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Restoration potential of pioneer plants growing on lead-zinc mine tailings in Lanping, southwest China

LEI Dongmei[1,2], DUAN Changqun[1,*]

1. Laboratory for Conservation and Utilization of Bio-Resource & Institute of Environmental Sciences and Ecological Restoration, Yunnan University, Kunming 650091, China. E-mail: dmlei@ynufe.edu.cn
2. Institute of Land & Resources and Sustainable Development, Yunnan University of Finance and Economics, Kunming 650221, China

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Abstract

This study focused on the restoration potential of ten pioneer plants (*Artemisia roxburghiana*, *Artemisia tangutica*, *Carex inanis*, *Cyperaceae hebecarpus*, *Plantago depresa*, *Cynoglossum lanceolatum*, *Potentilla saundesiana*, *Coriaria sinica*, *Oxyria sinensis*, and *Miscanthus nepalensis*) during the early phase of Pb-Zn mine tailings phytostabilization, in Lanping, China. The concentrations of heavy metals (Pb, Zn, and Cu) and soil fertility (the available N, P, K, and organic matter) in the rhizosphere of these species have been compared. The results showed a general improvement in the rhizosphere soil properties of pioneer plants. Of the ten species, the concentrations of Pb, Zn, and Cu in the rhizosphere of *A. roxburghiana* have the greatest reduction of 56.23%, 83.00%, and 84.36%, respectively, compared to the bulk soil. The best improvement in soil fertility was found in the rhizosphere of *P. saundesiana*, with an increase of 241.83%, 170.76%, 49.09%, and 81.60%, respectively, in the available N, P, K, and organic matter. Metals accumulated by the plants have been mainly distributed in the root tissues, and only small amounts transferred to the aboveground tissues. The highest contents of Pb and Zn have been recorded in *C. hebecarpus* with 57.84 and 87.92 mg/kg dry weight (dw), respectively. The maximum Cu content was observed in *C. inanis* with 1.19 mg/kg dw. Overall, pioneer plants will be ideal species for the phytostabilization of mine tailings, but the potential use varies in different pioneer plant species. Among these ten species, *A. roxburghiana* has been identified to be the most suitable for phytostabilization programs, due to its greatest improvement on physical-chemical properties in the rhizosphere soil.

Key words: pioneer plant; mine tailings; phytostabilization; rhizosphere soil

Introduction

Mine tailings produced by the mining activities are of environmental concern due to the potential hazards of surface and groundwater pollution (Bleeker *et al*., 2002; Wong, 2003). They are characterized by high concentration of heavy metals, lack of nutrients, and low water retention capacity (Rao and Tarafdar, 1998; Shu *et al*., 2001; Singh *et al*., 2004a). Restoration of vegetation coverage can fulfill the objectives of stabilization, pollution control, visual improvement, and removal of the threats to human beings (Zhang *et al*., 2001; Wong, 2003; Freitas *et al*., 2004; Archer and Caldwell, 2004).

Phytoremediation refers to the use of plants and their associated microbiota, soil amendments, and agronomic techniques to remove, accumulate, or render harmless environmental contaminants (Cunningham and Ow, 1996). Phytoremediation of heavy metal contaminated soils basically includes phytoextraction and phytostabilization. Phytoextration is also called phytoaccumulation, which involves the uptake and translocation of heavy metals by hyperaccumulator plants. Phytostabilization is the use of metal-tolerant plant species to immobilize trace metals through absorption and accumulation by roots, adsorption onto roots, or precipitation within the rhizosphere (Freitas *et al*., 2004). By using metal-tolerant plant species for stabilizing mine spoils, it can also provide improved conditions for natural attenuation (Wong, 2003).

Since mine tailing soil has abnormally chemical and physical properties, only the plants that have evolved through natural selection and adapted to specialized environments can colonize such sites (Rao and Tarafdar, 1998). Therefore, selection of appropriate plant species that can establish, grow, and colonize in metal-contaminated soils is important for the successful reclamation of degraded mine sites. Successful establishment and colonization of several pioneer plant species tolerant to Pb/Zn mine tailings has been already identified, such as *Paspalum distichum*, *Cynodon dactylon* (Shu *et al*., 2002a), *Sesbania rostrata* (Yang *et al*., 1997; Wong, 2003), and *Leucaena leucocephala* (Zhang *et al*., 2001).

However, much of the previous studies on the restoration efficiency of pioneer plant species have focused on the uptake and translocation of heavy metals (Shu *et al*., 2002b;

* Corresponding author. E-mail: chqduan@ynu.edu.cn.

Freitas *et al.*, 2004). It is well known that the research on the rhizosphere has been a burning issue because of the important role it plays in agriculture and environment (Wang *et al.*, 2002). In recent years, the changes in the rhizosphere soil for heavy metal speciation and the bioavailable fractions of metals, have been extensively studied (Lin *et al.*, 2003; Cattani *et al.*, 2006), but little attention has been paid to soil fertility. The study of soil fertility has been emphasized in restoration studies because soil is one of the primary agents for determining vegetation development (Singh *et al.*, 2004a). Furthermore, the most common methods used for studying the rhizosphere, the rhizobox or rhizobag techniques, have a downside of assuming similar conditions in the greenhouse and in the fields (Wang *et al.*, 2006). Therefore, the study about metal content and soil fertility of the rhizosphere environment, especially in the field, combined with a study of plant metal absorption and translocation, should be investigated, so that restoration effect of pioneer plant species growing on the mine tailings can be better understood.

This study was carried out on typical Pb-Zn mine tailings at Lanping of Yunnan Province, southwestern China, where a number of pioneer plants have been observed. The primary objective of the present study was to compare the restoration potential of ten pioneer plants in mine tailing phytostabilization, based on the changes in the soil metals and soil fertility in the rhizosphere, combined with metal absorption and translocation characteristics of these species. It is expected that the results generated from this study will be useful for the complete understanding of the restoration potential of pioneer plants in the phytostabilization of mine tailings.

1 Materials and methods

1.1 Study site

This study has been carried out at Lanping Pb-Zn mine tailings, located in Yunnan Province, China, between latitudes 26°24.106′–26°23.893′N and longitudes 99°25.696′–99°25.505′E and at an elevation above sea level of 2,240 m. Lanping Pb-Zn mine area is the largest lead and zinc ore accumulated area in Asia. The total reserve is about 1.4×10^8 tons. The climate of the area is low-latitude, mountain-plateau monsoon, with an annual rainfall of about 1,002 mm, and an annual average temperature of 11.7°C.

Mine tailings produced from the milling process were deposited as abandoned field. These tailings had been abandoned since 2003. The tailings surface of the soil was dry and almost completely devoid of vegetation except some pioneer plant species. Characteristics of the mine tailings soil were described by Lei *et al.* (2007). Specifically, the available Pb, Zn, and Cu in mine soils were low, reaching 166.56, 47.71, and 11.44 mg/kg, respectively.

1.2 Plant and soil sampling

Ten pioneer plant species were investigated, based on their relatively higher biomass production and coverage, after community surveys for all the mine tailings were complete. The specimens were collected from the Pb-Zn mine tailing in Lanping from May to June, in 2005. They represented 10 genera in eight families, and their community surveys are presented in Table 1.

Soil strongly adhered to roots (0–4 mm from the root surface) was collected as rhizosphere soil. Rhizosphere soil (approximately 110–130 g) was collected using the following method: the whole plant was taken out of the soil with minimum injury to its roots, generally shaking the roots until the soil was not tightly adhering to the roots. After it was removed, the soil closely adhering to the roots system was collected by putting the roots into a paper bag and vigorously shaking the roots (Wang and Zabowski, 1998). Ten soil samples outside the rooting area were collected at a depth of 10–30 cm, and they were thoroughly mixed to yield one composite sample as the bulk soil (reference soil) of the mine tailing.

1.3 Soil and plant analysis

Soil samples (of rhizosphere soil and bulk soil) were air-dried for two weeks. After removing large pieces of plant debris and rock materials, they were passed through a 1-mm sieve. The following physical and chemical properties of the soils were measured according to the standard methods of China (Liu *et al.*, 1996), as follows: the available N was determined by hydrolyzation and deoxidation through addition of $FeSO_4$ and $NaHCO_3$, then titrated against 0.1 mol/L HCl. The available P was extracted by using 0.5 mol/L $NaHCO_3$ and the amount in the extract was measured with the blue coloration method. The available

Table 1 Distribution and quantitative feature of ten pioneer plants growing in Lanping Pb-Zn mine tailings, China

Pioneer plant	Family	Coverage (%)	Dominance (%)	Biomass (dw) (g)		
				AC	UC	Clump
Artemisia roxburghiana	Compositae	14.58	22.59	6,064.84	2,987.16	45.26
Artemisia tangutica	Compositae	20.12	40.04	17,041.45	8,393.55	50.87
Carex inanis	Cyperaceae	15.45	20.15	2,010.21	990.43	15.00
Cyperaceae hebecarpus	Cyperaceae	8.88	12.29	1,165.80	374.20	8.70
Plantago depresa	Plantaginaceae	25.51	48.50	3,109.47	1,531.53	15.47
Cynoglossum lanceolatum	Boraginaceae	10.24	13.41	6,105.04	3,006.96	45.56
Potentilla saundesiana	Rosaceae	20.17	31.72	5,604.86	1,253.14	22.86
Coriaria sinica	Coriariaceae	5.68	6.89	10,506.94	3,175.06	78.41
Oxyria sinensis	Polygonaceae	20.57	20.19	4,430.55	1,834.45	20.55
Miscanthus nepalensis	Gramineae	15.65	20.22	2,155.56	912.44	15.34

dw: dry weight; AC: aboveground biomass of communities; UC: underground biomass of communities.

K was extracted with 1 mol/L NH_4OAc (pH 7) and the amount in the extracts was determined using atomic absorption spectrophotometry (AAS, TAS-990, Beijing Purkinje General Instrument, China). The organic matter was determined by dichromate oxidation and titration with ferrous ammonium sulfate.

The concentrations of Pb, Zn, and Cu in the soil were analyzed by X-ray analysis (Fanfani *et al*., 1997). According to the principle of the X-ray analysis method, this method was especially suitable to determine the soil of mine tailings with high metal concentrations, and the results of this method could be compared to that of the chemical method. The X-ray analysis was performed on a Niton XLp 9200 environmental analyzer (Niton, USA), which contained sealed 109Cd and/or 55Fe and/or 241Am radioactive isotope sources. The X-ray powder diffraction spectra were obtained on the air-dried specimens. A quantitative estimation of the metal content was performed by comparison with specific standards of known mixtures which were given with the apparatus.

The plant samples were washed thoroughly with deionized water to remove any soil particles attached to the plant surface. The plants were then separated into roots and aboveground tissues, oven dried at 70°C to constant weight, and powdered for Pb, Zn, and Cu concentration analysis. The plant materials were digested with a mixture of HNO_3 and $HClO_4$ (4:1, *V/V*) (Allen, 1989). Concentrations of Pb, Zn, and Cu in digested plant materials were analyzed with AAS (Allen, 1989).

1.4 Statistical analysis

A statistical comparison of the means of the soil physical and chemical properties data was examined between rhizosphere soil of pioneer plant species and bulk soil in the mine tailings with a *T*-test, as available in the EXCEL statistical package, to observe the effect of pioneer plants on the rhizosphere soil properties.

The translocation factor (TF) for metals within a pioneer plant was expressed as:

$$\mathrm{TF} = C_{\mathrm{at}}/C_{\mathrm{r}} \qquad (1)$$

where, C_{at} and C_{r} are metal concentration in aboveground tissue and root, respectively, which showed the metal translocation properties from roots to aboveground parts (Stoltz and Greger, 2002).

The restoration effect of different pioneer plants in the rhizosphere soil in mine tailings was assessed by perturbation analysis. Perturbation analysis is usually engaged in evaluation of different systems, each of which has a large number of parameters to show the state of the system studied (Duan *et al*., 2000). The perturbation value (*PV*) is used to quantitatively measure the difference between the systems and can be obtained from any system only if each of them shares the same parameters.

In this study, the perturbation analysis was conducted among the ten pioneer plants (the systems) (i.e., $F = F_1$, F_2, ···, F_j, ···, F_{10}). The contributing parameter set (*f*), selected to calculate *PV*, included the concentration of Pb, Zn, and Cu, and the soil fertility indexes in the rhizosphere of the pioneer plant species. Hence the authors had seven contributing parameters, (i.e., $f = f_1, f_2, \cdots, f_j, \cdots, f_7$), to calculate *PV* with the following equation:

$$PV_j = \sum_{j-1}^{r} ((1/2(1/r + a_j)) \times (1 - \frac{(P_j \times f_j)_{\mathrm{Min}}}{(P_j \times f_j)_{Max}})) \qquad (2)$$

where, PV_j is the relative value of *PV* of F_j; r is the total number of contributing factors (r = 10); a_j is the designated weighted coefficient of f contributing factor ($\sum a_j = 1$. As a rule, all weighted coefficients are usually designated equal in biological studies, because the most important factor is not known); $P_j \times f_j$ is parameter of F_j as to f_j contributing factors. As a result, the lower value of *PV* in this study indicates a higher restoration effect on the rhizosphere soil of pioneer plant species growing on mine tailings. Calculation for *PV* was performed with the PTB software programmed with FORTRAN 77 language.

2 Results and discussion

2.1 Concentrations of Pb, Zn, and Cu in the rhizosphere

Toxic metals such as Pb, Zn, and Cu can adversely affect the number, diversity, and activity of soil organisms, inhibiting soil organic matter decomposition and N mineralization processes. Therefore, the removal of these metals from the soil plays a key role in the phytostabilization of mine tailings. Compared to the bulk soil, the metal concentrations in the rhizosphere of pioneer plant decreased, except for the concentrations of Pb in *C. lanceolatum*, *O. sinensis*, and *M. nepalensis*. The pH values in the rhizosphere of pioneer plant increased significantly (Fig.1).

The results indicated that the decreased metal concentrations varied with different pioneer plant species (Fig.1). The result of *T*-test indicated that significant variations in metal concentrations were found in the rhizosphere of *A. roxburghiana*, *P. depresa*, *C. inanis*, and *A. tangutica* ($P < 0.05$). Of the ten pioneer plant species, the maximum decrease in the concentrations of Pb, Zn, and Cu was in the rhizosphere of *A. roxburghiana* by 56.23%, 83.00%, and 84.36%, compared to the bulk soil, respectively (Fig.1). The pH values ranged from 7.63 to 8.41, indicating that the acidity of mine tailings was not serious, therefore, normal plant growth could be achieved (Shu *et al*., 2001).

In general, the content change of metals in the rhizosphere could be due to several factors. First, metal uptake by plants decreased the metal content in the rhizosphere. However, in the present study, no significant relationship was found between rhizosphere soil metal content reduction and pioneer plant metal accumulation ($P > 0.05$) (Fig.2). The results here were in agreement with the research results of Lin *et al*. (2003), which suggested that the depletion of Cd in the rhizosphere could not be simply attributed to the Cd uptake by rice, but to the complexing capabilities of soluble exudates for Cd. These results were not in agreement with the experimental results of Wang *et al*. (2006), which suggested that the decrease of metal concentration in the rhizosphere was due

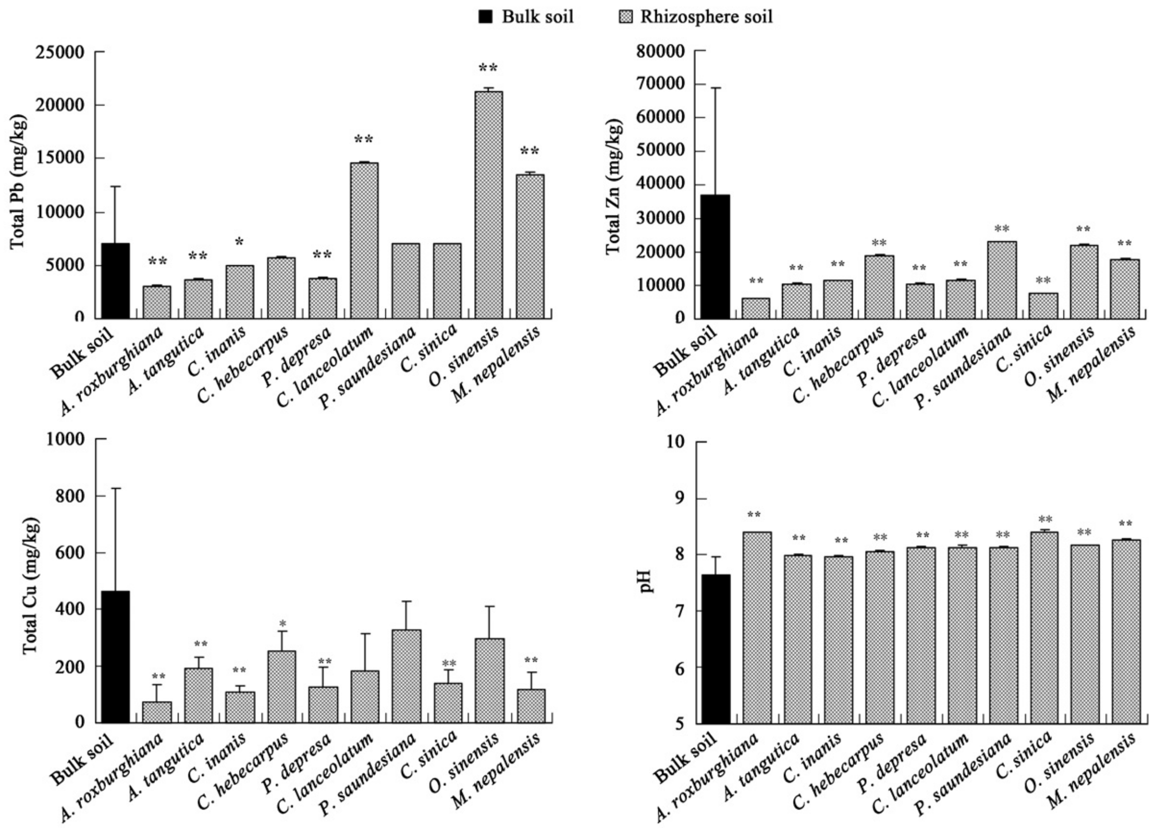

Fig. 1 Total Pb, Zn, Cu content, and pH in the rhizosphere soil of ten pioneer plants as compared to the bulk soil (values represent as mean ± SE, n = 4, * $p < 0.05$, ** $p < 0.01$).

to the metal uptake by plant (*Hippochaete ram osissimum*) growing on the mine tailings. Second, the metal mobility induced by the plant (Singh *et al*., 2004a, 2004b), the microbial activity (Wang and Zabowski, 1998; Khan *et al*., 2000), and the flooding (Otero *et al*., 2000), would influence the metal content in the rhizosphere. For example, decomposing plant remains in the rhizosphere might provided humified organic matter to which metals would readily bind, increasing the solubility and mobility of these metals (Bolan and Duraisamy, 2003); plant roots excreted aromatic acids and phospholipids surfactants that could profoundly modify the physical and chemical adsorption properties of soil, and could increase the bioavailability of metals in the rhizosphere (Read *et al*., 2003; Singer *et al*., 2003). Third, pH affected the solubility of chemicals, including toxic metals and nutrients in soils. Sorption reactions on oxide minerals depended on pH and as a result metal mobilization was influenced (Darland and Inskeep, 1997; Jones *et al*., 1997; Bleeker *et al*., 2002).

In this case, the major reason for decreased metal concentration in the rhizosphere may be the increase in pH value. As previous studies show, the metal concentrations in soils decrease with the increase in pH value, by sorption reactions or by forming metal complexes (Dudka and Adriano, 1997; Alastuey *et al*., 1999). The bioavailability of heavy metals to plants is controlled by their total concentration in the soil and their chemical forms (Freitas *et al*., 2004). In addition, the decreased metal concentrations in the rhizosphere may well be influenced by leaching and water erosion (Shu *et al*., 2001; Bleeker *et al*., 2002), or related to microhabitat selection, which refers to some pioneer plants growing only on less metal-contaminated soils (Baker, 1987). On the other hand, the results of the increase of Pb in the rhizosphere of *A. roxburghiana*, *P. depresa*, *C. inanis*, and *A. tangutica* further support the conclusion that the chemical processes of metals is complex, and is influenced by many factors.

2.2 Soil fertility in the rhizosphere

Soil fertility in mine tailing is poor, commonly due to the lack of organic matter (Wong, 2003), and low concentration of important nutrients such as N, P, and K. Due to low organic content in most spoils, N is the primary limiting nutrient for plant growth. The importance of maintaining an adequate N supply to vegetation on colliery spoil is well documented (Davison and Jefferies, 1966). P is an essential element for plant growth and is also a limiting nutrient in spoil sites. In this case, the results show that pioneer plant have a positive effect on soil fertility indexes (Fig.3).

Compared to the bulk soil, there was a general improvement of soil fertility in the rhizosphere of pioneer plant (Fig.3). The maximum values of four soil fertility indexes in the rhizosphere of different pioneer plant species were recorded. The available N in *P. saundesiana* increased by 242.03%; the available P in *P. depresa* increased by 286.61%; the available K in *C. lanceolatum* increased by 59.78%; and the organic matter in *C. hebecarpus* increased by 111.02%. These results indicated that differences between the soil properties could be attributed primarily to

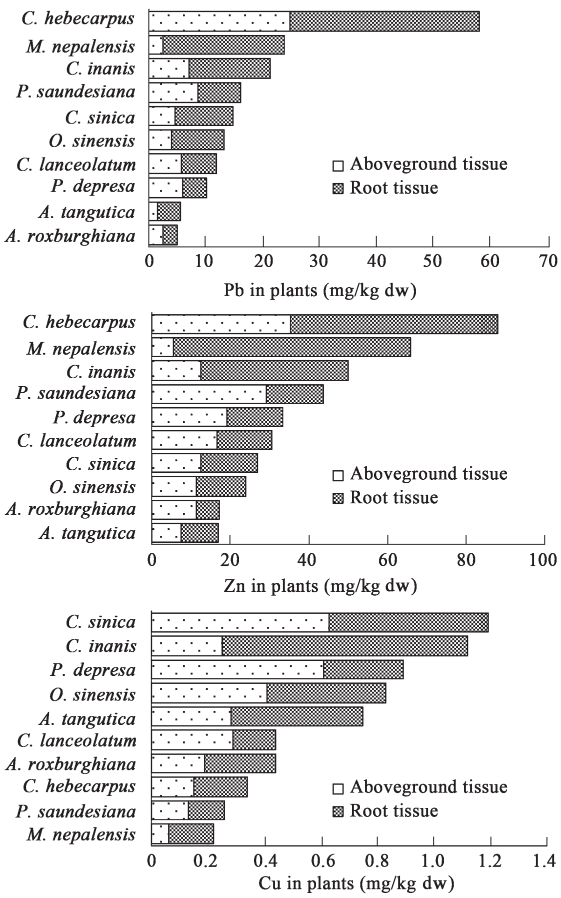

Fig. 2 Accumulation of Pb, Zn, and Cu in the ten pioneer plant species of Lanping Pb-Zn mine tailings.

the difference of species (Singh *et al*., 2004a).

Organic matter is important for the sustainability of vegetation. High levels of organic matter can improve aggregation and infiltration capacities and increase the availability of nutrients (Singh *et al*., 2004a). Previous studies have documented that pioneer plant species modify soil fertility of mine tailings, possibly by supplying more organic matter (Jacob and Marinus, 2004; Archer and Caldwell, 2004; Singh *et al*., 2004a). As expected, in the present study, the organic matter in the rhizosphere of the ten pioneer plants has increased when compared with the bulk soil (Fig.3). The main reasons for the organic matter increase in the rhizosphere are plant litter, decaying aerial parts and roots, and rhizomes (Rao and Tarafdar, 1998; Filcheva *et al*., 2000; Singer *et al*., 2003).

Similarly, several studies showed that plantations improve soil conditions by increasing the mass of organic matter and the concentrations of available nutrients, and by decreasing the soil bulk density (Singh *et al*., 2004a; Wang *et al*., 2006). Singh *et al*. (2004a) reported that both the establishment of *Albizia procera* and *Albizia lebbeck* increased the levels of N in mine soil. Yang *et al*. (1997) reported that an annual legume native to Africa, *S. rostrata*, which possessed stem as well as root nodules could be used to modify properties of mine spoils by supplying more needed N and organic matter.

2.3 Metal uptake and translocation in ten pioneer plant species

Analysis of metals performed in plant materials (root and aboveground tissues) indicated that different parts of the plant have different budgets of metals (Fig.2). It is generally accepted that plants growing on contaminated soils respond differently on their ability to take in or exclude a variety of metals (Bech *et al*., 2002). This is in agreement with Freitas *et al*. (2004), who found that the accumulation of various metals (total Ag, As, Cu, Ni, Pb, and Zn) by different plant species (24 plant species established in an abandoned copper mine) were different.

Metal concentration in pioneer plant ranged from 4.92 to 57.84 mg/kg dw for Pb, 17.00 to 87.92 mg/kg dw for Zn, and 0.22 to 1.19 mg/kg dw for Cu (Fig.2). The maximum contents of Pb and Zn were recorded in the species *C. hebecarpus*, and that of Cu was observed in *C. sinica*. The results further supported the fact that metal concentrations in pioneer plant were low (Freitas *et al*., 2004). According to the definition of a hyperaccumulator (Brooks, 1998), the ten pioneer plant species investigated in this study were not identified as hyperaccumulators. Plant species found in metal contaminated soils were expected to take up metals and eventually accumulate them (Baker, 1981). As the previous researches indicated, pioneer plant took up and accumulated certain essential nutrients from soils, but the levels of heavy metals only accumulated up to 0.1–100 mg/kg dw in most plants (Cunningham *et al*., 1995). Furthermore, the pioneer plant growing on mine tailings were also metal-tolerant plants (Wong, 2003; Freitas *et al*., 2004). Tolerant plants generally had the advantage of a strongly reduced metal root to shoot transport, so far as they were not specific accumulators (Bleeker *et al*., 2002). Of course, on the other hand, as for plants, the bioavailability was governed by the factors that controlled the activity of the soluble metal species in the soil solution that was preferentially taken up (Wong, 2003). In mine spoils, primarily N and P limited the aboveground biomass (Vetterlein *et al*., 1999). Due to their higher biomass (Table 1), the pioneer plants could be very effective for metals phytostabilization, especially when established in the mine tailings, during the early phase (Yang *et al*., 1997; Freitas *et al*., 2004).

The values of TF varied from 0.12 to 1.42 for Pb, 0.09 to 2.05 for Zn, and 0.29 to 2.17 for Cu (Table 2). *P. depresa*

Table 2 Translocation factors (TF) and perturbation values (PV) in ten pioneer plant species growing on Lanping Pb-Zn mine tailings

Pioneer plants	*PV*	TF		
		Pb	Zn	Cu
A. roxburghiana	0.166	0.96	1.92	0.76
A. tangutica	0.405	0.38	0.81	0.60
C. inanis	0.373	0.50	0.33	0.29
C. hebecarpus	0.349	0.74	0.67	0.79
P. depresa	0.281	1.42	1.36	2.17
C. lanceolatum	0.409	0.91	1.20	1.93
P. saundesiana	0.370	1.13	2.05	1.00
C. sinica	0.461	0.45	0.86	1.13
O. sinensis	0.530	0.45	0.91	0.98
M. nepalensis	0.473	0.12	0.09	0.38

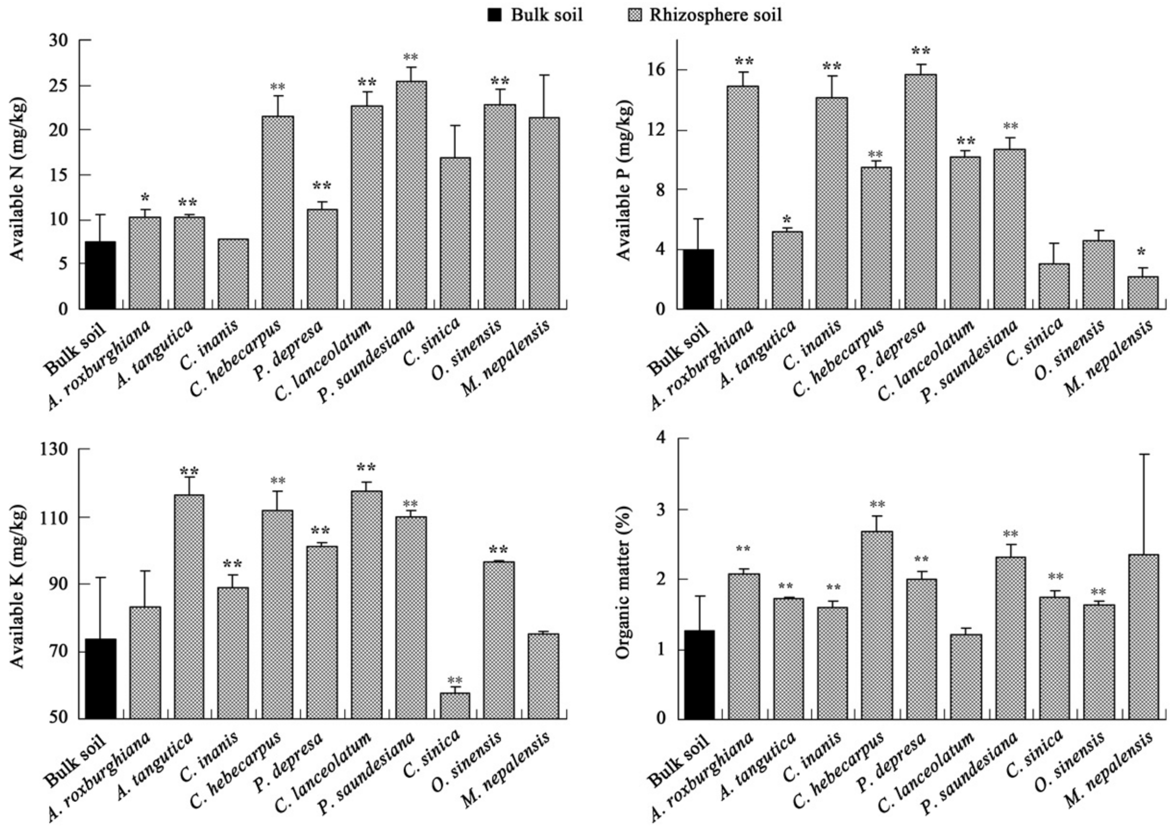

Fig. 3 Available N, P, K, and organic matter content in the rhizosphere soil of ten pioneer plants as compared to the bulk soil. (Values represent mean ± SE, $n = 4$, * $p < 0.05$, ** $p < 0.01$).

showed a higher translocation of Pb and Cu in plant tissues than any other pioneer plants. *P. saundesiana* showed a higher translocation of Zn in plant tissues than others. In most pioneer plants, metals were mostly distributed in the root tissues, with few of these metals being partitioned to the aboveground tissues (Fig.2, Table 2). It indicated that the pioneer plant species growing on Lanping Pb-Zn mine tailings had the characteristics of metal-tolerant plants, e.g., in metal-tolerant plants the metal concentration in the root tissues was higher than that in the aboveground tissues, and the metal transferred from the root tissues to the aboveground tissues was minor, to decrease the adverse effect of metal on the photosynthetic apparatus (Vázquez *et al*., 1994). Stoltz and Greger (2002) showed that the plant growing on mine tailings had restricted translocation of metals and As to the shoot, and most species were found to be root accumulators.

2.4 Restoration potential of pioneer plant species

Perturbation analysis results are presented in Table 2. The sequence of *PV* among the ten pioneer plant species was *A. roxburghiana* < *P. depresa* < *C. hebecarpus* < *P. saundesiana* < *C. inanis* < *A. tangutica* < *C. lanceolatum* < *C. sinica* < *M. nepalensis* < *O. sinensis*. The results indicated that the restoration effect on the rhizosphere soil had a diversity of different pioneer plant species. Of the ten pioneer plant species, *A. roxburghiana* exhibited the greatest restoration effects on the rhizosphere. The pioneer plant plantations improved the rhizosphere soil conditions by increasing the concentrations of organic matter and available nutrients (Freitas *et al*., 2004; Singh *et al*., 2004a, 2004b; Wang *et al*., 2006) and by decreasing the soil metal contents (Wang *et al*., 2006). The process of phytostabilization by pioneer plants could reduce metal mobility and also reduce metal bioavailability of entry into the food chain (Wong, 2003). However, the selection of pioneer plant species significantly affected these results.

Some species increase the soil fertility more than others, and other species may not have an effect on soil chemistry (Montagnini *et al*., 1995). Therefore, mine restoration may benefit from a broader perspective including different groups of plant species, as they can perform distinct functional roles in the remediation process. For example, the combined use of perennials and annuals can provide substantial inputs in terms of organic matter and nutrient recycling, thus contributing in distinct ways to the development of the soil (Hooper and Vitousek, 1997).

Except for the restoration effect on rhizosphere soil, there are also two advantages for pioneer plant being an ideal species for phytoremediation of mine tailings. First, pioneer plants are tolerant to toxic metals, and also have the advantage of adapting to other stress factors, particularly nutrient restrictions and drought (Tordoff *et al*., 2000), therefore, it will be an ideal species to accelerate the ecological succession of mine tailings, the man-made habitats (Singh *et al*., 2002). By planting pioneer plant in mine tailings, it will fulfill the dual purpose of stabilizing the site and modifying soil properties suitable for the colonization of other plants. For example, Vetiver grass (*V. zizanioides*), a pioneer plant in the Pb-Zn mine tailings in South China, is highly tolerant to soil salinity, sodicity, acidity, Al, Mn, and heavy metals (i.e., As, Cd, Cr, Ni, Pb, Zn, Hg, Se, and Cu) toxicities in the soil (Wong, 2003), and also to prolonged drought, flood, submergence, and extreme temperature. It has been found that Vetiver grass is the best plant species (in terms of biomass production and coverage) when compared with other three grass species, namely, *Paspalum notatum*, *C. dactylon*, and *Imperata cyclindrica* var. major, used for revegetating Pb-Zn mine tailings in South China (Shu *et al*., 2002a).

Second, the metal accumulated by pioneer plant is low, especially in the aboveground tissue (Fig.2). For revegetation of contaminated sites, it is desirable that the levels of metals in the aboveground biomass are as low as possible, to protect grazers and their predators from metal accumulation (Bleeker *et al*., 2002). In the present study, the minimum accumulation of metal has been recorded in the species *A. roxburghiana* for Pb, *A. tangutica* for Zn, and *M. nepalensis* for Cu. These species are also considered suitable for stabilizing mine tailings, because the danger of transferring toxic metals to grassing animals is minimal.

3 Conclusions

Pioneer plant growing in Pb-Zn mine tailings could improve the soil property in the rhizosphere. Compared to the bulk soil of mine tailings, in the rhizosphere the metal concentration decreased and the soil fertility increased in different levels. Of the ten pioneer plant species, the rhizosphere soil of *A. roxburghiana* presented more soil fertility and less metal concentration than other pioneer plants, indicating greater restoration efficiency, at least in the early phase of mine phytostabilization. Furthermore, the metal accumulated by the ten pioneer plants was low, with little of these metals being transferred to the aboveground tissues of plants. This could protect grazers and their predators from metal accumulation. In general, pioneer plant would be the ideal species for phytostabilization of mine tailings in Lanping, but the restoration effect on rhizosphere soil and its potential use varied with different pioneer plant species.

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