Accumulation of Pb, Zn, Cu and Fe in plants and hyperaccumulator choice in Galali iron mine area, Iran

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ABSTRACT: In current time the environment is heavily polluted by various toxic metals, which create a danger for all living beings. Phytoremediation can be potentially used to remediate metal-contaminated sites. A major step towards the development of phytoremediation of heavy metal impacted soils is the discovery of the heavy metal hyperaccumulation in plants. This study evaluated the potential of 23 species growing on a contaminated site in a mining area. The case study was represented by a mining area in Hamadan province in the North West part of Iran. This study showed that the most of sampled species were able to grow on heavily metal-contaminated soils and also were able to accumulate extraordinarily high concentrations of some metals such as Pb, Zn, Cu and Fe. Based on the obtained results and using the most common criteria, Euphorbia macroclada can be classified as hyperaccumulator of some measured heavy metals and, therefore, it has suitable potential for phytoremediation of contaminated soils.

Keywords: Heavy metals; Hyperaccumulator; Phytoremediation; Galali mine; Euphorbia macroclada

INTRODUCTION

Human activity has continuously increasing the level of heavy metals circulating in the environment. Heavy metal pollution of the biosphere has accelerated rapidly since the onset of the industrial revolution and heavy metal toxicity poses major environmental problems (Gisbert et al., 2003). Phytoremediation is a relatively new approach to removing contaminants from the environment. It may be defined as the use of plants to remove, destroy or sequester hazardous substances from environment. It has become a topical research field in the last decades as it is safe and potentially cheap compared to traditional remediation techniques (Salt et al., 1998; Mitch, 2002; Glick, 2003; Pulford and Watson, 2003). Phytoremediation is currently divided into many types: phytoextraction (hyperaccumulator), phytodegradation, rhizofiltration, phytostabilization and phytovolatilization (Salt et al., 1998). Most of reviews focus on the phytoremediation of the metallic pollutants in soil, particularly the area of metal hyperaccumulator, which is the area of major scientific and technological progress in the past years (Brown et al., 1995; Cunningham et al., 1995; Cunningham and Ow, 1996). There were many reports of hyperaccumulating plant (Berti and Cunningham, 1993; Brown et al., 1995; Shen and Liu, 1998; Ozturk et al., 2003). A hyperaccumulator has been defined as a plant that can accumulate: 1000 mg/kg of Cu, Co, Cr, Ni and Pb, or 10000 mg/kg of Fe, Mn and Zn in their shoot dry matter (Baker and Brooks, 1989; Market, 2003), and in accumulator plants, the metal concentrations in shoots are invariably greater than that in roots, showing a special ability of the plant to absorb and transport metals and store them in their above-ground part (Baker and Brooks, 1989; Baker et al., 1994; Brown et al., 1995; Wei et al., 2002). Meanwhile, a hyperaccumulator is regarded as plant which the concentrations of heavy metal in shoots are greater than that in soils, meaning higher metal concentrations in the plant than in the soil, which emphasizes the degree of plant metal uptake (McGrath and Zhao, 2003; Yanqun et al., 2005). To some extent, it will be useful to find some plants that have accumulating ability to heavy metals. In this study, we investigated the concentrations, translocation and enrichment factors of Pb, Zn, Cu and Fe of 23 plant species in...
Galali Iran mine with the objective to (1) get better knowledge of the accumulating capacity of 23 plant species to Pb, Zn, Cu and Fe, and (2) choose hyperaccumulator that would be used for the remediation of agricultural field polluted by heavy metals and metal mine area soils.

MATERIALS AND METHODS

Site description
The plant and soil samples used in this study were collected of Galaly Iron Mine located at the north west of Hamedan 58 Km far away from Hamedan and 50 Km from Asadabad (Figure 1). The average rainfall is about 330 mm and annual temperature is between 33 and 40 °C. The dried waste pools of the mines should be considered as high concentrated metal sources because the sedimentations of wastewater resulted from washing processes of mining were stored in pods and then dried. An artificial old dried waste pool of an Iron mine, located between Hamedan and Asadabad in Iran, was studied as a polluted area in this research.

Figure 1. A map of Iran that show Galali Iron mine at the north west of Hamedan

Sampling
Samples of plant and soil were collected from studied area. 23 plant species were collected in the surrounding area of Galali mine from May to June 2011. (Table 1).

<table>
<thead>
<tr>
<th>Plant name</th>
<th>Family</th>
</tr>
</thead>
<tbody>
<tr>
<td>Achillea wilhelmsii C. Koch.</td>
<td>Asteraceae</td>
</tr>
<tr>
<td>Centaurea oxyacantha M. B.</td>
<td>Asteraceae</td>
</tr>
<tr>
<td>Centaurea iberica Trev. ex Spreng.</td>
<td>Asteraceae</td>
</tr>
<tr>
<td>Centaurea virgata Lam</td>
<td>Asteraceae</td>
</tr>
<tr>
<td>Cirsium lappaceum M.B. var. tomentosum Boiss.</td>
<td>Asteraceae</td>
</tr>
<tr>
<td>Tanacetum polyccephalum Schultz. Bip.</td>
<td>Asteraceae</td>
</tr>
<tr>
<td>Xanthium strumarium L.</td>
<td>Asteraceae</td>
</tr>
<tr>
<td>Heliotropium europaeum</td>
<td>Asteraceae</td>
</tr>
<tr>
<td>Chenopodium botrys L.</td>
<td>Chenopodiaceae</td>
</tr>
<tr>
<td>Euphorbia cheiradenia Boiss. et Hohen ex Boiss.</td>
<td>Euphorbiaceae</td>
</tr>
<tr>
<td>Euphorbia macroclada Boiss. &amp;Buhse.</td>
<td>Euphorbiaceae</td>
</tr>
<tr>
<td>Astragalus gossypinus Fisch.</td>
<td>Papilionaceae</td>
</tr>
<tr>
<td>Salvia spinosa L.</td>
<td>Labiatae</td>
</tr>
<tr>
<td>Ziziphoran clinopodioides Lam.</td>
<td>Labiatae</td>
</tr>
<tr>
<td>Malva neglecta</td>
<td>Malvaceae</td>
</tr>
<tr>
<td>Epilobium frigidum Hausskn.</td>
<td>Onagraceae</td>
</tr>
<tr>
<td>Silpa barbata Desf.</td>
<td>Gramineaceae</td>
</tr>
<tr>
<td>Reseda lutea L.</td>
<td>Resedaceae</td>
</tr>
<tr>
<td>Sanguisorba minor Scop.</td>
<td>Rosaceae</td>
</tr>
<tr>
<td>Galium grandiflorum</td>
<td>Rubiaceae</td>
</tr>
<tr>
<td>Scrophularia striata Boiss.</td>
<td>Scropholiaceae</td>
</tr>
<tr>
<td>Verbescum speciosum Scharder.</td>
<td>Scropholiaceae</td>
</tr>
<tr>
<td>Tamarix ramosissima Ledeb.</td>
<td>Tamaricaceae</td>
</tr>
</tbody>
</table>
Plant analysis

To estimate the total heavy metals in the plants, samples (roots, shoots and leaves) were dried at 105 °C for 24h in acid-washed and reweighed volumetric 100 ml Pyrex conical flasks. The content (about 1 g) was digested in 20 ml of boiling concentrated (65%) nitric acid (especially made pure for spectroscopy). The solution was boiled in a hot plate until light fumes were given off. Next, the samples were cooled down and the digests were filled up to 100 ml with deionized water and left overnight to allow the remaining soil particles to settle out of the suspension. Finally, 20 ml of each sample solution was used for heavy metal concentration measurements, using the flame atomic absorption method for Pb, Cu, Zn and Fe (Anaalyst 800, Perkin-Elmer). The accumulator plants were identified regarding the concentration of heavy metals in the subjected plants.

Soil analysis

Heavy metals were determined in soil samples of the sediment of the mine area that was regarded as a polluted soil and the soil samples of 5Km further than the mine that were regarded as natural soil. At each subjected plot, 10-15 samples of the soil (depth 10-15 cm) were taken and sieved through a 1 cm sieve.

RESULTS

Concentrations of Pb, Zn, Cu and Fe in plants

Total Pb concentrations in the plant samples collected from the site were variable, ranging from 10 to109.49 at roots and 13.97 to 120.55 mg kg⁻¹ at shoots, with the maximum level in the roots of Stip barbata and shoots of Carthamus oxyacantha. Zn concentrations in plant roots differed among species at the polluted site from 9.12 mg/kg to 2478.00 mg/kg and in shoots from 10.74 to 2101/91 mg/kg, with the maximum content in the roots of Salvina spinosa and shoots of Malva neglecta. Total Cu concentrations in the plant roots ranged from 16.39 mg/kg to as high as 1275.29 mg/kg and plant shoots from 40.88 mg/kg to as high as 1262.37 mg/kg, with the maximum level in the roots of Euphorbia macroclada and shoots of Verbascum Speciosum. Fe concentrations in plant roots differed among species at the polluted site from 36.64 mg/kg to 93266.00 mg/kg and in shoots from 151.56 to 35722.80 mg/kg, with the maximum content in the roots of Centurea iberica and shoots of Carthamus oxyacantha. Concentrations of Cu, Zn, Pb and Fe in collected plant species are provided in Table 2. The study indicated that the best Cu accumulator plant in aerial part, was Euphorbia macroclada (1275.29 mg/kg) but some species including M. neglecta (1116.59 mg/kg), V. speciosum (1262.37) and S. striata (777.37 mg/kg) also accumulated Cu considerably (Fig 2). Analyzing the amount of Fe in the experimental plants showed that we can consider C. oxyacantha as the best Fe accumulator (73906.7 mg/kg) in aerial parts but the amount of Fe in Euphorbia macroclada, R. lutea and C. iberica was also more than the other studied plants (Fig3).

Results showed that the best Pb accumulator overall was C. oxyacantha (120.55 mg/kg), while the plants M.neglecta, C. iberica, M. neglecta and Euphorbia macroclada were an accumulated it more than others (Fig 4). Results showed that the best Zn accumulator overall was while M.neglecta, Euphorbia macroclada, Tanacetum polycephalum, R. lutea, C. oxyacantha, C. iberica, S. barbata and S. striata were other accumulators (Fig 5).

![Figure 2. The density of copper in roots and shoots of plant species](image-url)
Table 2. The comparison of the results of heavy metals analysis in roots and shoots of collected plants in Galali Iron mine (DW mg/kg)

<table>
<thead>
<tr>
<th>Plant name</th>
<th>Plant part</th>
<th>Cu</th>
<th>Fe</th>
<th>Pb</th>
<th>Zn</th>
<th>Plant name</th>
<th>Plant part</th>
<th>Cu</th>
<th>Fe</th>
<th>Pb</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Euphorbia macroclada</td>
<td>Root</td>
<td>1275.29</td>
<td>66148.00</td>
<td>29.50</td>
<td>1015.74</td>
<td>Centaurea iberica</td>
<td>Root</td>
<td>856.75</td>
<td>93266.00</td>
<td>30.69</td>
<td>499.21</td>
</tr>
<tr>
<td></td>
<td>Shoot</td>
<td>520.43</td>
<td>41370.50</td>
<td>24.58</td>
<td>354.43</td>
<td></td>
<td>Shoot</td>
<td>543.23</td>
<td>35722.80</td>
<td>28.44</td>
<td>527.11</td>
</tr>
<tr>
<td>Salvia spinosa</td>
<td>Root</td>
<td>812.48</td>
<td>57375.10</td>
<td>26.59</td>
<td>2478.00</td>
<td>Verbascum speciosum</td>
<td>Root</td>
<td>740.76</td>
<td>25452.20</td>
<td>30.14</td>
<td>135.27</td>
</tr>
<tr>
<td></td>
<td>Shoot</td>
<td>630.72</td>
<td>13460.00</td>
<td>45.65</td>
<td>1057.69</td>
<td>Stipa barbata</td>
<td>Shoot</td>
<td>1262.37</td>
<td>26081.00</td>
<td>29.25</td>
<td>802.60</td>
</tr>
<tr>
<td>Tanacetum polycephalum</td>
<td>Root</td>
<td>456.71</td>
<td>24154.70</td>
<td>26.64</td>
<td>626.46</td>
<td></td>
<td>Root</td>
<td>1254.82</td>
<td>24428.00</td>
<td>109.49</td>
<td>807.22</td>
</tr>
<tr>
<td></td>
<td>Shoot</td>
<td>673.19</td>
<td>14005.40</td>
<td>26.67</td>
<td>914.08</td>
<td></td>
<td>Shoot</td>
<td>257.39</td>
<td>23379.50</td>
<td>33.99</td>
<td>312.02</td>
</tr>
<tr>
<td>Reseda lutea</td>
<td>Root</td>
<td>394.00</td>
<td>18413.90</td>
<td>26.32</td>
<td>557.58</td>
<td>Scrophularia striata</td>
<td>Root</td>
<td>381.05</td>
<td>32841.08</td>
<td>32.49</td>
<td>646.23</td>
</tr>
<tr>
<td>Carthamus oxyacantha</td>
<td>Root</td>
<td>551.67</td>
<td>48116.10</td>
<td>21.26</td>
<td>481.59</td>
<td>Centaurea virgata</td>
<td>Shoot</td>
<td>777.37</td>
<td>12614.60</td>
<td>32.90</td>
<td>863.49</td>
</tr>
<tr>
<td>Malva neglecta</td>
<td>Root</td>
<td>779.83</td>
<td>38999.80</td>
<td>33.36</td>
<td>702.25</td>
<td>Chenopodium botrys</td>
<td>Root</td>
<td>694.11</td>
<td>32773.10</td>
<td>32.53</td>
<td>398.13</td>
</tr>
<tr>
<td></td>
<td>Shoot</td>
<td>1116.59</td>
<td>9826.90</td>
<td>42.81</td>
<td>2101.91</td>
<td></td>
<td>Shoot</td>
<td>543.91</td>
<td>23677.30</td>
<td>23.91</td>
<td>420.13</td>
</tr>
</tbody>
</table>

![Graph](image-url)  
Figure 3. The density of Iron in roots and shoots of plant species.
Concentrations of Pb, Zn, Cu and Fe in soils

Table 3 shows the values of the heavy metals in different localities on the mine activity areas. Here were detected the average values 272.052 mg/kg, 423.114 mg/kg, 1011.175 mg/kg, and 46600.100 mg/kg for Pb, Zn, Cu and Fe, respectively. Results showed that the amounts of the most studied metals are several times higher than natural soils. Based on the results we can conclude that this main area is a heavy metal polluted area.

Table 3. The results of soil analysis

<table>
<thead>
<tr>
<th>Element</th>
<th>Pb</th>
<th>Zn</th>
<th>Cu</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total amount of element</td>
<td>272.052</td>
<td>423.114</td>
<td>1011.175</td>
<td>46600.100</td>
</tr>
</tbody>
</table>

Figure 4. The density of lead in roots and shoots of plant species

Figure 5. The density of zinc in roots and shoots of plant species
DISCUSSION

This is the first report about the concentrations of Pb, Zn, Cu and Fe of 23 plant species and hyperaccumulator choice in Galali Iron mine area, Hamedan, Iran. The discussion will be concentrated on uptake and accumulation of Pb, Zn, Cu and Fe, and the choice of hyperaccumulator plants.

The present study showed that some plants can colonize sites with a wide range of metal concentrations in the soils. According to Istvan and Benton (1997) and Kabata-Pendias and Pendias (1984), 200 mg/kg Zn, 20 mg/kg Cu, 300 mg/kg Pb and 3800 mg/kg Fe, would be considered normal concentrations based on total fractions in soil. The metal contents (Zn, Cu, Pb and Fe) in the surrounding area of mine greatly exceed these ranges (Table 3).

Metal concentrations in plants vary with plant species (Alloway et al., 1990). According to Istvan and Benton (1997), toxic concentrations of heavy metals for various plant species are 100, 20, 300 and 500 mg/kg for Zn, Cu, Pb and Fe, respectively; therefore in the most of the plant samples, heavy metal contents were higher than toxic levels.

When categorizing plants that can grow in the presence of toxic elements, the terms “tolerant” and “hyperaccumulator” are used. A tolerant species is one that can grow on soil with concentrations of a particular element that are toxic to most other plants.

The concept of phytoremediation was first proposed by Chaney (1983) and involves the use of plant hyperaccumulators of heavy metals to remove pollutants from soils or waters. Hyperaccumulators accumulate appreciable quantities of metal in their tissue regardless of the concentration of metal in the soil (Prasad and Freitas, 2003). Accumulators are species capable of accumulating metals at levels 100-fold greater than those typically measured in shoots of common non-accumulator plants. Thus, an accumulator will concentrate more than 10 ppm Hg, 100 ppm Cd, 1000 ppm Co, Cr, Cu, and Pb, 10000 ppm Zn, and Ni (Baker et al., 2000; Dahmani-Muller et al., 2000). Regarding different habitats we need a wide variety of accumulating plants for phytoremediation in different conditions. Using the native plants is an interesting strategy to achieve this aim.

According to the results of the following study, the plants mentioned below can be regarded as heavy metal accumulators while they are different regarding their accumulating ability: Euphorbia macroclada, Reseda lutea and Centaurea virgata (Tables 2). Based on the results, Reseda lutea can be considered as a Fe accumulator. The study indicates that Euphorbia macroclada is the best Cu, Pb and Zn accumulator while, Centaurea virgata, Scariola orientalis and Cirsium Congestum also considerably accumulate these metals (Tables 2). To conclude, E. macroclada should be considered as the best and the right Pb accumulator plant (according to Baker et al., 2000) because it accumulated more than 1000 ppm (1138 ppm).

The study concludes that Euphorbia macroclada is an accumulator plant for most studied metals, and Reseda lutea for Fe. This is the first report on their ability as metal accumulator.

E. macroclada was selected as a good metal accumulator especially a good Pb accumulator, and then it was chosen for metal remediation. Its ability to remove heavy metals from polluted soils has been evaluated as well. E. macroclada is suggested for removing and detoxification of heavy metals, (especially Pb, Cu, Fe and Zn), from polluted soils. Amounts of heavy metals were determined in different parts of E. macroclada. The data indicated that the reaction of E. macroclada towards Cu is rhizofiltration while Fe, Pb, are accumulated in leaves followed by shoots, thus the reaction is bioaccumulation.

Phytoremediation has recently become a subject of intense public and scientific interest and a topic of many recent researches (Salt et al., 1995; Raskin et al., 1994; Cunningham et al. 1995; Cunningham and Ow, 1995; Raskin, 1997; Kumar Maili and Jaiswal 2007; Muneer et al., 2007; Sun, et al., 2007). E. macroclada is a xerophyte plant which grows in non-sufficient and poor soils. Phytoremediation of heavy metals is a cost-effective green technology; there are more advantages, when it comes to the use of native plants (such as E. macroclada). This is the first report on the ability of E. macroclada in soil detoxification.

CONCLUSION

The study concludes that Euphorbia macroclada is a multiple accumulator plant for most studied metals. Evaluation of its ability in detoxification metal-polluted soils indicate that E. macroclada is useful for detoxification of large polluted area. This is the first report on its ability as metal accumulator.

REFERENCES


