Review Articles

Heavy Metals in Plants and Phytoremediation

A State-of-the-Art Report with Special Reference to Literature Published in Chinese Journals

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Abstract

Goal, Scope and Background. In some cases, soil, water and food are heavily polluted by heavy metals in China. To use plants to remediate heavy metal pollution would be an effective technique in pollution control. The accumulation of heavy metals in plants and the role of plants in removing pollutants should be understood in order to implement phytoremediation, which makes use of plants to extract, transfer and stabilize heavy metals from soil and water.

Methods. The information has been compiled from Chinese publications stemming mostly from the last decade, to show the research results on heavy metals in plants and the role of plants in controlling heavy metal pollution, and to provide a general outlook of phytoremediation in China. Related references from scientific journals and university journals are searched and summarized in sections concerning the accumulation of heavy metals in plants, plants for heavy metal purification and phytoremediation techniques.

Results and Discussion. Plants can take up heavy metals by their roots, or even via their stems and leaves, and accumulate them in their organs. Plants take up elements selectively. Accumulation and distribution of heavy metals in the plant depends on the plant species, element species, chemical and bioavailiability, redox, pH, cation exchange capacity, dissolved oxygen, temperature and secretion of roots.

Plants are employed in the decontamination of heavy metals from polluted water and have demonstrated high performances in treating mineral tailing water and industrial effluents. The purification capacity of heavy metals by plants are affected by several factors, such as the concentration of the heavy metals, species of elements, plant species, exposure duration, temperature and pH.

Conclusions. Phytoremediation, which makes use of vegetation to remove, detoxify, or stabilize persistent pollutants, is a green and environmentally-friendly tool for cleaning polluted soil and water. The advantage of high biomass productive and easy disposal makes plants most useful to remediate heavy metals on site.

Recommendations and Outlook. Based on knowledge of the heavy metal accumulation in plants, it is possible to select those species of crops and pasturage herbs, which accumulate fewer heavy metals, for food cultivation and fodder for animals; and to select those hyperaccumulation species for extracting heavy metals from soil and water. Studies on the mechanisms and application of hyperaccumulation are necessary in China for developing phytoremediation.

Keywords: Accumulation; constructed wetland; distribution; phytoextraction; phytofiltration; phytostabilization; phytovolatilization; purification; soil; wastewater

Introduction

Since the soil, water and food are heavily polluted by heavy metals in China in some cases (Wu et al. 1989, Liao 1993, Guo 1994, Su et al. 1994, Wang et al. 2001), clearing up and remediating the heavy metal pollution in the environment to avoid its threats to animals and human beings is very urgently needed. Plants play an important role in the solar energy transport to bio-energy. On the one hand, it produces food for animals and human beings, while, on the other, it can clean the environment to make the environment more friendly. Plants would be one of the key actors in heavy metal remediation.

In China, more studies are focused on the interaction of heavy metals and plants (Zhao and Bi 1999, Zhang and Huang, 2000). The work on heavy metal phytoremediation has been started (Xia and Chen 1997, Jiang et al. 2000a, Wu et al. 2000). To use plants for heavy metal cleaning, the accumulation of heavy metals in plants and the role of plants in removing pollutants should be made clear. In this paper, the author compiles the research results of heavy metals in plants and the usage of plants in remediating heavy metal pollution, which have mostly been published in Chinese within the last decade, in order to make this information internationally accessible, and to provide a general outlook to develop phytoremediation techniques.

1 Accumulation, Distribution and Chemical Status of Heavy Metals in Plants

1.1 Accumulation and distribution

The accumulation ratio usually indicates the accumulation capacity of plants, is the ratio of the contents of metal in the plant or an organ to the content of this element in the cultivated solution and/or soil.

At an individual site, plants absorb elements selectively. In Cu polluted soil, the content of Cu in aboveground parts of *Eriachne pallescens* R. Br. was 132 mg/kg DW, 20 fold higher than that seen in other plants (Kong 1983, Hou 1959). Grown in acid soil, *Lycopodiaceae* and *Melastomaceae* species accumulated large amounts of Al, so that the contents even reach 1% in dry weight, although it was seen to be lower in other species (Liao 1993). Woody plants accumulate a high amount of Cd, but the capacities are different in varying species. The content of Cd in the stem of *Salix matsudana* was 8.72–22.67 mg/kg DW, higher than that of

Morus alba with a content of 1.78–5.59 mg/kg DW. (Huang et al. 1989). The leguminous species (*Acacia confusa* Merr. and *Ormosia pinnata* Dunn.) could obviously absorb more heavy metals (Cu, Zn, Pb and Cd) from the landfill site leachate than non-leguminous species (Jiang et al. 2001). Zhuang and Wang (2000) studied the heavy metal accumulation in plant leaves at a single site and found that they were different (**Table 1**) since cypress (*Sabina chinensis*) leaves accumulated highest Pb and Cd, while arborvitae (*Platycladus orientalis* or *Thuja orientalis* Linn.) >chinar (*Platanus acerifolia* Willd.) >holly (*Euonymus japonicus*) >cherry (*Prunus cerasifera*) for Pb, arborvitae >holly >cherry >chinar for Cd, chinar >cypress >arborvitae >holly >cherry for Cu, cypress >chinar >arborvitae >cherry >holly for Zn.

Table 1: Average contents of heavy metals in 5 species of trees in the urban at Yantai, China [mg/kg DW][a]

Species	Cd	Cu	Pb	Zn
Sabina chinensis	0.16	6.8	5.4	7.2
Platycladus orientalis	0.10	6.0	4.1	4.8
Platanus acerifolia	0.05	9.0	3.5	7.1
Euonymus japonicus	0.09	3.2	1.9	3.4
Prunus cerasifera	0.07	2.9	1.3	3.9

a) Zhuang and Wang (2000)

Plants absorb heavy metals from soil and they predominantly accumulate in the roots, then some portions are transported to other parts of the plant. Generally, the contents of heavy metals in underground parts are higher than that found in those parts above the ground (Liao 1993) and follows a pattern that root>leaf>shoot (stem)>fruit and lateral root>main root, old leaf>young leaf (Bai and Zhang 1989, Cheng et al. 2002). In compound pollution of As, Cd, Cu, Pb and Zn, the contents of heavy metals in roots were 55–61% of the totals in paddy plants (Wu et al. 1998a,b). The accumulation of Hg in the root, shoot and seed of wheat (Y) were significantly related to the content of Hg in soil (X) using the equation in **Table 2** (Bai and Zhang 1989).

Table 2: Relationship between the accumulation in wheat (Y) and the content in soil of Hg (X)[a]

Organ	Equation	r
Root	$Y = 17.4 \times 0.118^{1/X}$	0.9803
Shoot	$Y = 7.68 + 4.76X$	0.9687
Seed	$Y = 0.386 \times 0.265^{1/X}$	0.9968

a) Bai and Zhang (1989)

For vegetables, the contents of heavy metals in organs are: leaf>stem>root>fruit for cucumber and tomatoes, root>above ground part of cabbage, and above ground part >root for carrots (Li et al. 1986), vegetable leaves >root and vegetable rhizomes >fruit in wastewater irrigation farmland (Wang and Bai 1994). The ratio of Cd in the root, shoot, and brown rice in paddies was 80:5:1 (Xia 1988). Li et al. (1999) measured the accumulation of Pb in several vegetables in cultivated experiments and showed that the highest accumulation organ was the root. *Raphanus sativus* L. absorbed more than 20,000 mg/kg DW of Pb in the root, but 300 mg/kg DW in aboveground parts under 300 mg/L of Pb treatment. It also revealed species differences showing that *R. sativus* accumulated the most Pb, then *Brassic pekinensis* (Lour.) Rupr., *Ipomoea aquatica* Forsk, *Brassic juncia var. Multices tsen et* Lee, *Brassic chinensis* L.

On the other hand, plants transport large portions of heavy metals from the root to the stem, while the accumulation in the stem and leaf are even higher than that in the root. Huang et al. (1982) reported that poplar transported half of the Cd from the root to the stem, Cd could also be absorbed by the stem and leaf, accumulated in the absorbing organs and transported less to other organs. The content of Cd in leaves of tobacco was higher than that in roots (Lu et al. 1992). Sun and Zhong (1998) investigated the contents of Cd, Cu, Mn, Pb and Zn in the organs of *Gordonia acuminate* evergreen broad-leaved forest were 0.08–0.69, 1.55–5.24, 94.8–897, 1.51–16.0, 3.96–38.0 mg/kg DW, respectively. The accumulation of Cu in root was the lowest and 1/3 of that found in flowers, fruit, leaves, and stems, although Mn was opposite, revealing the highest content in roots. The highest accumulations of Cd, Pb and Zn were in the leaves.

The accumulation of heavy metals in plants is related to the elements and the chemical status of the heavy metals. Song et al. (1996) reported that the accumulation of heavy metals in the edible parts of spinach (*Spinacia oleracea* Linn.) depended on the doses, status of elements in the soil and interaction with an accumulation rate order: Cd>Zn>Pb. **Table 3** is the relationship between the contents of the metals on the edible part of spinach and their fractionation in the soil. The results showed that the largest contribution of Cd in soil to the plant was an exchangeable form, although the residual form was seen to be most prevalent for Pb and Zn and the oxidated form was most prevalent for Fe-Mn.

Therefore, the accumulation and distribution of heavy metals in plants depends on the environmental factors, such as plant species, element species, chemical and bioavailiability, redox, pH, cation exchange capacity, dissolved oxygen, temperature and secretion of roots (Xu and Yang 1995, Wu et al. 1998a, Bi et al. 2000, Yu et al. 2000, Su et al. 2000).

Table 3: The relationship between the contents of the metals on the edible part of spinach and their fractionation in the soil[a]

Elements	Regressive equation[b]	r
Cd	$Y = 9.56 + 47.63X_1 - 97.88X_2 - 129.86X_3 + 63.93X_4 - 5.46X_5$	0.8900[c]
Pb	$Y = 10.43 + 0.44X_1 + 0.002X_2 - 0.009X_3 + 0.007X_4 + 0.304X_5$	0.8648[c]
Zn	$Y = 36.95 + 0.95X_1 - 2.02X_2 + 3.08X_3 + 0.42X_4 + 0.06X_5$	0.7210[d]

a) Song et al. (1996); b) Y: content of metal in spinach, X_1: content of exchangeable form in soil, X_2: nitric acid form, X_3: Fe-Mn oxidation form, X_4: organic form, X_5: residual from; c) $p<0.01$; d) $p<0.05$

1.2 Chemical status

The transportation of heavy metals in plants is related to the chemical status in plants. The transport activities of the ethanol extractive and water dissoluble metal was the highest, then the sodium chloride extractive metal, the acetic acid and the hydrochloric acid extractive metal being the lowest (Xu et al. 1999a). In the roots, sodium chloride extractive Cd is the main portion, although the Pb is in an acetic acid extractive form. Cd was transported more easily than Pb from the roots to the above-ground parts and the toxicity of Cd was also higher than Pb. The sodium chloride extractive metal easily integrates proteins and Cd usually was accumulated in the proteinaceous parts of the plants.

Yang and He (1995) reported that the tolerance of plants to heavy metals was also related to the chemical form of heavy metals in plants, and that a higher portion of sodium chloride extractive metals showed a lower tolerance to Cd. 45–69% of Cd accumulating in cucumbers and spinach were not soluble, and 2.5–21% was deposited in the cell wall. For Pb, in contrast, 77–80% was deposited in the cell wall and 0.2–3.8% was not soluble (Yang and Bao 1993). The different distribution of Cd and Pb in the cells, may be the reason that Cd is much more toxic to plants than Pb.

Cu is mainly in a water-soluble and ethanol-soluble form, which can be easily translocated in plants. The total content of various chemically bound forms of copper was higher in the aboveground parts (rape 18.5 mg/kg DW and wheat 22.0 mg/kg DW) than in the underground parts (rape 16.7 mg/kg DW and wheat 13.2 mg/kg DW), and their content was decreased in the order of water soluble form (W.S.form) >ethanol soluble form (Eth.S.form) >residual form (Re.form) >acid soluble form (A.S.form), the percentage values in rapeseed were 37%, 31%, 22% and 10%, respectively (Wang et al. 2000a).

Zn is mainly in the form of acid soluble, which is hard to be transferred in crops. The total content of various chemically bound forms of zinc was lower in the aboveground parts (rape 28.1 mg/kg DW and wheat 23.5 mg/kg DW) than in the roots (rape 36.7 mg/kg DW and wheat 28.5 mg/kg DW), and their content was decreased in the order of A.S.form > Re.form> W.S.form> Eth.S.form, while the values in rapeseed were 58%, 24%, 14% and 4%, respectively (Wang et al. 2000a). In comparison with copper, a large amount of Zn was enriched in seeds and pods of rape. Analyzing the proportion of the chemically bound form of heavy metals in plants, the main parts of Zn in plants were seen to be low molecular weight compounds, metal proteins and free Zn, while less insoluble portions were seen to have combined with the cell wall. 58–91% of zinc in plants was not soluble and played an important role in the physiological activities of the plant (Xu et al. 1999a).

In spite of the chemical extraction forms, heavy metals also combined with inorganic substances (e.g. sulphides), and there were some small-molecular organic substances such as glutathione(GSH), oxalic acid, histidine, citrate and metal-binding proteins in the plants (Zhang et al. 1999). A Cd-binding complex (Cd-BC) was isolated and purified from roots of wheat (*Triticum aestivum* L.), the molecular weight was around 10 KD, and the composition of Glu/Gln, Cys and Gly was 4:4:1 (Gong et al. 1990). The contribution of metallothioneins and phytochelatin in the heavy metal transport in the plants, however, have not been studied.

2 Purification of Heavy Metals Polluted Water by Plants

Since plants have a capacity to uptake heavy metals from the environment, plants are used to purify heavy metal polluted water, to keep the water clean and/or to be used for some utilization, as well as to reclaim metals.

Macrophytes and the eco-system are commonly used to purify mine tailing water (Dai et al. 1990, Tang 1993). The purification capacity of *Typha latifolia* Linn. (Zheng and Li 1996, Xu et al. 1999b) and *Cyperus alternifolius* Linn. (Cheng et al. 2002) in the eco-system are listed in **Table 4**. The absorption of heavy metals in organs of cattail was in the rank: root>rhizome>leaf (Zheng and Li 1996). The accumulation of heavy metals by *Cyperus alternifolius* Linn., which is planted in constructed wetland, occurred in the following rank: highest in lateral roots, then main roots, rhizomes, leaves and lowest in shoots, except for the highest content of Cd in the main roots. It was more than 2,000-fold of the Cu in the lateral roots and in the leaves and shoots, and about 120-fold of the Al, 70-fold of the Mn, 60-fold of the Pb and Zn, and 30-fold of the Cd (Cheng et al. 2002).

Macrophytes show a high performance in the removal of individual heavy metals. A biomass of 0.5 kg *Azolla filiculoides* Lamk removed 98.8% of Pb in 15 mg/L Pb solution and 87% of Hg in 10 mg/L Hg solution within 7 days (Ren and Tang 1996). Some macrophytes, *Eichhornia crassipes*, *Phragmitees communis*, *Zizania latifolia*, *Polygonum hydropiper*, *Acrous alamus*, *Echinochloa crusgalli*, *Sagittiaria sagittifolia*, *Oryya sativa*, *Spirodela polyrrhiza* and *Lemina minor*, showed a high purification capacity for removing 66.0–100% of Ag (Dai et al. 1990). *E. crassipes* is a potential species for reclaiming Ag and Au from wastewater (Fan and Jia 1999). *Nymphoides peltata* (Gmel) O. Kuntz removed 99.5% and 96.8% Cd from 1 mg/L and 2mg/L Cd solutions, respectively (Gu et al. 2000). *Alternanthera philoxeriodes, Ottelia alismoides, O. cordata, Hydrilla verticillata, Vallisneria spinulosa, V. denseserrulata, Pistia stratiotes, Jussiaea repens* removed 54–100% of Cu in the wastewater with concentrations of Cu around 0.5 mg/L within 6 days,

Table 4: Removal performance of heavy metals by several plant ecosystems [%]

Species	Al	Cd	Cu	Fe	Hg	Mn	Pb	Zn	Ref.
Typha latifolia	n.d.[a]	60.0	n.d.	41.2	n.d.	n.d.	97.1	84.8	b
	n.d.	96	n.d.	n.d.	n.d.	n.d.	83	87	c
Cuperus alternifolius	100	100	100	100	n.d.	42.2	100	100	d

a) n.d. : no data; b) Zheng and Li (1996); c) Xu et al. (1999b); d) Cheng et al. (2002)

these plants can play an important role in removing Cu from sewage and mine tailing water (Yan et al. 1990). Hong et al. (1996) used *Acorus tatariouwii* Schott. to remove Cu from wastewater and got a performance of 80% in 7 days. In a static experiment, 0.262 kg *Oenanthe javanica* 98.9%, 99.2% and 97.2% Au from 15 liters 0.5, 1 and 2 mg/L Au solution, respectively, within 72 hrs. The content of Au in the root even reached 1.22% (Dai et al. 1998), that is to say the utilization of *O. javanica* to reclaim Au is possible. Economy aquatic plants are potential plants for removing heavy metals. You et al. (2000) investigated the contents of heavy metals (Cu, Cd, Pb, Zn) in *Ipomoea aquatica* and *O. javanica* for purification of eutrophic water and revealed that heavy metals mainly accumulated in the roots, while the contents in the stem and leaf were in the range of being edible (**Table 5**).

Table 5: Contents of heavy metals in economic macrophytes [mg/kg DW][a]

Species	Organ	Cd	Cu	Pb	Zn
Ipomoea aquatica	Root	0.63	12.8	2.75	37.0
	Stem	0.03	5.42	0.14	12.3
	Leaf	0.04	6.93	0.21	18.6
Oenanthe javanic	Root	0.67	20.1	3.76	31.7
	Stem	0.04	3.34	0.38	14.4
	Leaf	0.02	3.36	0.39	13.2

a) You et al. (2000)

Litter leaf detritus of plants can also absorb heavy metals to purify wastewater. **Table 6** lists the removal capacity of litter leaf detritus of four mangrove species (Zheng et al. 1998). The absorption abilities of Pb and Cd in *Avicennia marina* litter leaf detritus were higher, while those of Cu and Ni in *Kandelia candel* were higher. The salt-exclusion species (*K. candel* and *Rhizophora stylosa*) and the salt-excretive species (*A. marina* and *Aegiceras croniculatum*) were different in absorption ability of heavy metal, i.e. Cd>Pb>Cu>Ni for the former, while Pb>Cd>Cu>Ni for the latter; with a rise in the heavy metal ion concentration (from 2 mg/L to 5 mg/L), the amount of absorption was increased, which suggested that the litter leaf detritus of the mangroves has high potential absorption capabilities.

The purification capacities of plants to heavy metals from wastewater are affected by several factors, such as concentrations of heavy metals, species of elements, plant species, exposure duration, and temperature and pH (Hong et al. 1996, Ren and Tang 1996, Gu et al. 2000).

Table 6: Removal performance of heavy metals by litter leaf detritus [%][a]

Species	Cd	Cu	Ni	Pb
Kandelia candel	70.6	70.5	50.5	76.9
Rhizophora stylosa	56.9	55.0	38.0	73.2
Avicennia marina	74.2	47.5	23.5	83.6
Aegiceras croniculatum	51.1	32.0	19.0	76.2

a) Zheng et al. (1998)

3 Heavy Metal Phytoremediation Techniques

There are several ways to remediate heavy metal pollution in soil: i) to abate the toxicity of heavy metals in soil by using bacteria; ii) to add bonds in soil to solidify and stabilize heavy metals; iii) to remove heavy metals from soil by utilization of electricity dynamics; iv) to remove heavy metals from soil by thermic absorption; v) to remove heavy metals from soil by extraction and washing; vi) to remove heavy metals from soil by phytoremediation (Xia and Chen 1997, Jiang et al. 2000a, Wu et al. 2000). Studies on heavy metal phytoremediation have been very prevalent and started in China recently, some tens of reviews on the topic have been published (Chen 1999, Gao 1999, Han and Lu 2000, Jiang et al. 2000b, Sang and Kong 1999, Shen and Chen 2000, Shen and Liu 1998, Sun and Luo 1999, Tang et al. 1996, Wang and Ma 2000, Wang et al. 2000b, Wei and Chen 2001, Zhang 1999, Zhao et al. 2000). The basic phytoremediation methods are described and further research on heavy metal phytoremediation in China has been proposed.

Metal is different from organic substances, it cannot be decomposed by bacteria, and can only be absorbed and removed from the environment by organisms. To use bacteria for heavy metal remediation in large-scale sites, there are two limitations. On the one hand, the biomass is small and the absorption quantity of heavy metals will be small. On the other hand, the disposal is more difficult because of the micro-bodies. The advantage of a big biomass and easy disposal makes it possible for plants to remove heavy metals on site, and phytoremediation is a potential choice for solving the heavy metal pollution. Phytoremediation in situ is based on four points: phytostabilization, phytovolatilization, phytoextraction and phytofiltration.

Phytostabilization is used by plants and some additive substances to decrease the mobility, bioavailibility and toxicity of persistent pollutants. Although the heavy metal ions are stabilized temporarily and are not removed from the environment by phytostabilization, the bioavailibility of those heavy metals will be changed when the condition alters. Thus, phytostabilization is not an optimistic way to remediate heavy metal pollution.

Phytovolatilization uses plants to remove volatile pollutants from the environment. Plants absorb the pollutants and transfer them into gaseous substances, which are then released into the atmosphere. Therefore, using plants to remove Hg and Se from soil is possible. Since it is only used for volatile pollutants, limitations are revealed for its further utilization. Moreover, the pollutants are transported into the atmosphere and threaten the health of humans and wildlife. As a consequence, they should be used carefully. However, if equipment is established to collect the volatile toxic heavy metals before they are released into the air, it may make it effective to remove volatile metals from the soil.

Phytoextraction uses plants to accumulate and transport heavy metal ions and store them in aboveground plant organs, it is a more potential way of removing heavy metals from the environment. To study the accumulation discipline of heavy metals by plants, and to scan and select the hyperaccumulator are key points for phytoextraction techniques.

A perfect plant species for phytoextraction: i) reveals a higher accumulation efficiency on heavy metals in lower concentrations; ii) accumulates higher contents of heavy metals in organs which are easy to harvest; iii) accumulates several kinds of heavy metals; iv) grows rapidly and has a large biomass; v) resists diseases and pests; vi) demonstrates some environmentally-friendly economic utilization. Shen et al. (1998) used *Thlaspi caerulescens* J and C Presl to uptake Zn, Cu, Mn and Fe from solution, and proved that *T. caerulescens* is a hyperaccumulator for Zn (Shen and Liu 1998). *Brassica juncea* Coss. was a suitable plant for moderately polluted soil remediation with contents of Cu, Pb and Zn up to 250 mg/kg, 500 mg/kg, 500 mg/kg, respectively, but it demonstrated chlorosis in soil with Cd contents of about 200 mg/kg (Jiang et al. 2000b).

Phytofiltration or rhizofiltration uses the uptake capacity and large surface area, or the whole plant, to remove heavy metals from wastewater. The mechanism is similar to phytoextraction. Aquatic plants, wetland plants and terrestrial plants are all suitable material for phytofiltration. Constructed wetland is one of the potential methods to use phytofiltration to remove heavy metals from wastewater (Tang 1993, Cheng et al. 2002).

4 Conclusion

Plants can take up heavy metals by their roots, or even by stems and leaves, and accumulate them in organs, the accumulation depends on the specific metal element and plant species, and the environmental condition. Therefore, plant systems are used to remove heavy metals from wastewater and provide a good performance. Metal is different from organic substances, it cannot be decomposed by bacteria, and can only be absorbed and removed from the environment by organisms. The capacity of taking up and accumulating heavy metals in organs, the advantage of a big biomass and easy disposal makes it possible for plants to remove heavy metals by phytoremediation in situ.

5 Recommendations and Outlook

Based on the knowledge of the heavy metal accumulation in plants, it is possible to select those species of crops and pasturage herbs, for food cultivation and fodder for animals which accumulate fewer heavy metals; and to select those hyperaccumulation species for extracting heavy metals, which is the green and environmentally friendly technique to remove heavy metals from soil and water. For cleaning huge volumes of polluted water, phytoremediation is a more advantageous method because of its economy and effectivity. For example, to use constructed wetland to improve the water quality.

The research results from the Chinese papers have provided a general basis for phytoremediation. In accordance with the conditions in China, further studies are needed.

Select and cultivate more wild, hyperaccumulation plants. Establish the seed resource and database of hyperaccumulators. Study the molecular mechanisms of hyperaccumulation and translocation of heavy metals in plants. Combine the research on biotechnology and phytoremediation. For instance, to use gene recombination to cultivate more effective plant cultivars.

To avoid the direct threats of heavy metals to humans, studies on the transfer and sub-chronic toxicity of heavy metals in the food-chain from water, soil, plant, animal to human should be enhanced. The higher transfer of heavy metals from water and soil to plants is a target of phytoremediation.

The rhizosphere is a complex compartment. Root secretions and microorganism release make the ions of both nutrients and contaminants more mobile in the soil. The dynamics of bacteria in the rhizosphere and root exudates should be studied further to improve the efficiency of phytoremediation.

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