Integrated Vetiver Technique for Remediation of Heavy Metal Contamination: Potential and Practice

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Abstract: Metalliferous mining activities produce a large quantity of waste materials (such as tailings), which frequently contain excessive concentrations of heavy metals. These mining activities and waste materials have created heavy metal pollution problems through wind and water erosion. An integrated vetiver technique (IVT) for remediation of heavy metal contamination raised from mining activities is suggested in this paper. The remediation technique includes three aspects: phytostablization of mining wastes to reduce wind and water erosion, phytofiltration of heavy metals in wastewater with utilization of constructed wetlands, and phytoextraction of heavy metals from contaminated soils. Vetiver grass, due to its unique characteristics, such as higher biomass, fast growth, strong root system and higher metal tolerance etc., can play an important role in these aspects. Progress in the three aspects has been summarized based on our series of research (five experiments). The limits and further necessary research of these techniques is also discussed.

Key words: phytoremediation, phytoextraction, phytostablization, integrated vetiver technique, heavy metal, contamination

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1 INTRODUCTION

Heavy metals occur naturally in rocks and soils, but chiefly in forms that are not available to living organisms, such as constituents and replacement elements in rock and soil minerals. Increasingly higher quantities of heavy metals are being released into the environment by anthropogenic activities, primarily associated with industrial processes, manufacturing and disposal of industrial and domestic refuse and waste materials (Ross, 1994). Soils and water contaminated with heavy metals pose a major environmental and human health problem that needs an effective and affordable technological solution. Since most current technologies cannot selectively remove heavy metals, many contaminated sites can be remediated only by using labor-intensive and costly excavation and land filling technology. Many sites around the world remain contaminated with no remediation in sight simply because it is too expensive to clean them up with the available technologies (Salt *et al.*, 1995).

Phytoremediation is considered an innovative, economical, and environmentally compatible solution for remediating some of heavy metal contaminated sites. Phytoremediation is a general term used to describe various mechanisms by which living plants alter the chemical composition of the soil matrix in which they are growing. Essentially, it is the use of green plants to clean-up contaminated soils, sediments, or water. The advantages of this technique are evident in that the cost of phytoremediation is much less than traditional *in situ* and *ex situ* processes; plants can be easily monitored to ensure proper growth; valuable metals can be reclaimed and reused through phytoremediation; phytoremeditation is the least destructive method among the different types of remediation because it utilizes natural organisms and the natural state of the environment can be persevered. Specifically, several subsets of metal phytoremediation have been developed and they include: (1) phytostablization, in which plants stabilize the pollutants in soils, thus rendering them harmless; (2) phytoextraction, in which heavy metal hyperaccumulators, high-biomass, metal-accumulating plants and appropriate soil amendments are used to transport and concentrate metals from the soil into the above–ground shoots, which are harvested with conventional agricultural methods; (3) phytofiltration or rhizofiltration, in which plant roots grown in aerated water, precipitate and concentrate toxic metals from polluted effluents; and (4) phytovolatilization, in which plants extract volatile metals (e.g., Hg and Se) from soil and volatilize them from the foliage (Raskin & Ensley, 2000).

Plants play important roles in all subsets of phytoremediation. Metal tolerant plants with lower metal accumulation are preferred for phytostablization, and heavy metal hyperaccumulators are the best choice for phytoextraction, while plants that can adapt the wetland conditions are useful for phytofiltration. Vetiver grass (*Vetiveria zizanioides*), due to its unique morphological and physiological characteristics, has been commonly known for its effectiveness in erosion and sediment control (Greenfield, 1995; Grimshaw, 2000; Bevan & Truong, 2002), in addition to its tolerance to extreme soil conditions including heavy metal contamination (Truong & Baker, 1996). In Australia, *V. zizanioides* has been successfully used to stabilize mining overburden and highly saline, sodic, magnesic and alkaline (pH 9.5) tailings of coalmines, as well as highly acidic (pH 2.7) arsenic tailings of gold mines (Truong, 1999). In China, it has been demonstrated that *V. zizanioides* is one of the best choices for revegetation of Pb/Zn mine tailings due to its high metal tolerance (Xia and Shu, 2001; Shu *et al.*, 2002a), furthermore, this grass can be also used for phytoextraction because of its large biomass. Recent research also suggests that *V. zizanioides* also has higher tolerance to acid mine drainage (AMD) from a Pb/Zn mine, and wetland microcosms planted with this grass can effectively adjust pH and remove SO_4^{2-}, Cu, Cd, Pb, Zn and Mn from AMD (Shu, 2003). All of these demonstrate that *V. zizanioides* has great potential in phytoremediation of heavy metal contaminated soils and water, and an integrated vetiver technique can be developed for remediation of metal pollution, especially in mining areas. The following sections of this paper will focus on the various aspects of vetiver grass in phytoremediation of heavy metals, and the integrated vetiver technique for remediation of metal pollution raised from mining activities is suggested.

2 PHYTOSTABLIZATION OF HEAVY METALS

One developing alternative remediation technique for metal-contaminated sites is phytostablization, also called “inplace inactivation” or “phytorestoration”. It is a type of phytoremediation technique that involves stabilizing heavy metals with plants in contaminated soils. To be a potentially cost-effective remediation technique, plants selected must be able to tolerant high concentrations of heavy metals, and stabilize heavy metals in soils by roots of plants with some organic or inorganic amendments, such as domestic refuse, fertilizer, and others. Revegetation of mining wastes is one of the longest practiced and well-documented approaches for stabilization of heavy metals in mining wastes (Bradshaw & Chadwick, 1980).

Mining activities produce a large quantity of waste materials (such as tailings), which frequently contain excessive concentrations of heavy metals. These mining activities and waste materials have created pollution problem and generated land dereliction, without vegetation coverage. Phytoremediation of metalliferous mine tailings is necessary for long-term stability of the land surface, or removal of toxic metals. The success of reclamation schemes is dependent upon the choice of plant species and their methods of establishment (Bradshaw & Chadwick, 1980; Johnson *et al.*, 1994). There are some important considerations when selecting plants for phytostablization. Plants should be tolerant of the soil metal levels as well as the other inherent site conditions (e.g. soil pH, salinity, soil structure, water content, lack of major nutrients and organic materials). Plants chosen for phytostablization should also be poor translocators of metal contaminants to aboveground plant tissues that could be consumed by humans or animals. Additionally, the plants must grow quickly to establish ground cover, have dense rooting systems and canopies, and have relatively high transpiration rates to effectively dewater the soil (Raskin & Ensley, 2000). The most conspicuous characters of vetiver grass includes its fast growth, large biomass, strong root system, and high level of metal tolerance, therefore, vetiver grass is an important candidate for stabilization of metal-contaminated soils. During the past four years, three field experiments were conducted by our research group to assess the role of vetiver grass in stabilization of metal-contaminated sites at Guangdong Province, South China.

2.1 Experiment I.

Since 1999, a field trial has been conducted at Lechang Pb/Zn Mine, Lechang City of Guangdong Province. The aims were to: (1) compare the growth of four grasses (*Vetiveria zizanioides*, *Paspalum notatum*, *Cynodon dactylon* and *Imperata cylindraca* var. *major*) on Lechang Pb/Zn mine tailings with different amendments, for screening the most useful grass and the most effective measure for revegetation of tailings; (2) investigate the abilities of heavy metal accumulation in the four tested plants for assessing their different roles in phytoremediation. The ultimate goal of this project was to choose suitable species and develop a cost-effective method for stabilization of Pb/Zn mine tailings.

The climate at Lechang is sub-tropical and the annual rainfall is about 1500 mm. It is a conventional underground mining operation covering an area of 1.5 km^2, and produces approximately 30,000 t of tailings annually, with a dumping area of 60,000m^2 (Shu, 1997). Lechang Pb/Zn mine tailings contained high concentrations of heavy metals (Pb, Zn, Cu, and Cd) and low levels of major nutrient elements (N, P and K) and organic matter. Total Pb, Zn, Cu and Cd concentrations were 3123, 3418, 174 and 22 $mgkg^{-1}$, while DTPA-extractable concentrations were 98, 101, 4.28 and 0.79 $mgkg^{-1}$, respectively. The tailings were near neutral (pH 7.13), and with an EC value of 2.09 dSm^{-1}. Heavy metal toxicity and extreme infertility were the major constraints on phytoremediation. The four plants were planted on tailings with four treatments: tailings amended with 10 cm domestic refuse + complex fertilizer (NPK) (Treatment A); tailings amended with 10 cm domestic refuse (Treatment B) and tailings applied with complex fertilizer (NPK) (Treatment C) respectively, and tailings without any amendment used as control (Treatment D). Results indicated that both the domestic refuse and NPK fertilizer improved plant growth, and the combination of domestic refuse and NPK fertilizer (Treatment A) achieved the best growth. After six months, *V. zizanioides* growing on treatment A had 100% coverage and 2111 gm^{-2} dry weight yield. Its biomass was significantly greater than those of the other three grasses under the same treatment (Shu *et al*, 2002a).

Our present study also demonstrated that the strategies for heavy metals uptake by the four plants were different (Shu *et al.*, unpublished data). In general, concentrations of Pb, Zn and Cu in shoots and roots of *V. zizanioides* were significantly less than those of the other three species (Table 1), and the shoot/root metal concentration quotients (M_S/M_R, Table 2) for Pb, Zn and Cu in *V. zizanioides* were also lower than those of other three species, which indicated that *V. zizanioides* was an excluder of heavy metals. Firstly, roots of the species accumulated low levels of metals by avoiding or restricting uptake; Secondly, shoots of the species accumulated much lower concentrations of metals by restricting transport. In general, metal tolerance and metal uptake was functionally related, exclusion was one of the basic strategies of metal uptake by tolerant species (Baker and Walker, 1990). Judging from the metal contents in plant tissues, *V. zizanioides* was more suitable for phytostabilization of toxic mined lands than *P. notatum* and *C. dactylon*, which accumulated a relatively high level of metals in their shoots and roots. It was also noted that *I. cylindraca* accumulated lower amounts of Pb, Zn and Cu than *C. dactylon* and *P. notatum*, and could also be considered for phytostabilization of tailings.