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Heavy metal contents and enrichment characteristics of dominant plants in wasteland of the downstream of a lead-zinc mining area in Guangxi, Southwest China

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ABSTRACT

A field investigation on the content of heavy metals in soils and 17 kinds of dominant plants from wasteland of the downstream of a Pb-Zn mine in Northwest Guangxi Zhuang Autonomous Region was carried out. The absorption and accumulation characteristics of heavy metals between plants and soil were compared, and the candidate species for ecosystem restoration of the area were selected. The results indicated that the soils had been subjected to pollution of heavy metals in varying degrees. The concentrations of Cd, Pb, Zn were 46.5, 57.3 and 23.7 times higher than their corresponding background values, respectively. The contents of Cd, Pb and Zn in the most analyzed plants exceed the normal ranges and the phytotoxic level. *C. crepidioides*, *S. nigrum*, *B. pilosa*, *C. Canadensis*, *A. conyzoides*, *I. denticulata* and *E. crusgali* showed strong capability in accumulation and transport of Cd, and they could be used as good candidates for Cd- phytoextraction. Among which, Cd concentration in the aerial part of *C. crepidioides* exceeded the threshold of Cd-hyperaccumulator. Thus, *C. crepidioides* demonstrated the basic characteristics of a Cd-hyperaccumulator. The lower translocation ratios for Cd, Cu, Zn and Pb in *P. vittata* and *C. chinensis* make them suitable for phytostabilization in the study area.

1. Introduction

Mineral resources represent the key material foundation for socio-economic development, e.g. the utilization of mineral resources has been making a great contribution for economic development in China (Li et al., 2014). However, due to long-term improper mineral utilization, a large amount of mining wastes was generated without proper management. These wastes are usually deposited on the ground as tailings which occupy a huge area of land surface. In many cases, the mine tailings are characterized by high metal and metalloid concentrations (Conesa et al., 2007). Heavy metals from tailing would be leaded into soils and groundwater via rainfall, runoff and wind blowing, resulting in environmental contamination of the surrounding terrestrial and aquatic ecosystems, followed by the decline in crop quality and agricultural production. Even worse, heavy metals can also be accumulated in the human body through the food chain, breathing and skin adsorption, which represents a serious threat to human health (Banza et al., 2009; Lei et al., 2016). It is estimated that 1.5 million ha of wasteland have been generated by mining in China, and the annual increase of mining wasteland of 46,700 ha serves as a growing and persistent source of pollutants (Zhuang et al., 2009b). There are increasing evidences that heavy metal pollution of mined areas in China cause health damage to the local inhabitants (Lei et al., 2015; Shen et al., 2017; Xiao et al., 2017; Zhang et al., 2012; Zhuang et al., 2009a).

Rehabilitation of mine wastelands was a priority issue to be addressed for many provincial governments in China because the shortage of cultivated land was increasingly outstanding, especially for the karst regions in the southwest part like Guangxi Zhuang Autonomous Region, which are rich in the metallic ore resources (Li and Yang, 2008). Phytoremediation technology is regarded as one of the promising methods for reclaiming soils contaminated with toxic metals (Lasat, 2002; Marrugo-Negrete et al., 2016; Mulligan et al., 2001). Phytoremediation is defined as the use of plants to remove pollutants from soils or to render them harmless (Ali et al., 2013). Since it is performed in-situ and solar driven (LeDuc and Terry, 2005), phytoremediation is a sustainable approach which is economically viable and environmentally safe

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(Mahar et al., 2016). It is important to use native plants for phytoremediation because these plants are often better in terms of survival, growth, and reproduction under environmental stress than plants introduced from other environments (Yoon et al., 2006). However, minesoil is characterized by elevated heavy metal concentrations, poor physical structure, deficiency of available nutrients, extreme acidity and/or salinity, drought, and other stressful factors (Nirola et al., 2016; Shu et al., 2002). Nevertheless, there were still some plants that are adaptable to contaminated soil with high concentrations of heavy metals. This indicates that the plant itself has generated a series of physiological and biochemical reactions in the long-tern natural evolution for absorption and accumulation of heavy metals to form a series of mechanisms for suitable growth, resistance, tolerance and detoxification, which adapted to the specific environmental conditions (Dazy et al., 2009; Malik et al., 2010). These plants play a decisive role in the restoration and phytoremediation of heavy metal contaminated soil.

Guangxi Zhuang Autonomous Region, one of the most well developed karst areas, ranks the fourth of China in terms of Pb/Zn mining (Wang et al., 2012). The study area was located in a wasteland of the downstream of a Pb-Zn mine in Northeast Guangxi, which was one of the relatively large mine in Guangxi. The mine tailings were disposed by damming at the valley, which are unstable and prone to erosion. In 1970s, the collapse of the Pb-Zn mine tailing dam led to the spread of mining waste spills on the farmland along the river due to a catastrophic flood. Some former farmlands were abandoned due to serious pollution. Therefore, by sampling soil and dominant plants from wasteland of the downstream of the Pb-Zn mine, and by analyzing the concentrations of heavy metal in soil and dominant plants, the main objectives of this study were to evaluate metal accumulation and migration potentials in dominant plants and to screen out candidate species for application in rehabilitation of mining wasteland. This research will provide information for recovering areas affected by mining wastes and polluted soils in the study sites and in other similar areas affected by the same problems in southern China.

2. Materials and methods

2.1. Study site description

This study was carried out in the wasteland produced by upstream tailing dam collapse in a village, located 7 km southwest of the Pb-Zn mine. The area is characterized by a typical subtropical monsoon climate with a mean annual temperature of 19.5 °C and a mean annual precipitation of approximately 1700 mm. The soil types in this area are mainly limestone soil and siliceous soil with separate distribution.

2.2. Sample collection

Field surveys of the dominant plants and soils in the wasteland were carried out in May 2016. Natural settled dominant plant species which are vigorous, representative and great coverage were selected. There were three replicates of each species. For each replicate, five or more individual plants were randomly gathered within the sampling area and mixed to give a composite whole plant sample. Simultaneously, the associated soils (0–15 cm) of the sampled plants were also collected and homogenized for total metal analysis. Different parts of the plant, such as root, stem and leaf, were separated. All soil and plant samples were sealed in polythene bags for transport to the laboratory.

2.3. Analytical methods

Soil samples were air-dried, ground and passed through a 100 mesh plastic sieve. After being carefully and repeatedly washed with tap water and rinsed with deionized water, the plant samples were treated by high temperature desiccation under 105 °C for 30 min, then oven dried at 65 °C to constant weight. The dried plant tissues were milled to a fine powder. All procedures of handling were carried out without contacting any metals to avoid potential cross-contamination of the samples.

Soil pH (1:5 soil to water, w/w) was measured with conventional pH meter. For the analysis of heavy metals, the soil samples were digested using concentrated HNO_3-$HClO_4$-HF with a ratio of 6:2:2, and the plant samples were digested with a 4:1 ratio of concentrated HNO_3-$HClO_4$. The residuals were re-dissolved by HNO_3 (2%) and diluted with distilled water. The solutions from the digested samples were stored at 4 °C until analysis. Water used for dilution and dissolution was purified using a Millipore deionizing system at 18.2 MΩ. The utilized HF, HNO_3, and $HClO_4$ were suprapur reagents. The total metal concentrations in digestate solutions were determined by inductively coupled plasma optical emission spectrometry (ICP-OES, Optima 5300DV, PerkinElmer, US). Standard reference materials (GSS- and GSV-) obtained from the Center of National Standard Reference Materials of China, as well as blank samples, were included in each batch of analyses for quality assurance and quality control (QA/QC) procedures. All samples were analyzed in duplicate and the analytical precision was accepted when the relative standard deviation was within 5%.

2.4. Statistical analysis

The experimental data is processed by adopting Microsoft Excel (Ver. 2010) for analysis of the means, standard deviation and coefficient of variation, as well as for drawing analysis.

3. Results

3.1. Composition and characteristics of dominant plants

After a long period of natural succession, the vegetation of the wasteland had formed a natural community (Table 1). There were 17 dominant plant species in this survey belonging to 8 families (Compositae, Pteridaceae, Gramineae, Umbelliferae, Buddlejaceae, Solanaceae, Cyperaceae, Chenopodiaceae). Of these species, *A. conyzoides*, *C. crepidioides*, *B. davidii*, *P. vittata*, *I. cylindrical* and *P. revolutum* were most frequently encountered. Regarding the life form of plants, the wasteland vegetation was dominated by herbaceous plants, which accounted for 94.1%. This observation may be related to the survival potential and characteristics of herbs, like their ability to grow quickly, survive in barren sites, and drought resistance (Yang et al., 2014). In addition, herb plants with fine or light seeds can be easily distributed by wind (Li et al., 2007; Mikołajczak et al., 2017). Therefore, herbs were more likely to form heavy metal tolerance.

Table 1
List of dominant plant species growing on the study area.

Family	Species	Life Form
Compositae	*Conyza canadensis* (Linn.) Cronq.	Annual Herb
Compositae	*Ageratum conyzoides* Linn.	Annual Herb
Compositae	*Taraxacum mongolicum* Hand.-Mazz.	Herbs Perennial
Compositae	*Bidens pilosa* Linn.	Annual Herb
Compositae	*Artemisia iavandulaefolia* DC.	Herbs Perennial
Compositae	*Crassocephalum crepidioides* (Benth.) S. Moore	Annual Herb
Compositae	*Ixeris denticulata*	Annual Herb
Compositae	*Senecio scandens* Buch.-Ham. ex D. Don	Herbs Perennial
Pteridaceae	*Pteris vittata*	Herbs Perennial
Pteridaceae	*Pteridium revolutum*	Herbs Perennial
Gramineae	*Echinochloa crusgali* (Linn.) Beauv.	Annual Herb
Gramineae	*Imperata cylindrica*	Herbs Perennial
Umbelliferae	*Centella asiatica* (Linn.) Urban	Herbs Perennial
Buddlejaceae	*Buddleja davidii* Fr.	Deciduous Shrub
Solanaceae	*Solanum nigrum* Linn.	Annual Herb
Cyperaceae	*Carex chinensis* Retz.	Herbs Perennial
Chenopodiaceae	*Chenopodium ambrosioides Linn.*	Annual Herb

Table 2
Concentrations of heavy metals in soil from the study areas.

Metal	Concentrations (mg kg^{-1})			SD	CV	BV (mg kg^{-1})	Threshold (mg kg^{-1})
	Minimum	Maximum	Mean				
Cr	75.2	102.1	85.4	8.4	0.10	70.18	150
Cd	3.01	12.70	8.84	3.43	0.39	0.19	0.30
Cu	47.7	277.8	127.3	75.9	0.60	23.78	50
Zn	602.5	2189.5	1721.3	558.9	0.32	72.61	200
Pb	751.7	3838.5	1715.7	919.2	0.54	29.95	250
Ni	24.1	34.2	28.8	4.51	0.16	23.37	40

SD: standard deviation; CV: Coefficient of variation; BV: background values; Threshold: the Class-IIstandard of soil environment quality in China.

3.2. Heavy metal concentrations in surface soils

The results of soil pH determination showed that the soil pH of the wasteland soil averaged 5.42 (from 5.23 to 5.58), indicating an acidic nature. The contents of individual heavy metals (Cd, Cu, Pb, Zn, Ni, Zn) in the wasteland soil samples are summarized in Table 2. It can be seen from Table 2 that heavy metal elements contents in the wasteland soil all exceeded the soil background values in Northeast Guangxi (Zheng, 1993), indicating the increase of the metal contents contributed by the lead-zincs mining activities and haphazard piling of tailings. Of the six metals, the most seriously polluting metals in soil were Cd, Pb, and Zn, whose mean contents were 46.5, 57.3 and 23.7 times higher than their corresponding background values, respectively. The elevated Cd, Pb and Zn concentrations in the soils of this wasteland seem likely to impose toxic effects on plant establishment in addition to other constraints like nutrient deficiency and poor physical structure. The mean contents of Cr and Ni were consistent with the Grade-IIstandard limit values of soil environment quality (GB15618-1995) set by the State Environmental Protection Administration for soil protection in China. However, those of Pb, Zn and Cd far exceeded the national standard critical value.

3.3. Heavy metal contents of dominant plants

The average contents of heavy metals in different parts of the dominant plants grown on the polluted wasteland, as well as the normal range and phytotoxic levels of heavy meals in general plants are presented in Table 3. There were great variations of metal concentrations among plant species with Cd ranging from 1.7 to 219.5 mg kg^{-1}, Cr 2.4–76.8 mg kg^{-1}, Cu 6.4–94.0 mg kg^{-1}, Ni 0.7–28.9 mg kg^{-1}, Pb 11.0–1406.9 mg kg^{-1}, Zn 54.4–2787.0 mg kg^{-1}. In general, Zn occurred at the highest concentrations among the plant species, followed by Pb and Cu mainly due to differences in the total metal concentrations in the soils and their bioavailability. Compared with the content of heavy metals in general plants (He et al., 2013), Cd, Pb and Zn concentrations in most of the studied plants greatly exceeded the normal range, which is likely related to elevated Cd, Pb and Zn of the soils. The highest Cd, Pb and Zn concentrations were observed in the leaf of *C. crepidioides*, the root of *P. vittata*, and the root of *E. crusgali*, respectively. In addition, some Cu and Cr, as well as a few Pb levels surpassed the upper limit of the normal range. Concentrations of most heavy metals were higher in the leaves than those in the stems, this may be ascribed to the stem's playing the role of a transferring tissue (Planquart et al., 1999). In terms of phytotoxic level (Kabata-Pendias, 2011), the concentrations of Cd, Pb, Zn and Cu in most studied species reached the phytotoxic level, while the values of Ni and Cr for most plant species were below the phytotoxic range. According to Nadgórska-Socha et al. (2015), the concentrations of Cd, Pb and Zn in the aerial pants of all the examined plants exceeded allowable thresholds for animal feedstuffs, established at 100, 10, and 1 mg kg^{-1} for Zn, Pb, and Cd. Therefore, such natural vegetation sites should not be recommended as pastures. Note that *T. mongolicum* contained normal levels of Cu, Pb, Ni, Zn and Cr, with a relatively high Cd concentration in the leaves, indicating this species may have developed an avoidance strategy to the high level toxic metals. As observed for the other metals, however, these values were below the threshold.

3.4. Heavy metal accumulation and translocation in dominant plants

The bioaccumulation factor (BCF) and biological transfer factor (BTF) were also calculated to investigate the accumulation and translocation ability of trace metals in the soil-plant system. BCF refers to the ratio of the metal content in the plant and the corresponding content of heavy metals in the soil (Dai et al., 2013; Monterroso et al., 2014). A greater BCF indicates a stronger accumulation ability of heavy metals (Branzini et al., 2012). BTF was the ratio of the content of heavy metals of aboveground and underground parts of the plants, which roughly reflects the translocation capability for heavy metals from roots to the aboveground parts in plants (Dai et al., 2013; Pandey et al., 2016).

The BCFs and BTFs of the dominant plants in the wasteland are shown in Fig. 1. It is generally agreed that the BCFs and BTFs differ between plants species indicating their different strategies for metal accumulation (Chunilall et al., 2005). Among the plant species, the BCFs for Cd, Cu, Pb and Zn ranged from 0.32 to 16.94, 0.05–0.44, 0.01–0.19, and 0.16–0.96, respectively. All plant species screened for total metal concentration showed value of BCF < 1 for one or more heavy metals except Cd. The accumulation ability for metals decreased in the order of: Cd > Zn > Cu > Pb, which also has been demonstrated in the works of Zhan et al. (2014) carried out from lead-zinc smelting areas in Huixian County, Northwest China. Cd was the most enriched element in the study areas, especially *C. crepidioides*, its BTF for Cd was as high as 16.94, followed by *S. nigrum* (6.50) and *A. conyzoides* (5.39). *S. scandens* showed the highest BCF for Cu, while the BCF values of *C. crepidioides* and *A. iavandulaefolia* were highest for Zn, and of *C. canadensis* for Pb. The BCFs of most plants for Pb were lower than 0.1, suggesting lower enrichment and movement ability of Pb in plants and soil.

With regard to BTF, most of the plant species were efficient to take up and translocate more than one heavy metal from roots to shoots with a noticeable variation between BTF values. Most plants had relatively higher BTF values than their BCFs for Pb, Cu and Zn, suggesting those metal contents in root tissues of the examined plants were lower than those in their associated soils. Contrastingly, the BCFs for Cd in the plants were higher than their corresponding BTF values except for *T. mongolicum* and *C. ambrosioides*. Nevertheless, the plants showed a relatively high Cd transfer rate, while Pb and Cu were only poorly transported to the above-ground parts. *S. nigrum* was efficient in translocation Cd and Cu from roots to shoots with BTF values of 2.84 and 1.79, respectively. Highest BTF values for Pb and Zn were found by *C. Canadensis* and *T. mongolicum*, respectively. In addition, *C. crepidioides* was also characterized by higher BCF values for Cd (2.46), Cu (1.04) and Zn (1.69). It is easy for plant species with BTF > 1 to translocate metals from roots to shoots than those which restrict metals in their roots. The BTF values of < 1.0 for Cd, Cu, Pb and Zn in *P. vittata* and *C. chinensis* reflect the ability of these plant populations to restrict

Table 3
Heavy metal contents a of dominant plants in study area/ mg kg^{-1}.

Species	Parts	Cd	Cr	Cu	Ni	Pb	Zn
Normal range		0.2–0.8	0.2–8.4	0.4–45.8	0.1–10	0.1–41.7	1–160
Phytotoxic level		5–30	10–100	20–100	40–246	30–300	100–400
Pteris vittata	Stem&Leaf	2.5	27.6	16.6	6.5	104.0	1198.0
	Root	8.6	50.4	94.0	8.1	1406.9	2241.4
Pteridium revolutum	Stem&Leaf	5.0	5.5	33.7	6.4	690.1	1984.0
	Root	10.8	8.3	75.5	7.3	1300.0	1390.0
Imperata cylindrica	Stem&Leaf	8.3	16.6	14.8	3.4	200.8	1509.4
	Root	9.0	70.6	74.5	27.4	948.3	1737.8
Conyza canadensis (Linn.) Cronq.	Stem&Leaf	40.9	5.4	60.0	4.4	323.4	1731.7
	Root	27.1	6.8	55.2	6.6	221.0	923.7
Centella asiatica (Linn.) Urban	Stem&Leaf	23.1	7.1	32.9	2.4	107.3	904.5
	Root	20.8	6.9	46.1	3.6	253.9	1022.0
Echinochloa crusgali (Linn.) Beauv.	Stem&Leaf	35.4	5.7	17.1	2.2	80.3	1735.5
	Root	24.4	20.5	35.2	8.6	352.9	2787.0
Ixeris denticulata	Stem&Leaf	14.6	2.7	10.9	0.7	49.1	336.8
	Root	10.7	3.4	11.7	1.3	84.9	253.0
Carex chinensis Retz.	Stem&Leaf	6.7	41.4	6.4	15.1	15.5	357.8
	Root	14.5	76.8	15.4	28.9	91.3	1452.8
Ageratum conyzoides Linn.	Leaf	67.6	5.9	26.9	4.5	60.4	1480.1
	Stem	50.9	5.1	10.6	2.3	45.1	945.3
	Root	39.2	21.9	44.3	12.0	257.0	1636.9
Crassocephalum crepidioides (Benth.) S. Moore	Leaf	219.5	4.7	58.5	2.5	85.6	2196.9
	Stem	159.6	4.7	25.4	1.5	113.2	1405.5
	Root	79.8	53.1	43.8	12.5	411.3	1122.8
Artemisia iavandulaefolia DC.	Leaf	11.6	11.1	47.7	6.3	62.1	2216.5
	Stem	5.9	6.0	31.2	3.0	60.9	1331.4
	Root	10.1	12.2	40.4	6.4	262.2	1575.6
Buddleja davidii Fr.	Leaf	18.1	2.4	35.6	4.5	35.2	1709.0
	Stem	7.7	5.5	11.9	5.3	45.1	711.2
	Root	15.4	16.7	28.1	8.9	177.9	1423.3
Senecio scandens Buch.-Ham. ex D. Don	Leaf	5.3	6.0	23.6	3.1	46.0	317.6
	Stem	4.6	5.6	15.5	1.8	28.9	209.6
	Root	6.9	6.2	20.3	2.2	69.9	340.3
Bidens pilosa Linn.	Leaf	17.1	5.0	24.9	1.3	34.4	372.2
	Stem	9.7	4.4	12.8	1.1	16.5	178.2
	Root	7.9	16.5	49.8	6.6	109.2	246.7
Taraxacum mongolicum Hand.-Mazz.	Leaf	4.0	4.2	13.2	2.9	21.1	133.4
	Stem	2.2	4.6	9.6	0.7	12.6	101.8
	Root	1.7	4.7	9.3	1.1	12.9	54.4
Solanum nigrum Linn.	Leaf	23.1	5.8	30.1	2.3	36.2	183.6
	Stem	11.2	3.5	12.7	2.6	30.0	155.8
	Root	6.9	14.2	13.8	5.2	39.2	124.8
Chenopodium ambrosioides Linn.	Leaf	6.9	12.2	15.4	5.3	42.3	467.0
	Stem	3.0	5.5	8.3	1.5	11.0	175.3
	Root	4.0	7.6	11.3	3.2	26.5	413.3

their absorption and/or translocation to aerial parts.

4. Discussion

Cu, Ni and Zn are essential minor nutrients for plant growth and are associated with many enzyme systems and certain other proteins thus critical for a number of plant functions and health. However, their excessive concentrations in plant tissues lead to chlorosis and necrosis of plant leaves, nutrient deficiency and decrease of water uptake (Küpper and Andresen, 2016; Lewis et al., 2001). Cd, Pb and Cr are toxic metals for plants and usually adverse to the growth, metabolism, and water status of plants. The common toxicity symptoms of these metals are germination inhibition, chlorosis of leaves, reduction of plant biomass, mutagenic effects, etc. (Shanker et al., 2005; Nawab et al., 2015). The levels of Cd, Pb and Zn in the study soils greatly exceeded the Grade-IIstandard limit values of soil environment quality. In addition, the results showed that most of the investigated plant species accumulated higher concentrations of Cd, Pb and Zn than normal limits and reached the threshold values considered as toxic for normal plants. Nonetheless, the local environment with high contents of Pb, Zn and Cd in the soil posed no toxic effect on the dominant plants. Moreover, the plant species grew luxuriantly, had a large biomass, and could form small communities. The presence of the plant species in the study area with high levels of Cd, Pb and Zn indicated their ability to adapt to contaminated soils and possibly has developed specific mechanisms for metal detoxification (Ghosh and Singh, 2005).

The plant response to heavy metals in soil depends on the plant species, the total soil metal concentration, and the bioavailability of the metal itself depending on physico-chemical properties of the soils (Boularbah et al., 2006; Bonanno, 2011). In general, plants growing in metalliferous mine soils can be divided into three categories: excluders, indicators and accumulators (Baker, 1981; Usman et al., 2012). Excluders are the plants in which the absorption and transport of metals is restricted with low BCF and BTF values. Indicator plants can accumulate the heavy metal amounts in aerial parts proportional to the soil content, while in the last category-accumulators metal concentration in aboveground parts are higher than in the soil (BCF > 1). Among the accumulators, hyperaccumulator area able to excessively absorb heavy metals and constantly transfer them to the aboveground parts of the plants. In addition to the critical characteristics of metal concentrations suggested by Baker and Brooks (1989) to qualify a hyperaccumulator, once BCF and BTF are larger than 1, potential metal hyperaccumulators can be defined (Remon et al., 2007).

Phytoremediation technologies basically includes phytoextraction, in which hyperaccumulator plants remove metals from soil and concentrate them in the harvestable parts of the plants, as well as

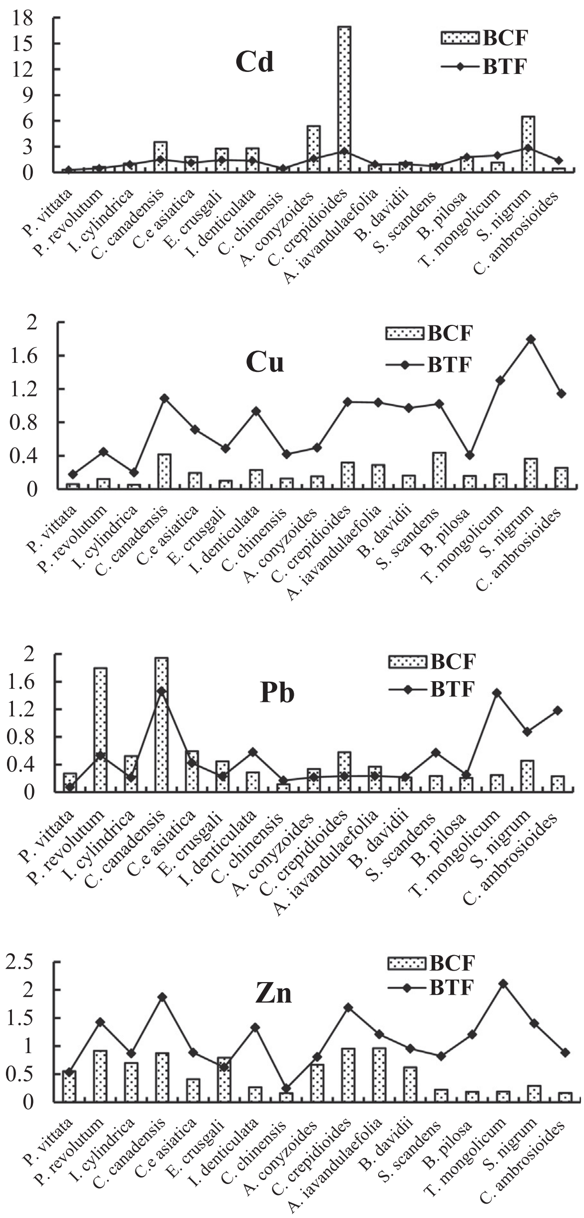

Fig. 1. BCFs and BTFs of heavy metals for plants of the wasteland area (The BCFs of Pb represent a 10 times conversion, for better presentation of the study plants).

phytostabilisation by excluder plants, which reduce the mobility and bioavailability of metals into the root tissue or precipitate them in the root zone (Ali et al., 2013; Guala et al., 2011; Nawab et al., 2016; Wei et al., 2012). Both BCF and BTF can be used to estimate a plant's potential for phytoremediation (Galal and Shehata, 2015). In the 17 kinds of dominant plant species, only the contents of *C. crepidioides* reached the Cd hyperaccumulator critical threshold values, fixed at 100 mg kg^{-1}. Combined with higher BCF and BTF values for Cd, *C. crepidioides* showed the basic characteristics of a Cd-hyperaccumulator. There is therefore a need to vertify the identification of Cd hyperaccumulator for *C. crepidioides* by further pot-culture or field experiments. Furthermore, in this work we have also observed *C. crepidioides,* revealed higher soil to shoot and root to shoot Zn transfer. Grasses/weeds have been more preferable in use for phytoaccumulation than shrubs or trees because of high growth rate, more adaptability to stress environment and high biomass (Malik et al., 2010). Therefore, this species clearly deserves further investigation to assess its potential for phytoextraction technologies, considering its promising character on polymetallic contaminated mining land.

Among the studied plants, *S. nigrum* and *B. pilosa* were reported Cd hyperaccumulator and their maximum Cd contents in leaves reached 194 mg kg^{-1} (Wei et al., 2004) and 401 mg kg^{-1} (Sun et al., 2009), respectively. However, the leaf Cd content in these two plant species were much lower in the present study. The difference may be caused by the great variation of soil Cd concentrations (3.0 mg kg^{-1} vs. 25 mg kg^{-1} and 8.1 mg kg^{-1} vs. 100 mg kg^{-1}). Nevertheless, the fact that the BCF and BTF values of *S. nigrum* and *B. pilosa* for Cd were greater than 1 corroborated that they can take up Cd from soil and store it in the shoots with great efficiency. *C. Canadensis*, *A. conyzoides*, *I. denticulata* and *E. crusgali* showed high phytoextraction potentials for Cd with respect to high BCF and BTF values for Cd. Although these species were not evaluated as hyperaccumulators in this study, they still demonstrated a high accumulation and transfer ability of Cd. According to Ghosh and Singh (2005), high root to shoot translocation of heavy metals indicated that these plants have vital characteristics to be used for phytoextraction of these metals.

While phytoextraction seems only promising for cleanup of slight to moderate polluted soils (Wong, 2003), phytostabilization is more appropriate for remediation of mine sites usually characterized by higher heavy metal concentrations. It has advantageous features over phytoextraction considering the fact that the disposal of the metal laden plant material is not required (Susarla et al., 2002). For an effective restoration of mine wasteland, identification and characterization of native appropriate plant species is essential to develop phytostabilization-based technique. A desired species with phytostabilization potential should possess an extensive root system and a large amount of biomass in the presence of high concentrations of heavy metals while keeping BTF as low as possible (Alvarenga et al., 2008). Furthermore, those plants should be native, which avoids the introduction of non-native and potentially invasive species that may result in decreasing regional plant diversity (Mendez and Maier, 2008). Of the 17 dominant plant species in this study, *P. vittata* and *C. chinensis* accumulated much lower concentrations of heavy metals in aerial parts than their roots with BCF and BTF < 1 for Cd, Cu, Pb, and Zn. In addition, these two species are common fast-growing herbs with well-developed root systems and plentiful biomass, indicating they have powerful diffusivity and adaptability, which can establish, grow on and colonize successfully mining wasteland and develop a good cover within a relatively short time period. Therefore, they are good candidates for phytostabilization purposes and could be used as ideal species in phytoremediation of lead-zinc mining wasteland in this region of South China.

5. Conclusions

The present field investigation demonstrated that the mining wasteland soil pH were less than 5.6, for acid soil. On the whole, the soil in the wasteland was polluted by various heavy metals, of which the pollution of Cd, Pb and Zn was the most serious The average concentrations of these metals were 29.5, 6.9 and 8.6 times higher than their respective value of national standard for soil environment quality (Grade-II). The 17 kinds of plant species collected in this study belonged to 8 families, most of them were herbaceous plants. The contents of Cd, Pb and Zn in most investigated plants were higher than the normal contents of general plants and reached the phytotoxic level. Low BCF and BTF values for Cd, Cu, Pb, Zn in *P. vittata* and *C. chinensis*, combined with their high biomass and proliferating root systems, indicated that they tolerated heavy metals by exclusion strategy and could be used for phytostabilization of Pb-Zn mining wasteland. The Cd concentrations in the stem and leave of *C. crepidioides* were 159.6 mg kg^{-1} and 219.5 mg kg^{-1}, respectively, which exceeded the amounts accepted for Cd-hyperaccumulators. In addition, the BCF and BTF values of *C. crepidioides* for Cd were 16.94 and 2.46. Thus, *C. crepidioides* demonstrated the basic characteristics of a Cd-hyperaccumulator.

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