml of a 3:1 HCl/ HNO₃ mixture. Tubes were left at room temperature overnight and were then placed in a heating block. Each tube was covered with an air condenser and refluxed gently at 100°C for 1 h. After cooling, the digests were filtered through a moistened filter

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paper into a 50 ml volumetric flask. The flasks were made to volume with distilled water. Ten milliliters of the digest were added to 15 ml tubes and the analysis for Zn, Pb, Cr, Cd, and Ni was performed by atomic absorption spectrophotometry (AAS, Shimadzu model AA 6200).

Results

The results indicated that in the first type of effluent the amounts of heavy metals were relatively high as follow; Zn (72 mg kg^{-1}), Pb (20 mg kg^{-1}), Cr (28 mg kg^{-1}), Cd (20 mg kg^{-1}), and Ni (118 mg kg^{-1}). In the second type of effluent, these amounts were 68 mg Zn kg^{-1} , 7 mg Pb kg^{-1} , 19 mg Cr kg^{-1} , 21 mg Cd kg^{-1} , and $115 \text{ mg Ni kg}^{-1}$. In galvanized unit effluent, these amounts were high; Zn (353 mg kg^{-1}), Pb (55 mg kg^{-1}), Cr (1768 mg kg^{-1}), Cd (22 mg kg^{-1}) and Ni (114 mg kg^{-1}). The pH of the first and second types and the galvanized unit effluent were 8.4, 8.8, and 9.2, respectively (Table 1).

Table 1. The amounts of heavy metals (mg kg^{-1}) and pH in three types of effluent

Type of effluent	Zn	Pb	Cr	Cr	Ni	pH
first type	72 ± 0.3	20 ± 10.1	28 ± 9.6	28 ± 9.6	118 ± 5.1	8.4
second type	68 ± 3.8	7 ± 2.5	21 ± 0.8	19 ± 19.3	115 ± 1.8	8.8
galvanized unit	353 ± 109.5	55 ± 8.7	22 ± 0.6	512.4 ± 1767	114 ± 8.4	9.2

Among species planted on the first type of effluent, *H. annuus* had more dry weight (910 mg/plant) and *M. Chenopodiifolia* and *T. caerulescens* had less dry weight (1 mg/plant). Among the species planted on the second type of effluent, *H. annuus* had more dry weight (600 mg/plant) and *M. Chenopodiifolia* and *E. sativa* had less dry weight (51 mg/plant). Among the species planted on the effluent of the galvanized unit only *Z. mays* was able to grow. Dry weight of these species was 900 mg/plant as shown in Table 2.

Table 2. Dry weight of the species planted on three type effluents in mg per plant

Type of effluent	<i>Z. mays</i>	<i>H. annuus</i>	<i>T. caerulescens</i>	<i>S. nigrum</i>	<i>E. sativa</i>	<i>B. napus</i>	<i>M. Chenopodiifolia</i>
first type	800 ± 12	910 ± 13.2	1 ± 0.2	10 ± 3	30 ± 5	30 ± 2.1	1 ± 0.1
second type	170 ± 10	600 ± 12	Not grow	Not grown	51 ± 7.7	Not grown	Not grown
galvanized unit	900 ± 13	Not grown	Not grown	Not grown	Not grown	Not grown	Not grown

The highest accumulation of Zn was taken up by *T. caerulescens* (91.5 mg/kg). The most accumulation of Pb by *T. caerulescens* was 74 mg/kg . The most accumulation of Cr by *T. caerulescens* was 637 mg/kg . The most accumulation of Cd by *B. napus* was 6.6 mg/kg . The most accumulation of Ni by *T. caerulescens* was 226.3 mg/kg .

In the second type of effluent, the most accumulation of Zn and Pb by *Z. mays* was 40.1 mg/kg and 117.2 mg/kg , respectively. The most accumulation of Cr by *E. sativa* was 117.2 mg/kg . Amount of Cd uptaken by *Z. mays*, *H. annuus*, and *E. sativa* were 12.2 mg/kg , 14.9 mg/kg and 14 mg/kg , respectively. The most Ni accumulation by *E. sativa* was 121.2 mg/kg .

Z. mays was the only species that could grow on the galvanized unit effluent. It could accumulate Zn, Pb, Cr, Cd, and Ni to 57 mg/kg , 68 mg/kg , 309 mg/kg , 32.5 mg/kg , and 55.4 mg/kg , respectively.

Discussion

In some countries excessive concentrations of toxic heavy metals such as Zn, Pb, Cd, Cr, and Ni in soils in mining areas and around smelters are the sources of serious environmental and health hazards. Among seven

species planted on the first type of effluent, *T. caerulescens* could accumulate Zn, Pb, Cr, and Ni to a large extent and it could almost grow on the industrial discharges. The hyperaccumulator plant *T. caerulescens* is able to grow on the contaminated soils by heavy metals. These species have received much attention as a potential candidate for phytoextraction of Zn and Cd from the contaminated soils. *B. napus* could accumulate Cd to a large extent. Brassica family (*B. napus*, *Brassica juncea* and *R. sativus*) has been suggested for phytoremediation of the heavy metals. Four species (*Z. mays*, *H. annuus*, *E. sativa* and *B. napus*) were able to grow well and uptake heavy metals from all types of effluents. Among seven species planted on the second type of effluent, *Z. mays* could accumulate Zn and Pb and *E. sativa* could accumulate Cr and Ni to a large extent. *H. annuus* was the only species tolerant on the effluent and could produce high biomass yield. Hence, these species have been described or proposed for phytoremediation of the heavy metals. Among seven species planted on the effluent of the galvanized unit, *Z. mays* was the only one able to well grow and accumulate Cr to a large extent.

Conclusion

The acquired results indicated that *Z. mays*, *H. annuus*, *E. sativa*, and *B. napus* were able to well grow and uptake heavy metals from the first type effluent. Among seven species planted on the second type of effluent, *H. annuus* was the best species for phytoremediation. For phytoremediation of heavy metals from the galvanized unit effluent, *Z. mays* was the only suitable species.

Keywords: industrial effluent of Mobarakeh Steel Complex, heavy metals, phytoremediation.