Heavy Metal Pollution Control Technology–Phytoremediation in China

by

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ABSTRACT

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As a worldwide problem, soil heavy metal pollution has a huge impact on human production and life. The world has invested a lot of manpower and material resources for environmental governance. Environmental pollution control has a new breakthrough with the emergence of phytoremediation technology. Phytoremediation, as a new technology, has the characteristics of low cost, more ecological and environmental friendly. This paper summarizes the mechanism of phytoremediation, the status of heavy metal pollution in China, and the application of phytoremediation in China. Meanwhile, the discussion on the development of phytoremediation was also explored.

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INTRODUCTION

Soil is one of the main natural resources for human survival and an important component of human ecological environment. Soil functions are numerous, for example, water supply, conservation and purification, provide growth matrix for plants, promote the recycling of inorganic matter and organic matter and so on. It can be said that without soil, human cannot survive because there would be no forest and food. However, with the rapid development of industrialization and urbanization, many toxic substances have entered the soil system. This has caused soil heavy metal pollution become a serious environmental problem facing the whole world. In China, soil pollution has which is another major pollution problem after water pollution, air pollution, noise pollution and solid waste pollution. The area of contaminated arable land is about 20 million hectares, which accounts for about one-fifth of the total cultivated land area (Chen 2005). Human activities are the main factors causing heavy metal pollution in the soil, such as mining, metal smelting, chemical industry, coal combustion, automobile exhaust emissions, domestic wastewater discharge, pesticide and chemical fertilizer application and atmospheric deposition.

Soil heavy metal pollution can cause change of soil composition, structure and function. Microbial activity will be inhibited and the toxic substances or decomposition products will accumulate in the soil. These toxic substances might be absorbed by humans through the mechanism of “soil—plant—human” or “soil—water—human”, thus endangering human health (Huang et al. 2013). Take the example of cadmium, long-term exposure to a certain dose of cadmium can cause damage to kidney, leading to osteoporosis and bone softening. In 1931 Toyama County, Japan, the “Itai-itai disease” is a typical case of cadmium poisoning. Therefore, prevention and control of soil heavy metal pollution is very important.

The remediation of heavy metal contaminated soil refers to the physical, chemical and biological methods to remove heavy metals from the soil or fix it in the soil to reduce the migration and bioavailability, as well as reduce the risk of heavy metals to human health and environment. At present, according to the measurements, remediation methods can be divided into the following three categories: physical remediation, chemical remediation, and bioremediation (Huang et al. 2013). The physical and chemical remediation technologies are convenient and flexible for implementation, and they are suitable for complex heavy metal pollution, thus they are widely used in remediation of heavy metal polluted soils. However, the implementation of these technologies is relatively of high costs, which to some extent limit the promotion of their application. Bioremediation technology mainly includes phytoremediation technology and microbial remediation technology. Compared with the former two methods, bioremediation has the following advantages: the remediation effect is better, the investment is lower, the cost is lower, the management and operation are easier, and the secondary pollution is not produced or relatively small (Huang et al. 2013). So it has been paid more and more attention and become the hotspot of heavy metal contaminated soil remediation.

Phytoremediation is the technology that can remove contaminants from the soil or reduce the concentration of contaminants in the soil to acceptable levels without destroying the soil structure through the extraction, adsorption, decomposition, and transformation and immobilization process of the plant (Zhang et al. 2013). The object of phytoremediation is the soil or water that contaminated by heavy metals, organic matter or radioactive elements. The phytoremediation relies on the comprehensive effect of soil, plant and rhizosphere microbes, and the restoration process is controlled by many factors, for example, plant species, soil physical and chemical properties, rhizosphere microorganisms (Zhou 2006). In general, phytoremediation is a promising green technology that can be used in soil pollution control management.

Phytoremediation relies on plant life activities to complete. As the speed of metabolism of various plants is not the same, as well as the physical and chemical properties of various metals are also in large differences, the effectiveness of phytoremediation might vary from different plant species. According to the types and functions of phytoremediation technology, phytoremediation technology can be divided into the following four categories: Phytoextraction, Rhizofiltration, Phytovolatilization, and Phytostabilization.

1. Phytoextraction: Using plants with high metal enrichment ability to absorb one or more heavy metals from soil, then transport and storage the heavy metal to the aerial parts of the plant. The aerial parts will be harvested and thus the heavy metals are be removed from the soil. By planting hyperaccumulators continuously, the heavy metal content in the soil can be reduced to the normal range (Huang et al. 2013).

2. Rhizofiltration: Phytoremediation of heavy metal contaminated water bodies or wetlands often relies on plant roots. When the heavy metals in water pass through

the plant roots, the rhizosphere can absorb or fix or precipitate these heavy metals, thereby reducing the concentration of heavy metals in water. Plants used in rhizofiltration method require well-developed root systems with large surface area for heavy metal adsorption and filtration (Huang et al. 2013).

3. Phytovolatilization: Phytovolatilization is associated with phytoextraction. Phytovolatilization reduce soil contaminants through the process of absorption, accumulation, volatilization, that is, plants will absorb the volatile heavy metals into its body and transport them to the aerial parts, and then release them into the atmosphere in the form of gas. Since phytovolatilization method will release heavy metals into the atmosphere, there is a high environmental risk, so its practical application is less (Huang et al. 2013).

4. Phytostabilization: Plants prevent the penetration or diffusion of heavy metals through the absorption, decomposition, redox and precipitation fixation process, to reduce migration and toxicity of heavy metals in the soil. Phytostabilization does not completely remove the heavy metals in the soil, but they are temporarily to be fixed so that there is no toxic effect for the biological environment. If the environmental conditions change, the availability of heavy metals may change. These plants can be used as a pioneer species of vegetation restoration in mining wasteland. The formation of vegetation cover can effectively prevent wind erosion and water erosion of contaminated soil, thereby reducing soil loss and infiltration in the mining area, and retarding the diffusion of heavy metals in the environment (Huang et al. 2013).

The key to phytoremediation is how to find and make rational use of hyperaccumulators. In 1977, the concept of hyperaccumulator was proposed, which refers to plants that can absorb heavy metals and transport them to the aerial part (Brooks 1977). Hyperaccumulators are plants that can absorb more than 100 times of heavy metals than other plants. The most used reference value of hyperaccumulators are proposed by Baker and Brooks in 1983, which is Cd up to 100mg/kg, Co, Cu, Ni, Pb up to 1000mg/kg and Mn and Zn above 10000mg/kg. In addition, the translocation factor (TF) should be greater than 1, that is, the content of heavy metal in the plant's aerial part is greater than that in the underground part. Hyperaccumulators can reduce toxic or harmful contaminants in soil or water by extraction, absorption, decomposition, and transformation and immobilization process. Over 400 species of hyperaccumulators have been identified (Chen 2005), 277 of them are hyper-enriched in Ni and are distributed in a few regions in the world (see Table 1).

Table 1. Hyperaccumulator plants based on all information available in 1994 (Source: Chen 2005)

Metal	No. of species	No. of families represented
Cadmium	15	5
Cobalt	36	12
Copper	34	11
Lead	5	3
Manganese	18	5
Nickel	277	36
Zinc	28	5
Total	413	77

In 1983, Chaney proposed the concept of using hyperaccumulators to remove soil heavy metal contaminants, then the research on hyperaccumulators gradually increased (Chaney 1983). Phytoremediation has been proposed as a technique to treat contaminated soils. The experimental research and field application of phytoremediation have demonstrated the great potential of commercialization of phytoremediation technology.

OBJECTIVE

The pollution process of heavy metals and organic pollutants in soil or water environment system always has hidden, long-term and irreversible characteristics. Therefore, the control treatment of heavy metals and organic pollutants in soil or water environment system has been a difficult and hot research topic in the world. In recent years, phytoremediation technology as a cheap and practical technology, is widely developed in the world. China has a vast expanse of land, rich plant resources, and diverse geographical and geological conditions, which means there should be a large number of hyperaccumulators. The phytoremediation technology in China has a very good prospects. In this paper, practical application, control treatment effectiveness and developing prospect will be explored, aiming at a detailed understanding of phytoremediation technology.

LITERATURE REVIEW

PRESENT SITUATION OF SOIL HEAVY METAL POLLUTION IN CHINA

Heavy metals that cause pollution in the soil are Mercury (Hg), cadmium (Cd), lead (Pb), arsenic (As), zinc (Zn), copper (Cu), nickel (Ni) and chromium (Cr). Statistic shows the probability of heavy metal pollution in soils of cultivated in China was about

16.67%, implying that 1/6 of cultivated land in China may suffer from heavy metal pollution (Song et al. 2013). Moreover, the proportions of pollution degrees ranked as clean, relative clean, light pollution, moderate pollution and severe pollution were 68.12%, 15.22%, 14.49%, 1.45% and 0.72% of the total area of cultivated land. Among the different contaminated soils, the pollution probability of Cd was about 25.20%, which significantly exceeds pollution levels of the other heavy metals (Table 2 below) (Song et al. 2013). The cultivated lands in Liaoning and Shanxi province, may be the key regions of heavy metal pollution.

Table 2. Pollution probability of major heavy metals in cultivated soils in China (Source: Song et al. 2013)

Pollution probability of major heavy metals in cultivated soils in China								
	Cd	Ni	Hg	As	Pb	Zn	Cu	Cr
Number of cases	127	58	121	109	138	79	86	128
Number of contaminants	32	3	4	1	1	0	0	0
Pollution probability	25.20%	5.17%	3.31%	0.92%	0.72%	0	0	0

Each year, there are more than 10 million tons of grain reduction caused by heavy metal pollution, and about 12 million tons of grain are polluted by heavy metals. The total economic losses are about 20 billion yuan (Zhou et al. 2014). Thus the remediation of the soil has great potential, for example, the grain per unit area (rice) production can be increased by more than 10% after remediation in moderate and slightly contaminated soil (Zhou et al. 2014). Moreover, the remediation of contaminated soils can improve and maintain the health of people in contaminated areas.

DEVELOPMENT PATH OF PHYTOREMEDIATION IN CHINA

As early as the 1970s, China had the idea of using plants to restore soil ecology and productivity (Gao 1986). In the 1980s, researches on the plant reclamation in abandoned land was studied and found that cadmium (Cd), mercury (Hg), lead (Pb) from can be absorbed by willow and poplar, which has a purifying effect on the environment (Lin and Huang. 1989). Since the late 1990s, under the support of the National Natural Science Foundation of China and the Chinese Academy of Sciences and other departments, heavy metal contaminated soil phytoremediation, especially the use of hyperaccumulators, have made significant progress in principles and technical research (Luo et al. 2005).

In 2001, Tang cooperated with Brooks, the author of the concept of hyperaccumulators, proposed *Elsholtzia splendens* and *Commelina communis*, which is widely grown in the middle and lower reaches of the Yangtze River in China, have good ability to absorb heavy metals such as chromium and copper (Tang et al. 2001). In the past 10 years, with the deepening of the emphasis on the remediation of heavy metal contaminated soil, the study of hyperaccumulation phytoremediation in China has entered a period of rapid development, not only a series of plants with super-accumulation ability for heavy metals were founded, a number of phytoremediation technology and strengthen measurements were developed. For example, using dihydrogen phosphate as a phosphate fertilizer could significantly increase the extraction of zinc and cadmium in *Sedum alfredii*, thus rational application of phosphate fertilizer can increase the amount of biodegradable carbon, enhance the removal of Zn and Cd from co-contaminated soils by *Sedum alfredii*, and shorten the time needed for accomplishing remediation goals. (Huang et al. 2012).

During the period of the 10th Five-Year Plan (2001-2005), the Ministry of Science and Technology "863 Program" for the first time to carry out research on phytoremediation technology of heavy metal contaminated soil, and established many phytoremediation demonstration projects on arsenic (As), copper (Cu), zinc (Zn) and other contaminated soil. Up to now, there have been more than 20 kinds of demonstration projects related to soil pollution phytoremediation, including As, Cu, Zn, Cd, Pb and other heavy metals pollutants (Luo 2009). In 2011, with the support of the Ministry of Environmental Protection and the Environmental Protection Department of the Guangxi Zhuang Autonomous Region, the People's Government of the Huanjiang County and the Institute of Geography and Resources of the Chinese Academy of Sciences jointly implemented the "Heavy Metal Pollution Control Project of the Dahuanjiang River Basin". The project uses the hyperaccumulators *Eremochloa ciliaris*, *Sedum alfredii* to reduce the heavy metals content in the soil, after nearly 2 years of repair, polluted farmland production and quality of agricultural products significantly improved. The production of mulberry leaves and silk heavy metal content are in line with relevant standards and the average yield of corn, rice and sugarcane increased by 154%, 29.6% and 105% (An et al. 2015). These successful stories of phytoremediation applications made China, to a certain extent, begin to lead the international forefront direction of research.

SCREENING OF HYPERACCUMULATORS RESEARCH IN CHINA

One of the key applications of phytoremediation technology is the screening of accumulators or hyperaccumulators with high biomass, rapid growth, insect and disease resistance, high tolerance to heavy metals and strong enrichment properties. Most of the hyperaccumulators found in nutrient-poor metal mining areas, which are naturally resistant to high concentrations of heavy metals. However, most of these plants limit their practical application due to factors such as small biomass, slow growth, and unstable metal absorption. At present, there are three main methods for finding hyperaccumulators in China (An et al. 2015). The first one is the field investigation method, that is, to find the hyperaccumulators in the place where the heavy metal pollution occurred. In addition, most of the hyperaccumulators are obtained by this method. Second, the special plant method, that is, according to some of the characteristics of plants to select some special plants to determine their enrichment of heavy metals. The third is the use of soil seed bank - heavy metal concentration gradient method to screen hyperaccumulators. Although China's hyperaccumulators screening work started late, since the 90s of last century, especially after 2000, China has found a series of heavy metal accumulators or hyperaccumulators. The following example is about cadmium hyperaccumulators.

Cadmium contaminated soil is the most common heavy metal pollution in China. The pollution area is about 13,000 km^2, involving 11 provinces (Zhou et al. 2014). Cadmium can be absorbed into the human body through the food chain and it will have a great harm to the human health, therefore, cadmium pollution control appears to be urgent. China has made some progress in the search and application of Cd-hyperaccumulators. *Sedum alfredii* has a super accumulation effect on Cd with many advantages, for example, large biomass, perennial, and asexual reproduction. In addition, *Sedum alfredii* not only has the ability to repair Cd pollution, but also has high tolerance of Zn and Cd compound pollution. It provides a new material for the further study of Zn and Cd super accumulation mechanism (Ye et al. 2003). Li studied the effects of nitrogen levels on plant growth and cadmium uptake of *Sedum alfredii* by water culture experiments. The results showed that nitrogen promoted the accumulation of cadmium in *Sedum alfredii*, and the content of cadmium increased gradually with the increase of nitrogen input (Li et al. 2007).

Through field investigation and greenhouse test, *Viola baoshanensis* was found as a Cd- hyperaccumulator in the Baoshan mining area, Chenzhou City, Hunan Province. Moreover, the water culture experiment indicates that the Cd content in the aerial parts increased linearly with the increase of Cd concentration in the growth medium, reaching the maximum at 50mg / L (Liu et al. 2003). Many other plants, for example, *Taraxacum mongolicum*, *Solanum nigrum*, also have high ability to accumulate Cd and have the basic characteristics of hyperaccumulators (Wei et al. 2003).

SAFE DISPOSAL OF HYPERACCUMULATORS

Heavy metal-enriched plant biomass (HMEPB) is rich in heavy metals such as cadmium, arsenic, zinc, and copper. These heavy metal enrichment plant biomasses once disposed of improperly, they are likely to be released into the environment to form a "secondary pollution", thus how to safely deal with heavy metal enrichment plant biomass is one of the important scientific problems that need to be solved in the future. At present, the main methods of dealing with HMEPB are: incineration, composting, compressing for landfilling, ashing, pyrolysis, and liquid phase extraction method. Each method has its own advantages, but meanwhile there are some inevitable shortcomings, thus there is still some controversy between the academic communities on how to reasonable choose and use these technologies in different situation (An et al. 2015).

Incineration and composting are currently the two most studied method in China. Incineration is a waste treatment process that involves the combustion of organic substances contained in waste materials, under high temperature conditions, pollutants are oxidized, pyrolyzed and destroyed. It can reduce the volume and solid mass greatly. For example, *Eremochloa ciliaris* is an arsenic hyperaccumulation plant, Chen established a safe burning equipment that can reduce 96% of its biomass after burning, meanwhile, and the tail gas achieved all the emission standards (Liu et al. 2014). Composting is an efficient and environmentally friendly HMEPB treatment technology that degrades and stabilizes the organic matter in solid waste by microbial action, it is essentially the process of stabilizing and humification of organic matter. It is one of the most successful cases in the phytoremediation and resource recycling technology by composting the *Elshirebizia* plant grown in Cu contaminated soil and then applying it to the copper-deficient soil to significantly increase wheat yield (Liu et al. 2014).

Phytoremediation research in China is focused on plant enrichment and detoxification mechanisms of heavy metals, such as plant uptake and transport mechanisms of heavy metals and strengthening measures for plant remediation of soil heavy metal pollution (Liu et al. 2014). Meanwhile, there are not many researches on heavy metal-enriched plant biomass disposal technology, which largely hinders the engineering application of phytoremediation technology.

MATERIALS AND METHOD

MATERIALS AND METHOD

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.

By analyzing these data, we can find the application status of phytoremediation in China and current status of heavy metal pollution. According to the severity of different heavy metal pollution and related researches in China, this paper mainly classifies and summarizes the related research progress of six heavy metal hyperaccumulators, cadmium, arsenic, lead, zinc, copper and chromium. Finally, the restrictions on the development of phytoremediation applications was discussed.

RESULTS

APPLICATION STATUS OF PHYTOREMEDIATION IN CHINA

Figure 1 indicates the application status of soil remediation technology in China from 2008 to 2016. In 120 soil remediation projects, bioremediation and physicochemical remediation are the main remediation technologies, accounting for 40% and 47% of the total applications, while the application of physical or chemical technology is relatively small (Li 2016).

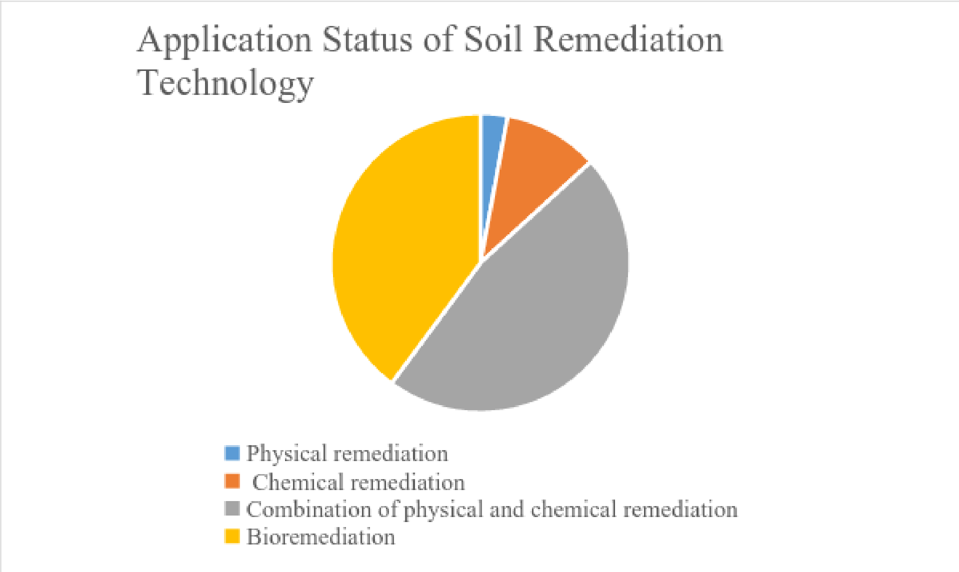

Figure 1. Application Status of Soil Remediation Technology (Source: Li 2016).

Figure 2 shows the application status of bioremediation technology. From the figure above, we can know that bioremediation is the main technology used in soil remediation projects. Among the bioremediation technologies, mine ecological restoration technology is the most widely used one, accounting for about 55% of the total projects. The other three technologies, microbiological remediation technology, phytoremediation technology, agricultural ecological restoration technology, has the same market share, at about 15% of the total projects (Li 2016).

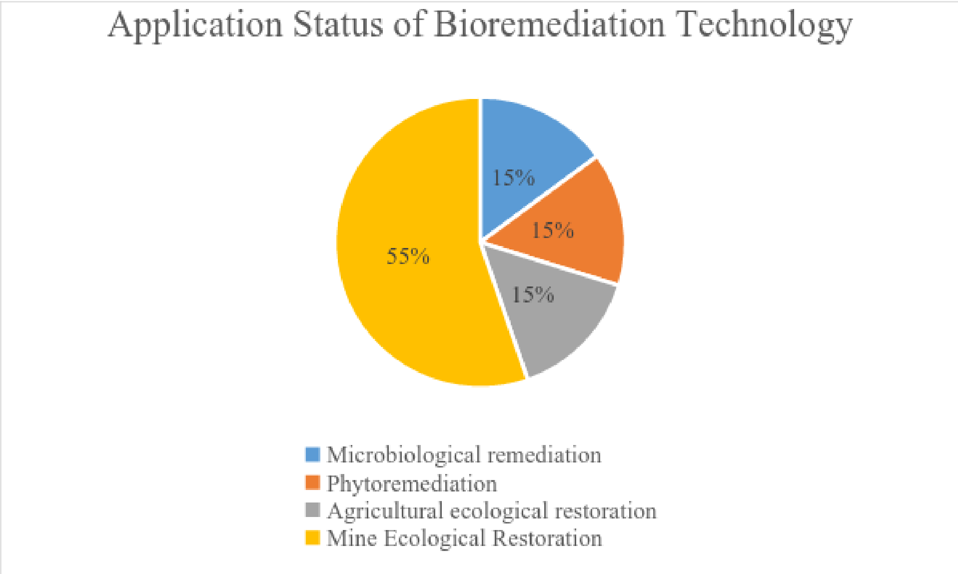

Figure 2. Application Status of Bioremediation Technology (Source: Li 2016).

Table 3. Common cadmium hyperaccumulators found in China.

Plant name	Concentration（mg/kg）	Translocation factor	Ref.
Bidens pilosa L.	119	1.52	a
Solanum nigrum L	228	>1	b
Phytolacca acinosa	403.41	>1	c
Viola baoshanensis	1168	>1	d
Rorippa globosa	1301	1.0-1.3	e

a)Sun et al.(2009);b)Wei et al.(2005);c)Nie(2006);d)Zhang et al.(2011);e)Sun et al.(2007)

Cadmium is a highly toxic heavy metal, under normal conditions, the content of cadmium in plant is generally not more than 1 mg/ kg. Compared with other heavy metals, cadmium is destructive to the environment, and the toxicity of cadmium is concealed and cumulative. Based on the strong droughts of cadmium, a lot of research work has been done on cadmium hyperaccumulators in China. The concentration of Cd and the translocation factor of the plants listed in the table all reached the reference standard. From the table above, we can find that *Rorippa globose* has the highest concentration of Cd of 1301 mg/ kg. In addition, *Phytolacca acinosa* has wide distribution area, large biomass, fast growth advantages, which is an ideal cadmium pollution remediation plants.

Table 4. Common arsenic hyperaccumulators found in China.

Plant name	Concentration （mg/kg）	Translocation factor	Ref.
Pteris vittata	2350-5018	>1	a
Pteris cretica	693	1-2.6	b

a)Chen et al.(2002);b)Wei et al.(2002)

In 2002, *Pteris vittata* was first found as an arsenic hyperaccumulators in China by field investigation and cultivation experiment. In addition, results show it can enrich and transport a large amount of As to its aerial area in many different concentration gradients, which suggests it can be an ideal arsenic pollution remediation plants. Later on, Wei discovered that *Pteris cretica*, from the same genus of *Pteris vittata*, is also an arsenic-accumulating plant.

Table 5. Common lead hyperaccumulators found in China.

Plant name	Concentration （mg/kg）	Translocation factor	Ref.
Carex gentiles	1834	9.96	a
Bidens maximovicziana	2164	1.25	b
Arabis paniculata	2484	1.96	c
Artemisia sacrorumvar	2857	10.38	d

a)Yang et al.(2009);b)Wang et al.(2005);c)Tang et al.(2005);d)Luo et al.(2010)

In nature, lead is easily to form covalent compounds with iron and aluminum oxide, and organic matter, so it is difficult to be absorbed by plants. The content is typically only about 10 mg/ kg (dry weight), common lead hyperaccumulators have been reported mainly in the following table. From the table, we can see that *Carex gentiles* and *Artemisia sacrorumvar* have relatively high translocation factor, which means they have high efficiency to transport Pb from their underground part to aerial part.

Table 6. Common zinc hyperaccumulators found in China.

Plant name	Concentration（mg/kg）	Translocation factor	Ref.
Sedum alfredii	4515	1.25-1.94	a
Arabis paniculata	20800	>1	b
Thlaspi caerulescens	39600	>1	c
Potentilla griffithii var.velutina	26700	0.71	d

a)Yang et al.(2002);b)Shi et al.(2015);c)Xie et al.(2009);d)Peng and Rong.(2009)

Zinc is an essential element for plant growth. It has many important physiological functions in the plant, such as, to regulate plant photosynthesis rate, to regulate protein synthesis process and promote auxin synthesis. But excess zinc can lead to decreased chlorophyll content in plants and many other adverse reactions. From the table, we can see that the concentration of *Sedum alfredii* is far lower than that of hyperaccumulators, but its translocation factor is high, so it can be used as a plant for remediation. The translocation factor of *Potentilla griffithii var.velutina* is lower than 1, but it can be used as remediation plant because of its high concentration level of Zn.

Table 7. Common copper hyperaccumulators found in China.

Plant name	Concentration（mg/kg）	Translocation factor	Ref.
Elsholtzia splendens	1500	>1	a
Rumex acetosa	1749	>1	b
Pteridium revolutum	567	3.88	c

a)Shi et al.(2004);b)Shi et al.(2015);c)Zheng et al.(2006)

Copper is the essential elements of plant growth, but also a heavy metal pollution element. There are many copper hyperaccumulators found in China, for example, *Elsholtzia splendens* and *Rumex acetosa* Linn. The concentration level of *Pteridium revolutum* is less than 1000 mg/ kg, but it can be used as remediation plant due to its high translocation factor.

Table 8. Common chromium hyperaccumulators found in China.

Plant name	Concentration（mg/kg）	Translocation factor	Ref.
Leersia swartz	2977	11.59	a

a)Zhang et al.(2006)

In a series of field investigation sand plant samplings around an electroplating factory in Guangxi Province, a hygrophyte with chromium hyper-accumulative properties, *Leersia swartz*， was found for the first time in China. *Leersia swartz* could significantly absorb chromium from the silt and water and enrich its leaves, stems and roots.

DISCUSSION

The results show the application status of phytoremediation in China, we can easily see that phytoremediation technology is not the main technology used in soil remediation projects. There are many advantages of phytoremediation technology compared with physical and chemical remediation technologies. It avoids the destruction of soil structure thus can protect topsoil and reduce soil erosion, meanwhile, it has low cost and less impact on the environment.

There are several explanations for the restrictions on the development of phytoremediation applications. First, the efficiency of phytoremediation is low. Most hyperaccumulators grow slow and the aerial biomass is small. In addition, only several of these hyperaccumulators have the ability to repair complex pollution, most of the hyperaccumulators can only be used in single heavy metal contaminant soil. Typically, the actual remediation period is longer than the theoretical time. Continuous harvesting of hyperaccumulators will lead to the reduction of effectiveness of soil heavy metals, as the result, plant absorption of heavy metals will also continue to decline as the effectiveness of soil heavy metals directly affects plant repair efficiency (Guo et al. 2013). Meanwhile, the introduction of some hyperaccumulators into a contaminant area is usually limited, because most hyperaccumulators are strict with the requirements of bioclimatic conditions and have strong feature of regional distribution.

The second explanation for the restrictions on the development of phytoremediation applications is the risk of secondary pollution. In the process of plant harvesting, plant litter that rich in heavy metal can be easily scattered with the wind or the river to the adjacent areas. This may lead to secondary pollution and the proliferation of non-point source pollution of the surrounding environment. Under this condition, the remediation area need to be strictly regulated, once these hyperaccumulators ate by livestock and poultry, the pollutants will be transferred to the food chain, causing more serious agricultural products crisis.

The third explanation for the restrictions on the development of phytoremediation applications is the low disposal technology of hyperaccumulators. As we mentioned above, phytoremediation produces large amounts of highly polluted plant residues, how to improve the disposal technology of HMEPB is still an important issue that needs to be addressed in phytoremediation (Liu et al. 2014). In order to reduce the difficulty of the treatment and transportation costs of plant residues, many methods are used to remove the excess water in the plant to reduce the volume of plant residues, for example, compression method and composting method. However, these methods have a certain risk of pollution to the surrounding environment or need for specialized equipment, which makes phytoremediation not that attractive than many other soil remediation technologies. In addition, there are not many researches on heavy metal recovery issue. The "waste into treasure" approach also increases the added value of phytoremediation technology, which can better drive the engineering application of the technology for maximum environmental and economic benefits (Guo et al. 2013). In other words, if the disposal technology is not well developed, it will restrict the commercialization of phytoremediation technology on a large scale.

In the results section, we can see that at present, the hyperaccumulators studied in phytoremediation are mainly herbaceous plants such as *Sedum alfredii, Pteris vittata, Solanum nigrum* and *Phytolacca acinosa*. The hyperaccumulators have strong enrichment and transport ability of heavy metals, but they also have many disadvantages, for example, their biomass is low, the plants are short, the growth is slow, and the main root is not well developed, which limited its application in soil remediation. Meanwhile, the research on application of forest trees as hyperaccumulators of heavy metal is relatively small. Fast-growing trees have large biomass, rapid growth, strong tolerance to heavy metal stress, and they are not connected with the food chain. In addition, these trees can be recycled as building materials, thus they have a certain economic benefits. Willow (*Salix* app.) and poplar (*Populus* app.) are the most studied trees, and they are widely distributed in China and the rate of asexual reproduction is high. In China, the use of fast-growing trees to repair heavy metal contaminated soil is still in the experimental stage. Lai (2005) planted poplar in different experimental areas of soil heavy metal pollution, and the results showed the contents of copper, lead, zinc and cadmium in the soil were decreased by 22.15%, 19.61%, 36.64% and 2.03% respectively. According to Li (2012), poplar have a high cadmium translocation factor, which suggest poplar have a good ability to remove cadmium from soil. Fast-growing trees grow rapidly, especially in juvenile period, for example, willow seedlings' high growth over fast growing period accounted for 60.5% of total height growth and diameter growth accounted for 64.0% of total growth (Zhong et al. 2016). Fast-growing trees can also play a role in the purification of air and water, landscaping, they are widely used in landscaping and afforestation and their utilization prospects is good.

Over the past 20 years, phytoremediation has focused on strengthening plant uptake of heavy metals or the discovery or cultivation of new hyperaccumulators, the research on the feasibility of its commercialization is relatively small. Therefore, in recent years, studies have begun to explore the ideas and methods to treat the disadvantages of phytoremediation such as low remediation efficiency and high treatment cost, for example, improve transgenic technology and fertilization techniques can increase the remediation efficiency (Guo et al. 2013). In fact, the biggest constraint to the current phytoremediation is the cost problem, changing the use of polluted land may be a long-term benign plant remediation path. In other word, the ability to reuse the polluted land while repairing the soil will significantly reduce costs, for example, grow the economic plants that are far from food chain, and use seedlings transplanting method to repair heavy metal contaminated soil.

CONCLUSION

Phytoremediation relies on physiological functions of hyperaccumulators to achieve absorption, degradation, evaporation and enrichment of heavy metal contaminants in the soil. Compared with the traditional repair methods, phytoremediation has the characteristics of low technical cost, simple operation process, eco-friendly and sustainable. As a worldwide problem, environmental pollution has a huge impact on human production and life. At the same time, we can see that, like many countries, China is also taking the old path of treatment after pollution (Chen 2005). Industrialization and urbanization process, resulting in numerous industrial waste, municipal waste and household waste. In addition, nonstandard and backward waste disposal technology, has brought a wide range of water, soil and air pollution.

Based on this, taking appropriate measures to control all kinds of pollution, reduce and eliminate secondary pollution has become a hot and difficult research. Using phytoremediation in the pollution control treatment, as well as building the sewage, garbage disposal facilities, will be able to effectively alleviate the environmental pollution, and gradually achieve ecological restoration, and thus maintain the ecological balance. In the future study, we should further strengthen the research on the utilization of hyperaccumulators and technologies that can remove the restrictions on the development of phytoremediation applications.

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