Assessment of heavy metal tolerance in native plant species from soils contaminated with electroplating effluent

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ABSTRACT

Heavy metals concentrations of (Cr, Zn, Fe, Cu and Ni) were determined in plants and soils contaminated with electroplating industrial effluent. The ranges of total soil Cr, Zn, Fe, Cu and Ni concentrations were found to be 1443–3240, 1376–3112, 683–2228, 263–374 and 234–335 mg kg^{-1}, respectively. Metal accumulation, along with hyperaccumulative characteristics of the screened plants was investigated. Present study highlighted that metal accumulation in different plants varied with species, tissues and metals. Only one plant (*Amaranthus viridis*) accumulated Fe concentrations over 1000 mg kg^{-1}. On the basis of TF, eight plant species for Zn and Fe, three plant species for Cu and two plant species for Ni, could be used in phytoextraction technology. Although BAF of all plant species was lesser than one, these species exhibited high metal adaptability and could be considered as potential hyperaccumulators. Phytoremediation potential of these plants can be used to remediate metal contaminated soils, though further investigation is still needed.

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1. Introduction

Heavy metal concentrations in past few years have reached to a promising toxic level due to consequences of anthropogenic activities and urbanization. Nowadays it is well-known that cities suffer from considerable pollution due to a wide array of substances that contaminate the air, water and soil (Rucandio et al., 2010). Metal persistence in soil for much longer periods than in other compartments of the biosphere is a matter of serious concern. International Agency for Research on Cancer (Beyersmann and Hartwig, 2008) has classified heavy metals like arsenic, cadmium, chromium, nickel, lead, etc. to be carcinogenic to humans and wildlife. Over recent decades, the annual world-wide release of heavy metals reached 22,000 t (metric ton) for cadmium, 939,000 t for copper, 783,000 t for lead and 1,350,000 t for zinc (Singh et al., 2003; Sarma, 2011). Conventional techniques that are used for remediation for contaminated soil are costly, disruptive and labor intensive (Raskin and Ensley, 2000; Butcher, 2009). For example the cost of cleaning up contaminated sites is extremely high, in the USA alone, $6–8 billion is spent annually in remediation efforts, with global costs in the range of $25–50 billion (Tsao, 2003). Recently there is considerable interest in developing sustainable, cost-effective technologies for remediation of heavy metal-contaminated soil and water (Chatterjee et al., 2010). Therefore, plants can be used to ameliorate heavy metal pollutants from the soil and this cost effective approach is called phytoremediation also referred as "green solution" (Willey, 2007; Butcher 2009). Phytoremediation is approximately 10 times less expensive than conventional strategies (Chappell, 1998). Phytoextraction is one of the most widely investigated approaches of phytoremediation, which involves the use of plants to remove the contaminants from the soil into above ground biomass. Phytoextraction is an effective means of remediating a site because it reduces the overall mass to be treated from tons of widespread contaminated soil to plant tissue that can be dried to a small volume (Doty, 2008). Hyperaccumulators may be one of the best choices for this application because they can accumulate excessively high amounts of metals in their harvestable part which are easy to dispose. According to Baker et al. (2000) metal hyperaccumulator is defined as a plant that can accumulate the metal to a leaf of 0.1% of nickel, cobalt, chromium, copper and lead, 1% of zinc and 0.01% of cadmium. Over 500 plant species comprising of 101 families have been reported, including members of the Asteraceae, Brassicaceae, Caryophyllaceae, Cyperaceae, Cunouniaceae, Fabaceae, Flacourtiaceae, Lamiaceae, Poaceae,

Violaceae and Euphobiaceae (Sarma, 2011). Metal hyperaccumulation occurs in approximately 0.2% of all angiosperms and is particularly well represented in the Brassicaceae (Kramer, 2010). Wide variety of species has been studied by many researchers for their phytoremediation potential for example, *Thlaspi caerulescens* for Cd and Zn (Brown et al., 1995), *Pteris vittata* for arsenic (Zhang et al., 2002), *Helianthus annus* for lead (Boonyapookan et al., 2005), *Alyssum* for Ni (Reeves and Brooks, 1983) and *Rorippa globosa* for Cd (Sun et al., 2010), etc. Importance of hyperaccumulators has emphasized on further research in exploring the contaminated sites and finding new hyperaccumulator plants. Many plant species have become metal tolerant due to the adaptive responses of plant species to heavy metals, as these species are growing in contaminated sites from a long period. According to Yoon et al. (2006) native plants should be preferred for phytoremediation because these plants are often better in terms of survival, growth and reproduction under environmental stress than plants introduced from other environment. In the vicinity of Rohtak city (Haryana, India), few electroplating industries are situated and these industries are discharging their effluent in nearby soils, which contain high amounts of Cr, Zn, Fe, Cu and Ni. The presence of heavy metals in industrial waste water poses serious problems when discharged into water bodies or soils due to its constant deposition, which affect our ecosystem. Therefore this study was performed (1) to determine the concentration of heavy metals in soil and plants of the contaminated area; (2) to compare metal concentration in shoots to those in roots and in soils and (3) to check the phytoremediation efficiency of plants dominating the contaminated sites. Plants having relatively high phytoremediation potential could be used for the remediation for metal contaminated soils of the sites.

2. Materials and methods

2.1. Site description

The study was conducted in Rohtak city (Haryana state, India), which is located between 76°25′ and 76°94′ East longitudes and 28°35′ and 28°80′ North latitude, lying at 219.84 m above sea level. The climate in this area is classified as continental with extremes of heat in summer and markedly cold in winters. Rohtak city receives an annual rainfall from 550 to 1100 mm and sandy loam and alluvial textured soil. Four different sites were taken from Rohtak city, where electroplating industries are situated. Laxmi precisions screw industries ltd. is the largest electroplating industry in the city and has two different plants (branches). Plant 1 is located nearby residential areas of Rohtak city and Plant 2 of this electroplating industry is surrounded by agricultural land. Vee automatics ltd. and Jai Bharat industries are located outside the residential boundary, still their industrial discharge is contaminating the soil as well as ground water of the city.

Plant 1 of Laxmi precisions screw industries ltd. was taken as site 1, plant 2 of Laxmi precisions screw industries ltd. industry as site 2, Vee automatics ltd. as site 3 and Jai Bharat industries as site 4.

2.2. Soil analysis

Soil samples (0–20 cm in depth) were collected from above mentioned different electroplating industries of Rohtak city during March 2008 to March 2009. For each site, 10–20 sub-samples were randomly collected and combined into a composite sample, and 1 kg sub-sample of composite sample was taken back to laboratory for sample preparation and analysis. Chemical characteristics of the soil used in the experiments are listed in Table 1. The samples were oven dried at 70 °C for 72 h, then ground into fine powder and sieved through a 2-mm nylon mesh sieve. In case of DTPA extraction soil was air dried. Soil pH and electrical conductivity (EC) were determined after mixing a soil and water (1:2) for 1 h. Organic matter was measured by the Walkley–Black titration method (Walkley and Black, 1934); total N by Kjeldhal method (Black, 1965) and cation exchange capacity (CEC) by leaching with NH_4OAc at pH 7 followed by distillation (Rayment and Higginson, 1992). Available P was extracted by the Bray II method (Bray and Kurtz, 1945) and available K using 1:5 (w/v) fresh sample: extractant ratio of 1 M NH_4OAc, at pH 7, shaken for 1 h on a reciprocating shaker at 250 rev min^{-1} (Helmeke and Sparks, 1996) and then analyzed by flame photometer. Sodium and sulfate analysis was done as per the methods given in USDA Handbook No. 60. To determine the total metal concentrations in soil samples, 0.5 g of each sample was digested in aqua regia (3:1 $HCl:HNO_3$ by volume) using hot block digestion procedure (USEPA Method 3050). Diethylene tri-amine penta-acetic acid (DTPA) extractable metal concentrations were determined according to Lindsay and Norvell (1978). The total and extractable metal concentrations were measured by a flame atomic absorption spectrophotometer (AAS Hitachi Z-6100).

2.3. Plant analysis

An ecological survey was done from March 2008 to March 2009. Plant samples were collected from the same sites as the soil samples. Plant identification was confirmed by the Forest Research of India, Dehradun. At least three to five individuals of all plant species were randomly collected within the sampling areas. Fresh plant materials were washed thoroughly the tap water, cleaned with distilled water and then separated into roots and shoots. All plant parts were oven dried at 72 °C for 72 h and then ground to powders using a Wiley Mill. For total metal concentrations in the plant components 0.5 g of plant samples were digested using the hot block digestion procedure (USEPA Method 3050). The total metal concentrations were measured by a flame atomic absorption spectrophotometer (AAS Hitachi Z-6100). To assess the analytical precision, three analytical replicates of each sample, an appropriate standard reference material (from Sigma-Aldrich Company) and a reagent blank were performed in each analytical batch.

2.4. Statistical analysis

Bioaccumulation factor (BF) is defined as the ratio of total metal concentration in shoots to that in soil (DM), which is a measure of the ability of a plant uptake and transport metals to the shoots (Caille et al., 2005). The translocation factor (TF) is defined as the ratio of total metal concentration in the plants shoot to that

Table 1
Characteristics of soils from four studied sites.

Characteristics	Site 1	Site 2	Site 3	Site 4
pH (1:2)	6.33 ± 0.05[a]	6.92 ± 0.07[a]	6.58 ± 0.00[a]	6.86 ± 0.08[a]
EC (dS m^{-1})[*]	0.23 ± 0.01[a]	0.34 ± 0.00[b]	0.27 ± 0.00[a]	0.58 ± 0.00[c]
Organic matter (g kg^{-1})	8.1 ± 1.15[a]	7.3 ± 0.86[a]	9.6 ± 1.04[b]	12.4 ± 2.08[c]
CEC (cmol$_c$ kg^{-1})[**]	7.25 ± 0.46[a]	9.31 ± 0.23[b]	8.46 ± 0.36[c]	8.72 ± 0.42[c]
Available P (mg kg^{-1})	6.85 ± 0.73[a]	8.52 ± 0.57[c]	7.11 ± 0.63[c]	5.34 ± 0.46[b]
Available K (mg kg^{-1})	62.93 ± 0.28[b]	67.21 ± 0.49[b]	79.74 ± 0.72[a]	83.68 ± 0.88[a]
Sulfates (mg kg^{-1})	71.42 ± 0.98[a]	62.28 ± 0.65[b]	67.35 ± 0.38[b]	58.66 ± 0.44[c]
Total N (%)	0.08 ± 0.02[c]	0.11 ± 0.03[b]	0.09 ± 0.02[c]	0.07 ± 0.01[a]
Sodium (mg kg^{-1})	73.90 ± 0.32[a]	69.31 ± 0.38[a]	71.57 ± 0.46[a]	76.42 ± 0.58[a]
Total Cr (mg kg^{-1})	3240 ± 94.3[a]	1172 ± 29.5[d]	1443 ± 28.3[c]	2195 ± 54.1[b]
Total Zn (mg kg^{-1})	3112 ± 79.0[a]	1376 ± 35.4[d]	1645 ± 40.2[c]	1824 ± 36.6[b]
Total Fe (mg kg^{-1})	2228 ± 48.2[a]	805 ± 28.2[c]	683 ± 23.42[d]	1167 ± 33.1[b]
Total Cu (mg kg^{-1})	374 ± 15.6[a]	263 ± 16.7[d]	280 ± 12.2[c]	322 ± 14.9[b]
Total Ni (mg kg^{-1})	335 ± 12.2[a]	251 ± 11.8[c]	234 ± 13.6[c]	298 ± 10.1[b]

Mean values with rows followed by same letter are not significantly different according to Newman Keul's multiple range test ($p < 0.05$).

[*] EC = electrical conductivity.

[**] CEC = cation exchange capacity.