Overview of Phytoremediation Technology for Heavy Metal Contaminated Soil

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Abstract. Phytoremediation of heavy metal polluted soil has become an efficient and environment-friendly method. The main mechanisms of phytoremediation consist of phytoextraction, phytovolatilization phytostabilization, and phytotransformation. But there are some limitations in the actual remediation effect of plants enriching heavy metals. At present, a wealth of joint remediation methods have been carried out. This paper reviewed the phytoremediation mechanisms and the research status of phytoremediation, such as Cd, As and Pb, and put forward the research direction of phytoremediation and the combination with other technologies.

1 Introduction

Soil heavy metal pollution is a global problem which poses acute threats to the environment and human beings. Their Their sources are divided into natural and anthropogenic sources. The former include volcanic eruptions and weathering of metal-bearing rocks, while the latter include mining and various agricultural or industrial activities. As non-degradable persistent pollutants, heavy metals in soil can reduce biological activity, soil fertility and endanger human health through accumulation in the food chain. Therefore, the remediation of heavy metal polluted soil is of great significance for reducing environmental risks and maintaining human health and ecological security. The phytotechnologies are environmentally safe and cost-effective, which can compensate for other soil remediation technologies. Thus the use of phytoremediation is gradually being accepted by the public.

Phytoremediation has some limitations, too. Phytoremediation relies on the biological cycle and requires multiple crop cycles to repair the soil; phytoremediation can be carried out on sites with little or moderate contamination to ensure normal plant growth; root depth, plant growth rates, low overground biomass and are also limiting factors for phytoremediation; heavy metals bound tightly to soil are difficult to be repaired by plants because of their low biological benefit and so on. Thus phytoremediation began to try to combine with other technologies to improve the phytoremediation effect of heavy metals. This paper summarized the mechanisms of phytoremediation as comprehensively as possible, lists several application examples of phytoremediation, and put forward the research direction of the combination of phytoremediation and other technologies.

2 Phytoremediation

Phytoremediation which uses plants to remove heavy metals from contaminated soil is considered to be a sustainable bioremediation process.

Phytoremediation of heavy metal contaminated soil has multiple mechanisms, which include phytoextraction (uptake, accumulation and translocation of heavy metals), phytostabilization (stabilization of heavy metals in the root zone), phytovolatilization (emission to atmosphere) and phytotransformation (plant degradation).[1]

In phytoextraction, heavy metals are absorbed by the plants together with nutrients and water. The heavy metals are then accumulated and translocated to the overground parts of the plant (leaves, bud, shoot, etc.). Phytoextraction is split into natural phytoextraction and chemical induced phytoextraction. Natural phytoextraction is referred to the extraction of heavy metals from soil by using the natural accumulation capacity of plants. Its main advantages are simple process and low cost, but low extraction efficiency of heavy metals. Compared with natural phytoextraction, chemically induced phytoextraction promotes the extraction of heavy metals by adding chemical modifiers in the rhizosphere of plants and forming chelates with heavy metals in the rhizosphere soil. Therefore, it has the advantages of high extraction efficiency and large removal of heavy metals.

Phytostabilization refers to in-situ deactivation or immobilization of heavy metals that decreases the bioavailability of heavy metals and prohibits their ectopic transportation. In this way, heavy metals are fixed at the roots of the plants by absorption. The benefit

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of this technique is that it helps to protect the surface water and groundwater from heavy metal pollution. While, heavy metals are not really removed from the soil, which is the primary shortcoming of phytostabilization.

In phytovolatilization, heavy metals are absorbed by plants and pushed up through the xylem stream. They are finally converted into volatile forms entering the atmosphere via stomata. Phytovolatilization remediation only transfers pollutants from the soil to the atmosphere. Volatile pollutants are constantly dispersed and diluted in the atmosphere, and will not harm the soil in a short time. However, the state of pollutants cannot be tracked and controlled. So it is very important to monitor the migration of pollutants in the atmosphere for the application of phytovolatilization.

In phytotransformation, plants absorb heavy metals in soil and changed them into nontoxic or less toxic forms. Subsequently, metal ions are decomposed and mineralized by metabolism in plant cells or degradation of enzymes. The degradation of heavy metal pollutants in some plants is related to their own metabolic activities, which can degrade or mineralize heavy metals.The above processes are shown in Fig. 1.

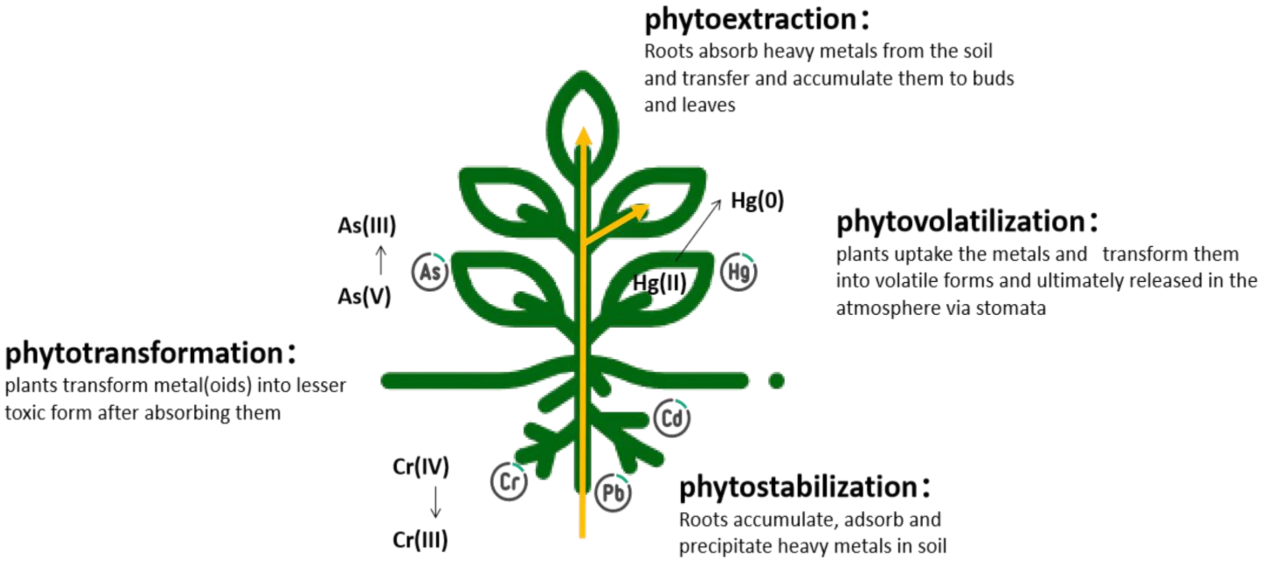

Fig. 1. Multiple mechanisms of phytoremediation.

3 The efficiency of phytoremediation of soils contaminated with different heavy metals

According to the National Soil Pollution Survey Bulletin, we selected a total of eight metals, including cadmium, chromium, zinc, arsenic, copper, mercury and lead, nickel to explore the restoration effect of which contaminated soil by different plants.

BCF (bioconcentration factor) and TF (translocation factor) are commonly applied to measure the efficiency of phytoremediation. TF is the ratio of the heavy metal element density in shoots to that in roots. And BCF is the ratio of heavy metal element density in roots to the that in soil[2]. Plants with both TFs and BCFs higher than 1 (TF > 1and BCF > 1) is promsing to be applied in phytoextraction.

In order to restore and reforest areas degraded by mining, Salas-Moreno, M.[3] planted *Paspalum fasciculatum Wild* in soils with three lead (Pb) concentrations (15, 30, 50mg/kg) and calculated the translocation factor (TF). TF value reached 1.68 after 30 days (Pb treatment concentration is 30mg/kg). They also found that the concentration of heavy metals in this plants declined as the extension of exposure duration, which demonstrates that the plant can be exposed to high concentration of Pb. Their tolerant mechanisms are accumulating the high concentration of Pb in the roots to avoid high concentration in the shoots and then minimize the lesion to the photosynthesis system. At the same time, this species can ameliorate soil conditions by reducing soil acidity and increasing the content of organics.

Azam, S.K. et al.[4] studied whether silicon affected the uptake and accumulation of As by *I. cappadocica*, an As hyperaccumulator, and how Si affected the physiological response under As stress. It indicated that 1 mM Si level enhanced the length of roots and shoots, photosynthetic pigment and biomass of *I. cappadocica*, and increased plant biomass contributed to improving the repair efficiency. Si reduces the concentration of bud as in *I. cappadocica* tissue, so Si addition can be used as a plant phytostabilizer in *I. cappadocica* as contaminated site. As the Si reduces the absorption and translocation of As, the use of Si cannot be used to promote the phytoextraction of *I. cappadocica*. Liu, X. et al.[5] found that P is an effective inhibitor of As uptake by plants. This is because As and P are chemical analogues, which are absorbed by P transporters in plants, and their affinity for P is higher than As (V). Inorganic phosphorus inhibits As uptake by *Pteris vittata*, which is not conducive to the phytoremediation of As contaminated soil, and phytate plays a beneficial role in enhancing As uptake.

Cu is a essential element needed in the growth of various organisms, but high concentration Cu has obvious toxicity to organisms. High concentration of Cu will inhibit plant photosynthesis, nutrient absorption and cell growth[6], and cause animal diseases, such as neurasthenia. Pan, X.C. et al.[7] proved that Cu accumulation in the shoot of *Elsholtzia haichowensis* was always higher than that in the root system due to the large shoot biomass accumulation. However, the concentration factors of roots was greater than that of shoot, and the tolerance of shoot was greater than that of root, indicating that *Elsholtzia haichowensis* mainly accumulated Cu into roots and precipitated to reduce the harm to the growth of shoot of *Elsholtzia haichowensis*.

Yu Xun et al. studied the mercury transport and bioaccumulation ability of *Cyrtomium macrophyllum* at different time (15d-60d) through pot experiments. A total of nine gradients of mercury contaminated soil samples were set.The experiments indicated that both TF and BCF decreased with the rise of the mercury concentration in soil, and BCF increased gradually with the extension of exposure duration. When it was exposed below 200 mg/kg, TF & BCF were greater than 1 in the whole duration of exposure, and when exposed above 500 mg/kg, TF & BCF were less than 1. *Cyrtomium macrophyllum* may be a potential plant for phytoremediation of mercury contaminated soil.

Medicago scutellata is a legume widely cultivated for which can produce high quality feed and has a wide range of uses. Shahrbanoo, P. et al. [8]found that *Medicago scutellata* can eliminate cadmium from polluted soil count on its strong absorption and accumulation ability of cadmium. In the research, the following two factors were mainly focused on, cadmium concentration and drought degree, respectively**.** TF was greater than 1 in all treatments, reflecting the high ability of *Medicago scutellata* to translocate cadmium from roots to shoots. The above results might be related to the differences in chemical functional groups of the roots and aerial parts of plants. It manifested that the above plant had an excellent ability of extracting cadmium from soil and could be regarded as a cadmium hyperaccumulator.

Vetiver, a perennial plant, which is known to prevent soil erosion can tolerate broad range of pH and withstand the increase of toxic metals. Jiang,Y.B. et al.[9] found that its processing effect is as follows: total absorption, rootsand shoots 248.3 (mg/kg dry soil),1.13 (BCF),0.796 (TF). In *Vetiver* plant, cadmium absorbed elements, remain attached to the cell wall or are stored in the roots vacuole. Another reason for the increase of cadmium in the roots of the *Vetiver* is its accumulation in the vacuoles; the accumulation of elements in cell vacuoles prevents their transmission to the aerial parts. Therefore, the value of these elements in the roots is far greater than the shoots. *Vetiver* showed the possibility for phytoremediation of heavy metal polluted lands.

Cassia tora, which possesses rapid growth, short lifetime and high biomass is greatly appropriate to grow and sustain in soil. Through research, Patra, D.K. et al.[10] found that the above plant in chrome polluted soil produced a wealth of biomass increasing with the absorption of heavy metals. In the study, the chrome stress improved the level of antioxidant enzymes and proline in plants. Besides, these plants protected themselves from oxidative stress by altering the sundry metabolic processes. Examples of the main phytoremediation of heavy metals are given in Table 1.

Table 1. TF or BCF of different plants in phytoremediation of heavy metal polluted soil.

Heavy metals	Plant(s)/Tree	TF, BCF
Cd	*M. Scutellata*[8]	1.76 (TF)
	Mulberry[11]	0.11 (TF),0.31 (BCF)
	Vetiver[9]	1.13 (BCF),0.796 (TF)
Cr	*Vetiver*[12]	0.53 (BCF),0.94 (TF)
	Cassia tora[10]	0.51 (BCF)
As	*Pteris vittata*[13]	7.99 (BCF)
	Pityrogramma calomelanos[14]	12.0 (TF)
Cu	*Ricinus communis*[15]	6.62 (TF)
	Commelina communis[16]	7.43 (TF)
Pb	*Paspalum fasciculatum Wild*[17]	1.68 (TF)
	Crambe abyssinica Hochst[18]	0.44 (BCF)
Zn	*Poinsettia*[19]	10.04 (BCF)
	Atriplex. hortensis var.purpurea[20]	2.35 (BCF)
Hg	*Cyrtomium macrophyllum*[21]	2.62 (TF)
	Jatropha curcas[22]	1.32 (BCF)
Ni	*Polypogon monspeliensis*[23]	1.07 (TF)
		1.85 (BCF)
	Rumex dentatus[23]	1.05 (TF)
		9.52 (BCF)

4 Conclusions and perspectives

Soil pollution caused by heavy metals is a global concern. Phytoremediation has been proved to be an important means to solve this problem. Its major strengths are feasible, cost-effective and eco-friendly. This paper reviewed the background and mechanisms of phytoremediation of heavy metal polluted soil, summarized the plant species and remediation effects of different heavy metal contaminated soil.

Combined with other remediation technologies, the phytoremediation effect of heavy metal pollution can be improved， such as plant microbial joint remediation, plant animal joint remediation, plant gene improvement remediation and chemical plant joint remediation. Plant microbial joint remediation provides favorable environment for plants to enrich heavy metals through bioaugmentation, and improves the enrichment effect of phytoremediation plants, For example, *Bacillus subtilis*-plant combined remediation of Cd contaminated soil can promote the accumulation of cadmium by plants and its transfer to the above ground. Plant animal combination technology refers to a remediation that uses the direct absorption and transformation of heavy metals by some lower animals (such as earthworms) in the soil, or improves soil physical and chemical properties to increase plant absorption of heavy metals. Plant gene improvement remediation is found on the over expression of specific genes participated in absorption, sequestration, translocation and plant tolerance of xenobiotic compounds in transgenic plants (Aken, B.V.)[24]. Chemical phytoremediation uses synthetic or organic chelating agents to assist plant extraction or induce plant extraction to improve their extraction ability. For example, some polymer materials can promote the absorption of cadmium by hyperaccumulators such as *Solanum nigrum* or *Amaranthus granatum*. The research on phytoremediation of heavy metal contaminated soil is still developing, whose existing limitations are shrinking with the research. Therefore, phytoremediation has broad development prospects.

This work was supported by Ningxia Hui Autonomous Region key research and development plan (2021BEG02002), Tianjin key research and development plan (21YFSNSN00030, 19YFZCSN00-450), Tianjin Agricultural Science and Technology Achievement Conversion and Extension Project (201901130).

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