Application of combined remediation in heavy metal polluted soil

Yan Xu 1, 2, 4, a, Yangjie Lu 1, 2, 4, Chang Tian 1, 2, 4, Jianqiang Yang 1, 2, 3

1 Key Laboratory of Degraded and Unused Land Consolidation Engineering, the Ministry of Land and Resources of China, Xi'an 710075, China.
2 Shaanxi Provincial Land Engineering Construction Group, Xi'an 710075, China.
3 Shaanxi Provincial Land Engineering Construction Group Ming Development and Environmental Management Co., LTD, Xi'an 710075, China.
4 Institute of Land Engineering and Technology, Shaanxi Provincial Land Engineering Construction Group, Xi'an 710075, China.

a 1213349323@qq.com

Abstract. Whether it is single or compound heavy metal pollution, it is universal, complex, and invisible. The soil pollution cannot be completely resolved only relying on a single repair technology, requiring multiple approaches often. The combined remediation technologies of soil pollution can exert respective advantages, abandon their shortcomings, and optimize the repair effect. Based on a large number of literature surveys, this article discussed the application of combined remediation in heavy metal-contaminated soils, in order to provide reference for the rehabilitation of heavy metal-contaminated soils.

1. Introduction
The combined remediation refers to the combination of two or more repair methods for soil remediation, which can not only improve the efficiency and rate of single contaminated soils, but also overcome the limitations of individual remediation technologies and achieve simultaneous restoration of composite pollutants. According to different repair technologies, the combined repair technology is currently divided into: microbial-plant remediation, microorganism-animal, microorganism-plant-animal, physical/chemical-microbial/plant/animal combined remediation, etc. At present, the application of microbial-phytoremediation is quite common. Based on a large number of literature surveys, this article discussed the application of combined remediation in heavy metal-contaminated soils, in order to provide reference for the rehabilitation of heavy metal-contaminated soils.

2. Microbial-plant remediation for heavy metal-contaminated soils
Microbial-plant remediation uses microorganisms to promote the secretion of surfactants, organic acids, and enzymes from the plant rhizosphere to increase the bioavailability of heavy metals in the soil and then promote the absorption, accumulation, or fixation of heavy metals by plants; on the other hand, the specific enzymes, plant hormones, vitamins, antibiotics, and nitrogen fixation (such as rhizobia) can promote the plant growth, thereby increasing the total accumulation of heavy metals[1]. On the contrary, the plant roots continuously secrete some organic compounds, such as sugar, protein, amino acids, etc.,
which not only provide a rich source of energy and carbon for microorganisms, but improve the physical and chemical properties of the rhizosphere soil, and the reproduction of microorganisms[2]. At present, more researches conducted are arbuscular mycorrhizal- phytoremediation and endophyte-phytoremediation.

3. **Arbuscular mycorrhizal- phytoremediation**

Arbuscular mycorrhiza (AM) is the most widely distributed type of mycorrhiza, which can reduce the toxicity of heavy metals on plants and promote the absorption and transport of heavy metals by plants. Its mechanism is divided into direct and indirect effects. The direct action refers to that AM mycelia accumulate heavy metals in the bacteria through chelation or reduce the toxicity of heavy metals to plants through secretions. Indirect action means that AM can enhance the absorption of nutrients by plants to increase their resistance [3]. For example, heavy metal ions Zn\(^{2+}\), Cd\(^{2+}\), Cu\(^{2+}\) can affect the uptake of P, while AM can significantly improve this situation.

4. **Endophyte-phytoremediation**

Endogenous bacteria which resistant to heavy metals are commonly found in hyper accumul-ators. Endophytes, especially the plant-derived endophytic bacteria (PGPE), are important components of the microecological systems [4]. The mechanism of endophytic bacteria resistant to heavy metal pollution is similar to mycorrhizal. Among them, the rhizobia-legume symbiotic system is typical. High concentrations of heavy metals can cause the loss of symbiotic nitrogen-fixing plasmids in rhizobia and legumes, as the development of plant roots and nutrient uptake, resulting in restrictions on nodulation and nitrogen fixation [5]. Rhizobium, as a type of endophyte, has formed a relatively stable and reciprocal relationship with plants through long-term evolution. It can provide nutrition to plants and promote its growth. At the same time, the plants provide nutrition and protection for them [6-7]. Rhizobium, like other growth-promoting bacteria, can secrete plant growth-promoting substances, promote the growth of leguminous and the accumulation of heavy metals, and is applied to the ecological restoration of heavy metal-contaminated soil.

Wei et al (2011) [8] investigated the natural plants grew in some heavy metal tailings waste in Shaanxi and Gansu province and found that there are indeed some different endurance-resistant legumes plants, which can adapt to the severe conditions of mining wasteland, especially Medicago lupulina, Melilotus albus, Acacia and Lespedeza cuneata, which showed some advantages in the wasteland (Table 1). These leguminous plants have yet to be excavated, screened and utilized, laying the foundation for the use of legumes to promote the restoration of abandoned mining areas in northwestern China.

**Table 1.** Some leguminous plants grew naturally in abandoned areas of heavy metal mining areas in parts of Northwest China

| Survey area          | Tailings          | Plants                                 |
|----------------------|-------------------|----------------------------------------|
| Shaanxi Taibai       | Gold mine         | Medicago lupulina                      |
| Shaanxi Fengxian     | Gold mine         | Medicago lupulina,Melilotus albus, Vicia sepium, Phaseolus vulgaris, Sophora viciifolia |
|                      | Lead and zinc mine| Medicago lupulina,Melilotus albus, Phaseolus vulgaris |
| Shaanxi Ningqiang    | Iron mine         | Medicago lupulina, Lespedeza cuneata, L. floribunda, Wh t e Clover |
|                      | Copper and zinc mine| Medicago lupulina, Lespedeza cuneata, L. floribunda, cowpea |
| Shaanxi Nueyang      | Gold mine         | Medicago lupulina,Melilotus albus, Acacia, Phaseolus vulgaris, Albizia |
|                      | Nickle mine       | Acacia                                 |
| Gansu Chengxian      | Nickle mine       | Lespedeza cuneata, L. floribunda       |
|                      | Lead and zinc mine| Medicago lupulina, Acacia, Melilotus albus, L. floribunda |
|                      | Gold mine         | Acacia, Melilotus albus, L. floribunda |
| Gansu Huixian        | Lead and zinc mine| Medicago lupulina, Acacia, Lespedeza cuneata, Sophora viciifolia |
In addition, Ren (2011) [9] conducted a study on the phosphorus-removing bacteria and Indian mustard to restore lead-contaminated soils in the mining area of northern Shaanxi. The results showed that addition of phosphate-solubilizing agents to the rhizosphere of Indian mustard can promote the absorption and utilization of phosphorus in soil, then promote the growth of Indian mustard and increase its biomass. The m of lead in different tissues of Indian mustard found that it has different degrees of lead accumulation in the aerial and roots parts of Indian mustard. Compared to the group without adding the phosphorus-solubilizing bacteria, the group which added accumulated more lead.

5. Animal-plant remediation for heavy metal-contaminated soils

In animal-plant remediation, the earthworm-plant remediation has received extensive attention. The results showed that in the whole process of soil remediation, the effect of animal-plant remediation was better than simply superposition of animal restoration and phytoremediation. Firstly, the growth of plant roots creates a good environment for earthworms. The earthworms can improve the soil structure, fertility, moisture, nutrients, and aeration through peristalsis and feeding, and its secretion and wormcast can increase the amount and activity of soil microorganisms. Secondly, a variety of microorganisms are carried in the body of earthworms, which can increase the amount of active microorganisms in the soil, thus improve the growth environment of roots, promoting the enrichment of heavy metals by plant.

Tian et al. (2013) [10] used white clover, ryegrass and earthworm to repair the heavy metals in the soil. The result showed that the content of Cd, Cu, and Pb in the soil decreased by 92.3%, 42.0%, and 24.7%, respectively after 18 months of remediation. The activities of either animal or plant can promote the repairing efficiency of the other party [11-12]. Therefore, the animal-plant remediation is completely feasible and suitable for large-scale promotion in the engineering practice.

6. Transgenic-plant combined remediation for heavy metal-contaminated soils

Using transgenic technology to convert metallo-morphogenesis-related genes, such as metallothionein (MTs), phytochelatins (PCs), and heavy metal transporter genes into hyperaccumulators can significantly increase the absorption of heavy metals by plants. Some researchers have transferred the merA and merB genes into arabidopsis and tobacco to convert methylmercury into inorganic mercury from the plants [13]. Shukla et al. transferred the Ceratophyllum phytochelatins synthetase genes into tobacco and found that the ability of plants to absorb Cd increased obviously after genetically modified [14].

7. Existing problems and trend

Whether it is a single heavy metal or compound pollution, it is universal, complex and invisible, and its repair cannot be completely resolved by relying on a single repair technology, but require multiple approaches, so in practical application, various methods can be combined to give full play to their respective advantages, and to form a comprehensive repair technology that is suitable for the conditions of on-site contaminated soil and integrates the advantages of various methods to achieve the purpose of completely rehabilitating the contaminated soil. In the future, the screening and rational collocation of hyperaccumulators and highly efficient degrading microorganisms, the repair mechanism, and the rhizosphere effect based on the microbial-plant remediation, to form a systematic combined remediation technology.

References

[1] Pengfei Xiao, Fayun Li, Baorong Fu. Soil contaminated by heavy metal and its phytoremediation[J]. Shen Yang: Journal of Liaoning University, 2004, 31(3):279-283 (in chinese).

[2] Fayuan Wang, Xiangui Lin. 2007. Role of a buscularm ycorrhizae in phytoremediation of heavy metal contaminated soils[J]. Acta Ecologica Sinica, 27(2):794-798 (in chinese).

[3] Yanping Xiao, Rui Yin, Shengyuan Shen, et al. 2010. Roles of arbuscular mycorrhizal in plant remediation of arsenic-contaminated soil[J]. Soils, 42(2):171-177 (in chinese).
[4] Mastretta C, Taghavi S, Vander L D, et al. 2009. Endophytic bacteria from seeds of Nicotiana tabacum can reduce cadmium phytotoxicity [J]. International Journal of Phytoremediation, 11: 251-267.

[5] Vijayaraghavan K, Yun Y S. 2008. Bacterial biosorbents and biosorption [J]. Biotechnology Advances, 26: 266-291.

[6] Lodewyckx C, Taghavi S. 2001. The affect of recombinant the heavy metal-resistant endophytic bacteria on heavy metal uptake by their host plant [J]. International Journal of Phytoremediation, 3(2): 173-187.

[7] Compan S, Clement C, Sessitsch A. 2010. Plant growth-promoting bacteria in the rhizo and endosphere of plants: Their role, colonization, mechanisms involved and prospects for utilization [J]. Soil Biology and Biochemistry, 42: 669-678.

[8] Gehong Wei, Zhanqiang Ma. 2010. Application of rhizobia-legume symbiosis for remediation of heavy-metal contaminated soils [J]. Acta Microbiologica Sinica, 50(11): 1421-1430 (in Chinese).

[9] Yongxia Ren. 2011. The study of microphyto combined remediation on polluted soil by heavy metals in mining area of northern Shannxi [D]. Xi’an: Northwest University (in Chinese).

[10] Weili Tian, Dan Liu, Jiasen Wu, et al. 2013. Application of animal and plant combination remediation technology in complex heavy metals contaminated soil [J]. Journal of Soil and Water Conservation, 27(5): 189-192 (in Chinese).

[11] Yang Li, Yuhui Qiao, Xiaohui Mo, et al. 2011. Analysis for earth worm feces as one of potential repair agents of heavy metal contamination in soil [J]. Journal of Agro-Environment science, 2010, 29(supplement): 250-255 (in Chinese).

[12] Fengling Feng, Jiemin Cheng, Dexia Wang. 2010. Potential application of earth worm for the phytoremediation of soils contaminated by heavy metals [J]. Chinese Journal of Soil Science, 2006, 37(4): 809-814 (in Chinese).

[13] Shukla D, Kesari R, Mishra S, et al. 2009. Expression of phytochelatin synthase from aquatic macrophyte Cerato phylum demersum L. enhances cadmium and arsenic accumulation in tobacco [J]. Plant Cell Reports, 31(9): 1687-1699.

[14] Lee S, An G. 2009. Over-expression of Osirt leads to increased iron and zinc accumulations in rice [J]. Plant, Cell and Environment, 32(4): 408-416.