Review in Strengthening Technology for Phytoremediation of Soil Contaminated by Heavy Metals

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Abstract. Phytoremediation technology has become the frontier and hot research of soil heavy metal pollution areas of resource, environmental and biological sciences internationally. In view of current problems of phytoremediation technology, this paper summarizes research progress for phytoremediation technology of heavy metal contaminated soil, discussing physics, chemistry, biotechnology methods of increasing plant biomass and heavy metal accumulation. This paper focuses on the mechanism and application effects of genetic engineering technology, chelate induced technology and microbial combined phytoremediation and the future research direction of phytoremediation was also prospected.

1. Introduction

In recent years, with the irrational development and utilization of mineral resources, sewage irrigation, the large-scale application of chemical fertilizers and pesticides, industrialization and urbanization, soil heavy metal pollution has become increasingly serious[1]. After heavy metals enter the soil ecosystem, they interfere with soil ecosystems through interaction with soil multi-media components, destroy the living environment of plants and microorganisms, and cause the soil quality to decline, thus posing a threat to crops[2]. At present, the area of soil contaminated by heavy metals in China has reached tens of millions of hectares, and the contaminated cultivated land is about 0.1 billion hm², accounting for more than 10% of the total cultivated land. Most of them are concentrated in economically developed areas, and the country is polluted by heavy metals every year. Up to 12 million tons, due to heavy metal pollution, the grain production has been reduced by more than 10 million tons, and the total economic loss is at least 20 billion yuan[3]. The problem of soil pollution has threatened the ecological environment, food safety, human health and sustainable development of agriculture, which has aroused strong concern from all walks of life. How to effectively control soil heavy metal pollution has become a hot spot in the current environmental research field.

At present, the traditional remediation methods for the treatment of heavy metal contaminated soil[4], such as vitrification, soil washing, electric power, thermal desorption, curing, guest soil, shower and so on, are usually expensive, small scale and easy to cause secondary pollution.

Phytoremediation technology as an environmentally friendly and low-cost new environmental
pollution technology has been recognized and selected by the scientific community and government departments. Although phytoremediation has a high potential in remediation of heavy metal contaminated soils, its inherent characteristics are greatly limited in practical application. Therefore, enhancing the efficiency of phytoremediation by strengthening technology is the key to remedy its defects.

2. Overview of Phytoremediation Technology

2.1 Phytoremediation technology concept
Raskin et al. [5] first proposed the term "phytoremediation" in 1994. Phytoremediation of soil contaminated by heavy metals refers to a technology that removes, volatilizes or stabilizes heavy metal pollutants in the soil environment or reduces the toxicity of heavy metals in pollutants through plant system and root system, so as to eliminate pollution, repair or treat soil. The principle of phytoremediation of heavy metal contaminated soil is to use the selective absorption and transport capacity of plant roots and the bioaccumulation, storage and degradation ability of the plant itself to fix heavy metals in the soil to the roots or to transform into less toxic metabolites[6]. According to the process and mechanism of plant treatment of heavy metal contaminated soil, phytoremediation of heavy metal contaminated soil can be divided into five types: plant extraction, plant evaporation, plant stability, rhizosphere biodegradation and root filtration[7]. Hyperaccumulators are ideal plants for phytoextraction which is currently the most studied and promising method of phytoremediation[8].

2.2 Advantages and disadvantages of phytoremediation
Phytoremediation technology for soil heavy metal pollution, as a reliable technology in biotechnology, has incomparable advantages over physical and chemical methods and has been widely focused by the society. It has low cost and long-lasting treatment effect; the technical operation is simple, and it is easy to implement in a wide range; the disturbance to the environment is small; the secondary pollution is not caused; the heavy metal pollutants in the soil can be cleaned at the same time, and the pollutants in the surrounding water body or the atmosphere can be cleaned; The value of beautifying the environment is welcomed by people[9]. Therefore, phytoremediation technology is a true "green repair technology."

Although phytoremediation shows great advantages compared with traditional methods, it also has certain limitations: (1) Plant tolerance is limited. High concentrations of metals in the soil have inhibitory effects on plants, so different ecological plants should be selected for soils with different pollution conditions. (2) Most hyperaccumulators can only accumulate certain heavy metals, and most of the soil pollution is the combined pollution of heavy metals, which limits the application of heavy metal complex contaminated soil treatment. (4) It is limited by the extent of root extension. The phytoremediation soil can only be confined to the extent that the plant roots can extend, generally not exceeding 20 cm of soil thickness [10]. (5) The heavy metals extracted from the hyperaccumulators return the heavy metals to the soil through the decay, fade or mechanical breakage of fruits, leaves, roots, etc., which indirectly reduces the repair efficiency, and the plant attack by pests and diseases will also affect the repairing effect [11].

Therefore, in the treatment of heavy metals contaminated by soil, it is difficult to achieve the expected effect quickly by using only phytoremediation technology, and appropriate strengthening technology should be supplemented to improve the phytoremediation performance, make up for its limitations, and improve the repair effect.

3. Advances in Strengthening Technology for Phytoremediation

3.1 Genetic engineering enhanced phytoremediation technology
Genetic engineering technology is considered as an effective way to improve the tolerance and enrichment of heavy metals in plants and has become one of the most potential development directions
in the field of strengthening phytoremediation. Introducing exogenous genes into plant cell genomes can effectively increase the extraction of heavy metals from plants and thus improve the efficiency of phytoremediation. Such as metal chelating agents, metallothionein (MTs), plant chelating peptides (PCs) and heavy metal transporters [12]. MerA and merB genes were introduced to nine plants such as arabidopsis thaliana and tobacco. It was found that transgenic plants can grow well in polluted soil with concentrations of 400 lxmol/L PMA and 500txmol/L HgCl, and the mercury content in the roots reaches 2,000 microns [13]. In addition, the use of genetic engineering technology can also improve the tolerance and accumulation of heavy metals in plants, thereby improving the efficiency of heavy metal repair in plants [14]. Grispen et al. [15] introduced AtMt2b and AtHMA4 genes of cauliflower Mosaic virus into tobacco, and found that compared with wild tobacco, transgenic tobacco enhanced the ability to transport cadmium and zinc from root to aboveground and the tolerance to cadmium.

According to research, although genetic engineering technology is used to strengthen the good repair efficiency of phytoremediation under laboratory conditions, it still has potential ecological risks and environmental threats in field practice. Zeller et al. [16] found that in the greenhouse environment, the yield of rice with anti-fungal powdery mildew Pm3b gene was increased by 2 times compared with non-transgenic rice, while in the field trial, the yield was reduced to 56%, and the infection rate of ergot disease was increased by nearly 40 times.

3.2 chelate enhanced phyto remediation technology

Chelate can break the balance between heavy metals in the soil liquid phase and solid phase, and reduce the soil holding strength of heavy metal-chelator complexes. It can make the equilibrium relationship develop in a direction conducive to the desorption of heavy metals, so that before reaching a new equilibrium, a large amount of heavy metals enter the soil solution, increase the concentration of heavy metals in the soil solution, and improve the efficiency of plant extraction and repair. There are two types of common chelating agents: one is a synthetic chelate, such as EDTA, HEDTA, CDTA, EGTA, etc; This has strong activation ability for heavy metals. EDTA (ethylenediaminetetraacetic acid) is the most effective and most commonly used in phyto remediation of heavy metal contaminated soils, which can significantly increase the ability of plants to absorb Cd and Pb. Seth et al. [17] found that after 28 days of EDTA treatment with 500 lxn/L concentration in lead-contaminated soil, the lead concentration in sunflower roots and aboveground parts increased by 135 g/g and 575 g/g respectively, and the toxicity of lead in soil was significantly reduced. Piechalak et al. [18] reported that when 292 mg EDTA was added to the soil of 200 mg/kg Pb, the enrichment of Pb in pea increased by 67% compared with the control. The other type is natural chelate, such as citric acid, oxalic acid, tartaric acid, etc. These chelators are not as strong against the heavy metals as they are, but they are widely concerned by researchers because of their biodegradability. Wang et al. [19] showed that treatment of Cr super-enriched plant Lishihe with 70 mg/L oxalic acid alleviated the decrease of biomass and the inhibition of Cr on root growth, indicating that oxalic acid may be involved in the detoxification of chromium inside Lishihe process. At present, the research focus has gradually shifted from refractory artificial chelators to natural chelators or degradable chelators that are less harmful to the environment. Biodegradable chelators such as ethylenediamine disuccinic acid (EDDS), aminotriacetic acid (NTA) and citric acid (CIT) have become research hotspots in recent years [20]. Surfactants are hydrophilic and oil-philic compounds, which can promote the desorption of heavy metals in soil and improve the bioavailability according to their solubilization and flow enhancement characteristics. Surfactants are mainly divided into synthetic surfactants and natural biological surfactants. The mechanism of surfactant is adsorption at soil interface, metal association and effective complexation to remove heavy metals[21]. Surfactants can reduce the adsorption of Cu, Pb, Cd and Zn in clay. Studies have shown that in the bioleaching test, the optimal dosage of surfactant Tween-80 is 6. 0g / L, the biooxidation rate of elemental sulfur is significantly improved, the acidification rate of sludge is accelerated, and the deposition of Gu and Zn The best solution is dissolved [22]. Wang Lizhen and Chen Yucheng et al. [21-22] have found that the combination of surfactants and chelating agents, through the activation of heavy metals in the soil, and the effect of surfactants on the permeability of plant roots to heavy metal
chelates can significantly promote plant heavy metals. Absorption and transport to the ground. Like chelating agents, surfactants also show some toxic effects on plant growth, and they are easy to bring about environmental impact. The development of biosurfactants that are easy to be degraded and non-toxic has become a hot spot of surfactant repair. Biosurfactants are produced by plants or animals. They are non-toxic or low-toxic and easily biodegradable. They will not adversely affect plants or change the physicochemical properties of soil. It not only promotes the absorption of heavy metals by plants, but also promotes the migration of heavy metals from roots to aboveground parts[23]. Potted experiment was carried out by inoculation of plant strain J119, which can produce surfactant, and the results showed that Pb concentrations of aboveground and root of rape increased by 31.0% and 35.0% respectively. It can be seen that biosurfactant is a promising remediation agent for heavy metals.

3.3 microbial combined phytoremediation

Microbial combined phytoremediation technology is to make full use of the coexistence of soil-microbial and plant, give full play to the respective advantages of plant and microbial remediation, make up for the deficiency of single method of remediation, and improve the efficiency of phytoremediation of soil contaminated by heavy metals. Microbial combined phytoremediation can be divided into two categories: bacterial combined phytoremediation and mycorrhizal fungal combined phytoremediation. Bacteria can secrete some plant growth regulators, chelating agents, antibiotics, etc. to enhance the environmental adaptability of plants, and can effectively alleviate the toxicity of heavy metals in the soil and supply plant nutrients, thereby regulating plant physiological processes, promoting plant growth, and beneficially improving Plant restoration efficiency. Zhao gencheng et al. [24] found that the addition of exogenous actinomycetes PSQ, shf2 and bacteria Ts37 and C13 to the soil contaminated by arsenic can significantly promote the growth of centipede grass and effectively improve the ability of centipede grass to accumulate arsenic. After inoculation of copper-resistant bacteria such as thick-walled bacteria in Haizhou camphor and comfrey, Sun et al. [25] found that the copper content in the shoots of the two plants increased by 63% to 125%, and the dry matter mass in the roots and shoots increased by 132%, 155% and 71% to 83%. It can be seen that the inoculation of obligate strains into the soil during the process of phytoremediation of heavy metals contaminated soil can not only increase plant biomass, but also increase the bioavailability of heavy metals in the soil [26].

Mycorrhizal fungi (AM) can enhance the tolerance of host plants to heavy metals and affect the absorption, transport and accumulation of heavy metals in plants, so as to strengthen the treatment of heavy metal pollution in soil by phytoremediation technology[27]. Mycorrhizal secretions can regulate the rhizosphere environment, affect rhizosphere ph and REDOX potential, and thus affect the bioavailability of heavy metals. At the same time, the mucus secreted by mycorrhiza can accelerate the circulation of nutrient elements, promote the absorption of nutrients and mineral elements in the soil, increase the stress resistance of plants, and increase the biomass of roots and aboveground parts[28]. Nogales et al. found that inoculated arbuscular mycorrhizal fungi (Glomus intraradices BEG 72) in 200 mg/kg of Cr (III) contaminated soil was more significant than the inoculation of Plantago lanceolata, the aboveground Cr concentration is also relatively low[29]. Wang Fayuan et al [30] found that arbuscular mycorrhizal fungi combined with plants can not only reduce the toxicity of heavy metals to plants, but also effectively affect the absorption and transformation of heavy metals by plants. Chen et al. [31-32] used indoor simulated potting methods to find that arbuscular mycorrhiza can reduce the concentration of Cu, As and Cd in plant shoots while improving plant phosphorus nutrition, thus slowing down the toxicity of heavy metals to host plants.

4. Conclusion

Researchers at home and abroad have also made some achievements in the relevant theory and practical application of strengthening technology. However, in general, there are still many problems to be solved in the industrial application and intensive restoration of phytoremediation. In the future, it is need to conduct in-depth research from the following aspects:
(1) The research on the theory and mechanism of microbial plant joint repair is far from enough, including the screening, identification and reproduction of functional strains, the preparation of bacterial agents, inoculation methods and engineering applications.

(2) Further research on genetic engineering, including the ecological safety of super-accumulated plants, the screening of valuable genes, and the genetic properties of transgenic plants.

(3) Develop the supporting equipment and technology of phytoremediation, get rid of the limitation of laboratory test, and lay a solid material foundation for popularizing phytoremediation.

(4) It is necessary to strengthen the practical application research of joint repair between different strengthening measures, and jointly improve the repair efficiency of heavy metal contaminated soil. It is difficult to achieve the expected effect by a single repairing technology. It should be based on phytoremediation, supplemented by physical and chemical microbial means to increase the bioavailability of heavy metals, and joint repair technology will be the main research direction of soil heavy metal repair in the future.

References

[1] Marques, A.P.G.C., Rangel, A.O.S.S., Castro, P.M.L., (2011) Remediation of heavy metal contaminated soils: an overview of site remediation techniques. J. Critical Reviews in Environmental Science and Technology, 41:879-914.

[2] Newman, M.C., McIntosh, A.W., (1991) Metal ecotoxicology: Concepts and applications[M]. Boca Raton Lewis Publishers & CRC Press.

[3] Luo, Y.M., Teng, Y., (2006) Status of soil pollution degradation and countermeasures in China. J. Soils., 38:505-508.

[4] Marques, A.P., Angel, A.O., Castro, P.M., (2009) Remediation of heavy metal contaminated soils: phytoremediation as a potentially promising clean—up technology. J. Critical Reviews in Environmental Science and Technology, 39:622—654.

[5] Raskin, I., Kumar, P., Du, S.K.S., et al., (1994) Bioconcentration of heavy metals by plants. J. Current Opinion in Biotechnology, 5:285-290.

[6] Hinehman, R.R., Negri, M.C., Gatilf, E.G., (1996) In Phyto—remediation:using green plants to clean up contaminated soil, groundwater and wastewater hi.International Topical Meeting on Nuclear and Hazardous Waste Management, Spectrum. C. 23:1-13.

[7] Li, W.Y., Xu W.H., Li, Y.R., et al., (2006) Research advances on heavy metals contaminated soils and phytoremediation. J. Pollution Control Technology, 19: 18-22.

[8] Xiong, X.T., Hao, H., Shen, F., et al., (2012) Reviewin strengthening technology for phytoremediation of soil contaminated by heavy metals. J. Environmental Science&Technology, 35:185- 193.

[9] Zhou, Q.X., (2001) ent protection. J. Journal of Safety and Environment, 1:48-53.

[10] Qu, X.R., Sun, Y.B., et al., (2008) Protection, 12: 45-47.

[11] Jin, L.S., Lin, G.L., Xu, Y.F., et al., (2008) Latest re-search on phytoremediation of heavy metal contaminated soil. J. World Agriculture, 8: 47-51.

[12] Ruiz, O.N., Daniell, H., (2009) Genetic engineering to enhance mercury Phytoremediation. J. CmTent Opinion in Bio—technology, 21:213-219.

[13] Thomas, J.C., Davies, E.C., Malicks, F.K., et al., (2003) Yeast metallothionein in transgenic tobacco promotes copper uptake from contaminated soils. J. Biotechnology Progress, 19:273-280.

[14] Grispen, V.M.J., Hakvoo, H.W.J., Bliek, T., et al., (2011) Combined expression of the A ra5idopsis metallothionein M I2b and the heavy metal transporting ATPase HMA4 enhances cadmium tolerance and the root to shoot translocation of cadmium and zinc in tobacco[J].Environmental and Experimental Botany,72:71—76.

[15] Nagata, T., Nakamura, A., Akizawa, T., et al., (2009) Genetic engineering of transgenic tobacco for enhanced uptake and bioaccumulation of mercury. J. Biological and Pharmaceutical
Bulletin, 32:1491-1495.

[16] Zeller, S., Kalinina, O., Brunner, S., et al., (2010) Transgenex environment interactions in genetically modified wheat. J. PLoS One. 7: 11-13.

[17] Seth, C.S., Misra, V., Singh, R.R., et al., (2011) EDTA—enhanced lead phytoremediatio0n in sunflower (Helianthus annuus L.) hydroponic ceuhure. J. Plant and Soil. 347:231—242.

[18] Piechalak, A., Tomaszewska, B., kiewicz, B.D., (2003) Enhancing phytoremediative ability of pisum sativum by EDTA application. J. Phytochemistry. 64(7): 1239-1251.

[19] Wang, D., Zhang, X., Liu, J., et al. Oxalic acid enhances cr tolerance in the accumulating plant leersia hexandra Swartz. J. International Journal of Phvtoremediation. 14:966—977.

[20] Sillanapp, M.E.T., Kurniawan, T.A., Lo, W.H., (2011) Degradation of chelating agents in aqueous solution using advanced oxidation process (AOP). J. Chemosphere, 83:1443-1460.

[21] Chao, Y., Yuan, X.Z., Zeng, G.M., et al., (2012) Application obiosurfactant in static forced-aeration composting of sewage sludge. J. Chinese Journal of Environmental Engineering, 6:1331-1336.

[22] Wu, S.D., Liu, Y.G., Zeng, G.M., et al., (2010) Surfactant-enhanced bioleaching of Cu and Zn from sewage sludge [J]. China Environmental Science, 30:791-795.

[23] Ye, H.S., (2006) Screening of Biosurfactant-producing Bacterial Strains and Their Effects on the Uptake of Lead and Cadmium in Soils by Plants. D. Nanjing: Agricultural University of Nanjing.

[24] Zhao, G.C., Liao, X.Y., Yan, X.L., et al., (2010) Enhancement of As-accumulation by Pteris vittata L. affected by Microorganisms. J. Environmental Science, 31:431-436.

[25] Niu, Z.Y., Sun, L.N., Sun, T.H., Plant-microorganism combined remediation of heavy metals – contaminated.

[26] Xu, J.F., Wang, L., Xiong, Y., et al., (2017) Research progress on strengthening phytoremediation technologies for heavy metals contaminated soil. J. Journal of Environmental Engineering Technology, 7:366-373.

[27] Bao, T., Sun, L.N., Sun, T.H., et al., (2010) Research progress in strengthening measures for phytoremediation of soils contaminated by heavy metals. J. Environmental Science & Technology, 33: 458-462.

[28] Leung, H.M., Wu, F.Y., Cheung, K.C., et al., (2010) Synergistic effects of arbuscular mycmThizal fungi and phosphate rock on heavy metal up take and accumulation by an arsenic hyperaccumulator. J. Journal of Hazardous Materials, 181:497-507.

[29] Nogales, A., Cortes, A., Velianos, K., et al., (2012) Plantago lanceolata growth and Cr uptake after mycorrhizal inoculation in a Cr amended substrate. J. Agriculture and Food Science, 21:72-79.

[30] Wang, F.Y., Lin, X.G., (2007) Role of a buscular mycorrhziae in phytoremediation of heavy metal –contaminated soils. J. Acta Ecologica Sinica, 27:793-801.

[31] Chen, B.D., Xiao, X.Y., Zhu, Y.G., et al., (2007) The arbuscular mycorrhizal fungus Glomus mosseae gives contradictory effects on phosphorus and arsenic acquisition by Medicago sativa Linn. J. Science of the Total Environment, 379:226-234.

[32] Dong, Y., Zhu, Y.G., Smith, F.A., et al., Arbuscular mycorrhiza enhanced arsenic resistance of both white clover (Trifolium repensLinn.) and ryegrass (Lolium perenne L.) plants in an arseniccontaminated soil.