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Heavy Metal Accumulation of 13 Native Plant Species Around a Coal Gangue Dump and Their Potentials for Phytoremediation

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ABSTRACT

This study was designed to investigate the heavy metal accumulation characteristics of 13 native plant species and associated rhizosphere soils around Taoyuan coal gangue dump, and to determine their potentials for phytoremediation. The mean concentrations of Cu, Cd, Pb and Cr in rhizosphere soils were 46.70, 0.43, 16.86 and 109.67 $mg \cdot kg^{-1}$, respectively. According to the pollution load index, the soils were strongly contaminated by Cd, moderately contaminated by Cu, slightly contaminated by Cr and uncontaminated by Pb. The concentrations of Cu, Cd, Pb and Cr in shoots of the 13 plant species ranged as 1.86-33.10, 0.10-0.94, 2.04-14.72 and 0.49-9.03 $mg \cdot kg^{-1}$, respectively, while in roots ranged as 0.44-91.56, 0.31-1.82, 4.83-50.49 and 0.37-99.63$mg \cdot kg^{-1}$, respectively. No plant species satisfied the concentration criteria of hyperaccumulator, but two high Cd-enriched species of *M. falcata* and *C. japonicum*, whose BCF and TF values were all greater than one, were recorded. Based on the Individual Phytoremediation Factors (IPF), *S. viridis* showed the strongest remediating capability per a single plant for Cu, while *M. falcata*, *S. viridis*, *C. eragrostis* and *C. japonicum* had relatively strong remediating capability per a single plant for Cd. The four plant species were proposed to be preferentially taken as the candidates for phytoremediation.

INTRODUCTION

Coal gangue, produced during the coal ore mining and utilization processing, is one of the greatest industrial solid wastes in China (Xue et al. 2014). Currently, the annual discharged amount of coal gangue is up to 1.5×10^8 t in China and only about 40% of it can be comprehensively utilized. The excessive coal gangues are inevitably piled up in the open in most coal mining areas of China. Under the long-term effect of external factors (weathering, leaching and biological reaction), heavy metals in these coal gangues will be released and cause serious pollution to the surrounding soil (You et al. 2016). Jiang et al. (2014) reported that potential ecological damage degrees of heavy metals in soils around Yangcaogou coal gangue dump were moderate to strong, and it decreased with increasing distance from the coal gangue dump. He et al. (2016) found high accumulation of toxic metals, especially Mn, Fe and Cr, in the soils within 250 m away from Liejiaqiao coal gangue dump.

Heavy metals accumulated in soils can cause great damage to the stability of the ecological environment, and harm human health through the food chain (Ahmad et al. 2011). It is necessary to reduce the negative effect of heavy metals and make the land resource available for agricultural production. Traditional remediation techniques, including excavation, leaching, electro kinetics, chemical stabilization, etc., for removing heavy metals from contaminated soils or reducing their availabilities are expensive and environmentally destructive. In contrast, phytoremediation is a less expensive and environmentally non-destructive restoration method for decreasing the environmental risk from the contaminated soils (Ali et al. 2013). This technology is carried out by using plants to extract the toxic metals from soil or to render them harmless in the contaminated sites. The efficiency of phytoremediation strongly depends on the accumulation and tolerance abilities of heavy metals in soil by the selected plant species. Thus, screening appropriate plant species is a critical step for successful phytoremediation. However, the species suitable for phytoremediation are relatively rare, and even usually endemic at the metal-enriched sites, because the accumulation and tolerance abilities of plant were generally evolved from the long-term stress of high concentration of heavy metals in soils (Ghaderian et al. 2012). Moreover, compared with the introduced plant species from other environment, the native species have more excellent adaptability of survival, growth and reproduction in the contaminated area. Therefore, increasing interests have been focused on the investigation and seeking of suitable metal-accumulator from the native plant species growing in metalliferous soils (Liu et al. 2014).

Taoyuan coal mine, located in the Huaibei coalfield in Anhui province of China, has a mining history of more than 20 years. The present study was conducted to investigate the accumulation characteristics of Cu, Cd, Pb and Cr in the 13 native plant species and associated rhizosphere soils around the coal gangue dump of Taoyuan mine, and to screen the species with phytoremediation potentials. This research is of important practical value for polluted soil treatment and ecological restoration in the coal mining area.

MATERIALS AND METHODS

Study Area and Sample Collection

Taoyuan coal mine is located in north-eastern Anhui Province, about 12 km from Suzhou urban area (Fig. 1). This region is characterized by a sub-humid monsoon climate, with an annual average rainfall of 890 mm and an annual average temperature of 14.4°C. The main soil types in Suzhou are Yellow fluvo-aquic soil and Lime concretion black soil. Taoyuan mine began production in October 1995 with an annual coal output of 1.6 million tons. During the past two decades, large amounts of coal gangue were produced going with coal exploitation, and a large coal gangue dump, covering an area of approximately 38800 m^2, was formed in eastern of the mining area. The height of the coal gangue dump is 65 m and the coal gangue stock is approximately 1.3 million tons.

Field sampling was carried out in October 2017. Fifty two plants and their corresponding rhizosphere soils were collected form the wastelands within 200 m from the coal gangue dump in Taoyuan mining area. The collected plants were consisted of thirteen species and eight families (Table 1). All the plant species were the common species in the mining area. For each species, three to five individual plants were selected randomly. Each soil sample was approximately 0.5 kg. After collection, the plant and soil samples were put into plastic self-sealing bags and labelled.

Sample Analysis and Quality Control

After the collected samples were transported to the laboratory, bulk density and moisture contents of soil were tested immediately. Then, each soil sample was air-dried at room temperature for two weeks and pulverised to pass through a 0.25-mm sieve. Soil pH was determined in a 1:2.5 soil/water (w/v) suspension using a pH meter. Organic matter of soil was measured by the Walkley-Black method. Total nitrogen (TN), total phosphate (TP) and total potassium (TK) were estimated by the standard methods of the Soil Science Society of China. Soil samples were digested with the mixed acids of aqua regia, $HClO_4$ and HF (4:1:1, v/v) in Teflon beakers, and the concentrations of Cu, Cd, Pb and Cr in soils were tested by an atomic absorption spectrophotometer (AAS, Model

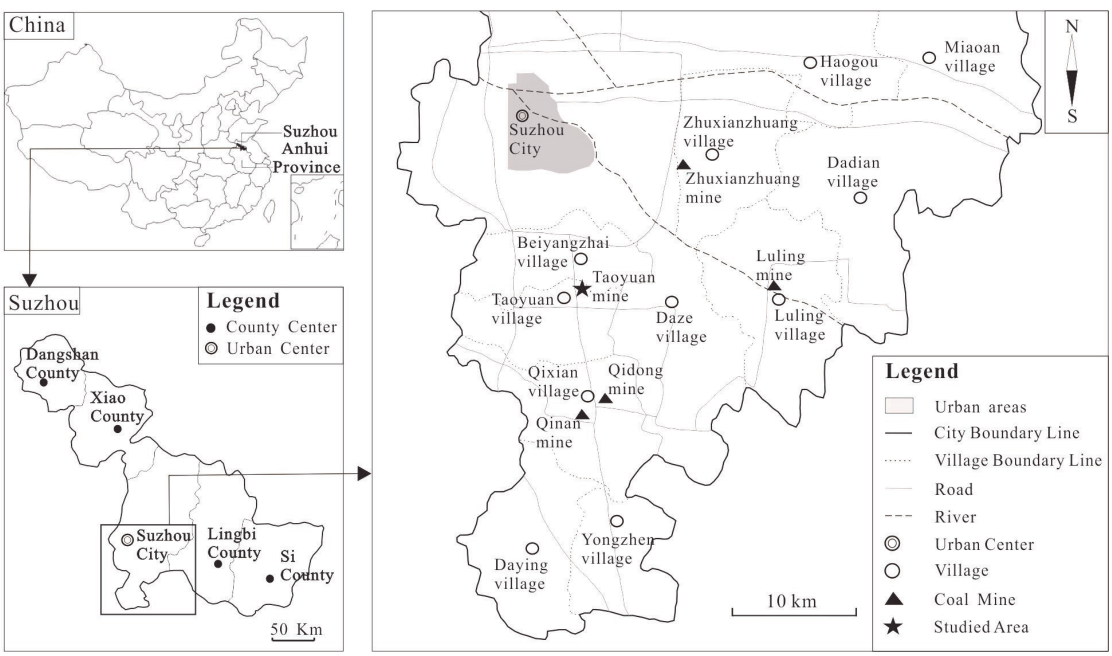

Fig. 1: Location of Taoyuan coal mine in Suzhou City, Anhui Province, China.

Table 1: Plant species collected from the investigated area and number of samples.

Family	Plant species	Species Code	Brief name	Sample number	Biomass (g·plant^{-1}, dry weight)	
					Shoot	Root
Compositeae	*Artemisia argyi* Levl. Et Vant.	1	A. argyi	4	0.82±0.16	0.19±0.05
	Conyza canadensis (Linn.) Cronq.	2	C. canadensis	5	5.02±0.63	0.21±0.04
	Cirsium japonicum Fisch. ex DC.	3	C. japonicum	3	3.83±0.47	0.33±0.02
	Xanthium sibiricum Patrin ex Widder	4	X. sibiricum	4	2.77±0.31	2.34±0.58
	Artemisia annua Linn.	5	A. annua	4	2.71±0.54	0.31±0.04
Gramineae	*Eleusine indica* (Linn.) Gaertn.	6	E. indica	3	8.76±1.98	0.16±0.04
	Setaria viridis (Linn.) Beauv.	7	S. viridis	5	12.25±2.05	0.18±0.02
Leguminoseae	*Medicago falcata* Linn.	8	M. falcata	4	5.95±1.36	0.78±0.05
Amaranthaceae	*Amaranthus spinosus* Linn.	9	A. spinosus	4	2.26±0.51	0.16±0.02
Crucifereae	*Capsella bursa-pastoris* (Linn.) Medic.	10	C. bursa-pastoris	4	1.93±0.10	0.15±0.01
Cyperaceae	*Cyperus eragrostis* Lam.	11	C. eragrostis	4	5.16±0.95	0.14±0.04
Solanaceae	*Physalis pubescens* Linn.	12	P. pubescens	4	0.59±0.11	0.13±0.03
Plantaginaceae	*Plantago asiatica* Linn.	13	P. asiatica	4	1.36±0.17	0.22±0.02

TAS-990FG, Purkinje General Instrument, Beijing, China).

Each wheat sample was carefully cut into two parts of root and shoot with a scissors. All the parts were thoroughly washed with running tap water to remove dirt and rinsed three times with deionized water. Then, the plant tissues were oven-dried at 80°C to constant weight and ground to pass through a 0.25-mm sieve. The plant powder samples were digested with the mixed acids of HNO_3, HCl and $HClO_4$ (5:1:1, v/v) in glass beakers, and the concentrations of Cu, Cd, Pb and Cr in different plant parts were also determined by AAS.

To ensure experimental accuracy, the reference materials (GBW07430 for soils and GBW007604 for plants) were performed through the digestion and determination processes. The recoveries of Cu, Cd, Pb and Cr in the soil and plant reference materials were all in the range of 100±10%. Reagent blanks were also employed in the analysis to eliminate analytical bias. All chemicals used in the experiment were of analytical grade, and all the vessels were treated with dilute nitric acid for 24 h followed by rinsing with MilliQ water for three times before use.

Data Analysis

Pollution load index (PLI) was applied in this study to evaluate the extent of the contamination by heavy metals in soil samples. It can be calculated by the following formula (Muhammad et al. 2011):

$$PLI = (CF_1 \times CF_2 \times \cdots \times CF_n)^{\frac{1}{n}} \quad \ldots(1)$$

Where, CF represents contamination factor of a single metal, and is obtained by dividing the concentration of each metal in the soil by the local background value. Based on the values of CF and PLI, the classification criterion of contamination level is listed in Table 2.

Table 2: Pollution load index and classification criterion of contamination level.

Contamination degree	CF		PLI	
	Value range	Contamination Level	Value range	Contamination Level
0	CF ≤ 0.7	No contamination	PLI ≤ 1.0	No contamination
1	0.7<CF ≤ 1.0	Light contamination	1.0<CF≤2.0	Slight contamination
2	1.0<CF ≤ 2.0	Slight contamination	2.0<CF≤3.0	Moderate contamination
3	2.0<CF ≤ 3.0	Moderate contamination	CF>3.0	Strong contamination
4	CF > 3.0	Strong contamination		

$$CF = \frac{C_{metal}}{C_{Background}} \quad ...(2)$$

Bioconcentration factor (BCF) and Translocation factor (TF) of the studied plant species were calculated based on the following equations.

$$BCF = \frac{C_{root}}{C_{soil}} \quad ...(3)$$

$$TF = \frac{C_{shoot}}{C_{root}} \quad ...(4)$$

In the above equations, C_{shoot} (mg·kg^{-1}), C_{root} (mg·kg^{-1}) and C_{soil} (mg·kg^{-1}) are the concentrations of a particular metal in shoot (including seed, leaf and stem aboveground), root and rhizosphere soil, respectively.

For comparing the phytoremediation potentials of different plant species, the coefficient of Individual phytoremediation factor (IPF) proposed by Li et al. was used in this study (Li et al. 2011). The formula is as follows:

$$IPF = \frac{C_{shoot} \times Biomass_{shoot}}{C_{soil}} \quad ...(5)$$

Where, $Biomass_{shoot}$ (g·plant^{-1}) is the dry weight of plant shoot.

Data reported in this article were analysed by Excel 2013 and SPSS 22.0 package for Windows, and all the figures were drawn by CorelDraw 2017. The mean values and the standard deviation of the metal concentrations in soil and different plant parts, and of BCF, TF and IPF were calculated.

RESULTS AND DISCUSSION

Physico-chemical Properties and Heavy Metal Contents in Rhizosphere Soil

The physico-chemical properties and heavy metal contents in rhizosphere soils around the coal gangue dump in Taoyuan mine are presented in Tables 3 and 4. As shown in Table 3, the investigated soils were found to be weakly alkalic, with the mean pH value of 7.81. The mean values of bulk density and moisture content were 1.32 g·cm^{-3} and 15.83%, respectively. Organic matter, total nitrogen, phosphate and potassium are the important indicators of soil nutrients and fertility. Compared with the classification criteria for soil nutrients in the second national census of soil in China, organic matter and total nitrogen in the studied soil samples were both in lacking level, total phosphate belonged to very lacking level, and total potassium remained at medium level.

Obvious differences between the minimum and maximum concentrations of Cu, Cd, Pb and Cr in rhizosphere soils were observed (Table 4), and indicated that metal concentrations varied widely among the soil samples collected from the studied area. It could be explained from the two respects. On one hand, heavy metals accumulated in soil around gangue dump were mostly released from the coal refuses, and their transporting process might be affected by many factors, such as landform, wind direction, the distance away from the gangue dump, etc. On the other hand, 13 plant species growing in different sampling sites had different uptake capacities for heavy metals from rhizosphere soil. The mean concentrations of Cu, Cd and Cr in rhizosphere soils were 46.70, 0.43 and 109.67 mg·kg^{-1}, respectively, which were evidently higher than the soil background values of Anhui province, while Pb concentration was lower compared to the background Pb level in Anhui. Based on Environmental Quality Standard for Agricultural Soil in China (GB15618-2018, Grade II), the levels of Cu, Pb and Cr satisfied grade II quality, and only Cd concentration significantly exceeded the standard.

According to the equation (1) and (2), contamination factor (CF) and pollution load index (PLI) of heavy metals in soils were calculated and given in Table 5. The highest mean CF value of selected metals was Cd (4.45), followed by Cu (2.29), Cr (1.62) and Pb (0.63), suggesting that soil in the investigated area was strongly contaminated by Cd, moderately contaminated by Cu, slightly contaminated by Cr and uncontaminated by Pb. Taking all metals as a whole,

Table 3: Physico-chemical properties of soils around the coal gangue dump in Taoyuan mine, Suzhou, Anhui Province, China (N=52).

Parameters	Values (Mean±Standard deviation)
pH	7.81±0.79
Bulk density (g·cm^{-3})	1.32±0.08
Moisture content (%)	15.83±1.87
Organic matter (g·kg^{-1})	13.76±2.02
Total nitrogen (g·kg^{-1})	0.95±0.18
Total phosphate (g·kg^{-1})	0.33±0.05
Total potassium (g·kg^{-1})	16.91±2.43

Table 4: Heavy metal contents ($mg \cdot kg^{-1}$) in soils around the coal gangue dump in Taoyuan mine, Suzhou, Anhui Province, China (N=52).

	Cu	Cd	Pb	Cr
Min.	25.52	0.26	10.94	53.32
Max.	79.72	0.68	25.08	243.79
Mean	46.70	0.43	16.86	109.67
SD	12.90	0.09	3.19	34.41
Background[a]	20.4	0.097	26.6	67.5
EQS[b]	100	0.3	120	200

[a]Background values of Cu, Cd, Pb, Cr in soil of Anhui Province; [b]Environmental quality standard for agricultural soil in China (GB15618-2018, Grade II)

the mean PLI value was 1.76, which indicated that the soil suffered moderate compositive contamination from the investigated metals.

Heavy Metal Contents in Different Parts of the Investigated Plants

Heavy metal contents in different parts of the investigated plants growing around the coal gangue dump are presented in Table 6. As given in Table 6, heavy metal contents in the plants of different species displayed great differences. The highest Cu content in plant shoot was found in *X. sibiricum* (33.10 $mg \cdot kg^{-1}$), and in root was found in *C. bursa-pastoris* (91.56 $mg \cdot kg^{-1}$). Besides, compared to other plant species, *P. pubescens* accumulated considerably higher Cu content in both shoot (31.86 $mg \cdot kg^{-1}$) and root (82.61 $mg \cdot kg^{-1}$). The lowest Cu content in shoot and in root were found in *E. indica* (1.86 $mg \cdot kg^{-1}$) and *C. japonicum* (0.44 $mg \cdot kg^{-1}$), respectively. Total Cd contents in plant samples were ranged from 0.10 to 0.94 $mg \cdot kg^{-1}$ in shoot and from 0.31 to 1.82 $mg \cdot kg^{-1}$ in root, and the highest content in the shoot and root were obtained in *C. japonicum* and *P. pubescens*, respectively. Pb contents differed among plant species from 2.04 to 14.72 $mg \cdot kg^{-1}$ in shoot and from 4.83 to 50.49 $mg \cdot kg^{-1}$ in root. Among the 13 plant species, *P. asiatica* had the maximum Pb content in shoot and the minimum Pb content in root. For Cr in plants, the highest content in shoot of *P. asiatica* (9.03 $mg \cdot kg^{-1}$) and in root of *A. annua* (99.63 $mg \cdot kg^{-1}$) were recorded, while the lowest content in shoot was found in *E. indica* (0.49 $mg \cdot kg^{-1}$) and in root was found in *C. japonicum* (0.37 $mg \cdot kg^{-1}$).

Bioconcentration Factor and Translocation Factor

To evaluate the ability of different plant species for metal accumulation and translocation, BCF and TF values of 13 plant species were calculated and listed in Table 7. As given in Table 7, BCF values of Cd of most plant species were higher than those of the other three metals, indicating that Cd in soil environment was more readily absorbed by plant roots. Among the four metals, BCF values of Cr of almost all the plant species were lowest, with only one exception of *A. annua*. The highest BCF values of Cd and Pb were 4.97 and 2.77 by *P. pubescens*, of Cu was 2.08 by *C. bursa-pastoris*, and of Cr was 1.58 by *A. annua*. Conversely, the lowest BCF values of Cu (0.01), Pb (0.29) and Cr (0.003) by *C. japonicum*, and of Cd (0.77) by *X. sibiricum* were found.

Metal translocation abilities from roots to shoots can be quantitative as indicated by the TF values, which varied greatly among different plant species in this study. *C. japonicum* and *A. argyi* were found to be the excellent transporter of Cu, with the TF values of 9.09 and 8.93, respectively, which were over 100 times than the lowest TF value of Cu by *C. bursa-pastoris* (0.07). Among all the plant species, *M. falcata* and *C. japonicum* were the only two species whose TF values of Cd were greater than one, while *P. asiatica* was the only one species whose TF value of Pb was greater than one. Besides, the highest TF value of Cr was also found in *P. asiatica* (15.74), showing its exceptional ability of Cr transferring from roots to aerial parts.

Table 5: Contamination factor (CF) and pollution load index (PLI) of heavy metals in soils (n=52).

Item	CF				PLI
	Cu	Cd	Pb	Cr	
Min.	1.25	2.73	0.41	0.79	1.21
Max.	3.91	7.03	0.94	3.61	2.25
Mean	2.29	4.45	0.63	1.62	1.76
Contamination level	Moderate	Strong	No contamination	Slight	Moderate

Table 6: Heavy metal contents in different parts of plant samples from the investigated area.

Plant species	Plant part	Cu Content ($mg\cdot kg^{-1}$)	Cd Content ($mg\cdot kg^{-1}$)	Pb Content ($mg\cdot kg^{-1}$)	Cr Content ($mg\cdot kg^{-1}$)
A. argyi	Shoot	9.95±2.14	0.35±0.05	2.96±0.77	0.75±0.28
	Root	1.12±0.05	0.48±0.14	6.98±2.32	1.98±0.55
C. canadensis	Shoot	10.65±2.17	0.53±0.15	4.49±0.49	1.54±0.60
	Root	40.25±3.96	1.26±0.09	20.03±6.95	8.44±3.17
C. japonicum	Shoot	4.00±0.27	0.94±0.02	3.50±0.37	0.77±0.10
	Root	0.44±0.01	0.88±0.48	4.83±1.87	0.37±0.06
X. sibiricum	Shoot	33.10±3.46	0.10±0.02	4.73±1.71	8.14±3.80
	Root	30.11±5.83	0.31±0.07	14.31±0.93	4.53±1.91
A. annua	Shoot	18.64±1.88	0.35±0.22	6.14±0.74	3.03±0.81
	Root	6.50±1.30	0.52±0.17	12.25±4.14	99.63±23.72
E. indica	Shoot	1.86±0.01	0.11±0.02	2.04±0.40	0.49±0.17
	Root	53.82±5.16	0.78±0.15	10.68±3.68	2.33±1.03
S. viridis	Shoot	15.83±3.57	0.30±0.14	4.77±1.29	1.31±0.67
	Root	38.28±8.60	1.04±0.24	16.81±5.64	4.38±2.10
M. falcata	Shoot	4.98±1.36	0.74±0.21	3.88±1.17	1.31±0.34
	Root	6.22±0.34	0.47±0.15	7.71±1.68	5.90±2.05
A. spinosus	Shoot	20.38±1.34	0.22±0.04	4.61±1.39	0.86±0.22
	Root	42.30±9.31	0.45±0.12	11.12±2.42	1.56±0.69
C. bursa-pastoris	Shoot	6.06±0.74	0.34±0.10	2.19±0.66	2.57±0.65
	Root	91.56±15.31	0.58±0.26	16.11±3.50	8.87±5.55
C. eragrostis	Shoot	11.52±1.26	0.77±0.13	3.83±1.16	1.12±0.46
	Root	12.83±3.15	1.50±0.46	23.43±5.09	5.34±1.41
P. pubescens	Shoot	31.86±5.90	0.31±0.08	3.21±0.97	0.56±0.18
	Root	82.61±7.92	1.82±0.21	50.49±10.98	7.44±1.83
P. asiatica	Shoot	7.66±0.86	0.52±0.17	14.72±4.44	9.03±1.03
	Root	1.97±0.50	0.85±0.27	4.83±1.05	0.63±0.19

Accumulated Amount of Heavy Metal in The Investigated Plants

Combined with plant biomass, metal amounts accumulated in different parts of 13 plant species were calculated and illustrated in Fig. 2. As shown in Fig. 2, *S. viridis* accumulated the largest amounts of Cu (202.1 $\mu g\cdot plant^{-1}$) and Pb (60.73 $\mu g\cdot plant^{-1}$), *M. falcate* had the largest accumulated amount of Cd (4.65 $\mu g\cdot plant^{-1}$), while *A. annua* had the largest accumulated amount of Cr (38.63 $\mu g\cdot plant^{-1}$). The lowest amounts of Cu (8.45 $\mu g\cdot plant^{-1}$), Cd (0.37 $\mu g\cdot plant^{-1}$), Pb (3.72 $\mu g\cdot plant^{-1}$) and Cr (0.99 $\mu g\cdot plant^{-1}$) were found in the plant species of *A. argyi*. Compared with the different parts of plant, the mean amounts of Cu, Cd, Pb and Cr in shoots of the 13 plant species were 52.25, 1.82, 18.32 and 7.73 $\mu g\cdot plant^{-1}$, respectively, which were significantly higher than that of 10.38, 0.23, 5.43 and 4.05 $\mu g\cdot plant^{-1}$ in roots (two-tailed t test, $p<0.05$, n=52). In most plant species, the aerial part, occupying over 80% of the total metal amount in the whole plant, was proved to be the dominant organ involved in heavy metal accumulation.

Screening for The Plant Species with Phytoremediation Potential

The plant species naturally growing on the metal contaminated soil are precious germplasm resources for phytoremediation. For the purpose of identifying hyper accumulator and the native plant species with phytoremediation potentials, several judging standards have been given in the previous

Table 7: Bioconcentration factors (BCF) and translocation factor (TF) of the studied plant species.

Plant species	BCF				TF			
	Cu	Cd	Pb	Cr	Cu	Cd	Pb	Cr
A. argyi	0.03±0.01	1.66±0.58	0.43±0.21	0.02±0.01	8.93±2.18	0.78±0.30	0.43±0.04	0.40±0.18
C. canadensis	1.07±0.34	2.66±0.58	1.28±0.63	0.08±0.02	0.27±0.06	0.42±0.12	0.25±0.09	0.19±0.06
C. japonicum	0.01±0.00	1.81±0.82	0.29±0.14	0.00±0.00	9.09±0.44	1.26±0.71	0.77±0.22	2.10±0.09
X. sibiricum	0.46±0.06	0.77±0.15	0.86±0.07	0.05±0.03	1.11±0.09	0.33±0.08	0.33±0.11	2.20±1.64
A. annua	0.22±0.07	1.26±0.10	1.04±0.38	1.58±0.37	3.00±0.97	0.69±0.40	0.55±0.23	0.03±0.00
E. indica	1.29±0.47	1.75±0.05	0.65±0.23	0.03±0.00	0.03±0.00	0.15±0.05	0.20±0.03	0.25±0.19
S. viridis	1.04±0.37	2.22±0.30	0.79±0.21	0.04±0.02	0.43±0.13	0.31±0.21	0.33±0.19	0.36±0.27
M. falcata	0.15±0.03	1.14±0.39	0.45±0.06	0.06±0.02	0.80±0.23	1.71±0.87	0.50±0.11	0.26±0.17
A. spinosus	0.65±0.09	1.12±0.32	0.69±0.31	0.02±0.01	0.50±0.16	0.53±0.24	0.41±0.09	0.68±0.49
C. bursa-pastoris	2.08±0.39	1.35±0.54	1.02±0.32	0.08±0.05	0.07±0.01	0.65±0.27	0.14±0.03	0.36±0.20
C. eragrostis	0.24±0.10	2.85±1.22	1.38±0.12	0.05±0.02	0.92±0.12	0.54±0.19	0.16±0.04	0.22±0.11
P. pubescens	1.75±0.28	4.97±1.12	2.77±0.46	0.04±0.02	0.39±0.10	0.17±0.04	0.06±0.01	0.08±0.03
P. asiatica	0.04±0.01	2.09±0.80	0.34±0.15	0.01±0.00	4.13±1.52	0.61±0.03	3.04±0.68	15.74±7.00

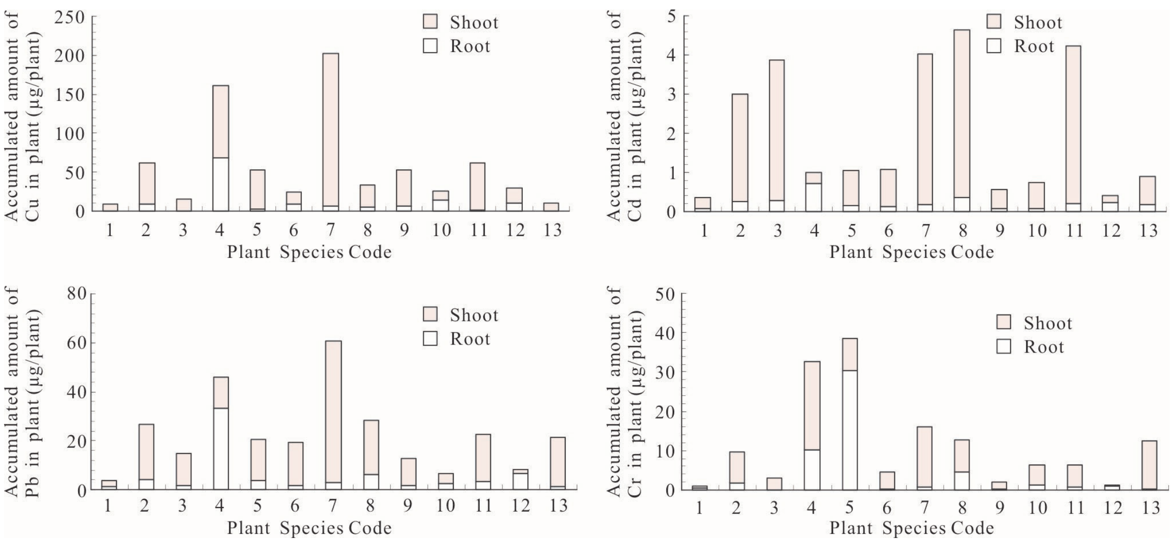

Fig. 2: Accumulated amount of heavy metals in the investigated plants.

literatures. Baker & Brooks (1989) suggested that the critical contents of different metals and metalloids in the stems or foliage of hyper accumulator were 100 mg·kg^{-1} for Cd, 1000 mg·kg^{-1} for Cu, Pb, Co, Ni and As, and 10000 mg·kg^{-1} for Zn and Mn. Subsequently, Van der Ent et al. (2013) proposed that these values should be 100 mg·kg^{-1} for Cd, 300 mg·kg^{-1} for Cu, Cr and Co, 1000 mg·kg^{-1} for Pb, Ni and As, 3000 mg·kg^{-1} for Zn, and 10000 mg·kg^{-1} for Mn. In this study, metal concentrations in all the 13 plant species were far below these criteria, thus none of them could be considered as a hyper accumulator.

Generally, metal concentration in plant is directly associated with that in the soil where it grows. In the polluted sites, bioconcentration factor (BCF) and translocation factor (TF) have been considered to be the important indicators widely used for determining metal accumulation abilities and distinguishing phytoremediation potentials of different plant species. Plant species with both BCF and TF values greater than one can potentially be used for heavy metal phytoremediation (Boechat et al. 2016, Yoon et al. 2006). Based on this view, only two species *M. falcata* and *C. japonicum* in this investigation satisfied the criteria for phytoremediation of Cd.

Table 8: Individual phytoremediation factor (IPF) of the studied plant species.

Plant species	PM			
	Cu	Cd	Pb	Cr
A. argyi	0.24±0.10	0.96±0.09	0.15±0.08	0.01±0.00
C. canadensis	1.42±0.61	5.76±2.51	1.39±0.39	0.07±0.02
C. japonicum	0.28±0.04	7.59±0.02	0.78±0.08	0.02±0.00
X. sibiricum	1.42±0.27	0.72±0.32	0.77±0.24	0.26±0.17
A. annua	1.70±0.30	2.19±0.87	1.39±0.28	0.13±0.05
E. indica	0.40±0.20	2.15±0.25	1.06±0.03	0.05±0.02
S. viridis	5.33±2.22	8.46±5.33	2.93±1.60	0.16±0.06
M. falcata	0.67±0.16	10.21±1.9	1.35±0.52	0.08±0.04
A. spinosus	0.70±0.04	1.26±0.44	0.68±0.40	0.02±0.00
C. bursa-pastoris	0.27±0.07	1.54±0.42	0.27±0.09	0.05±0.02
C. eragrostis	1.13±0.49	7.84±3.50	1.19±0.51	0.05±0.02
P. pubescens	0.40±0.10	0.50±0.20	0.11±0.04	0.00±0.00
P. asiatica	0.22±0.07	1.78±0.78	1.45±0.80	0.09±0.02

Furthermore, phytoremediation potential does not merely depend on the concentration of heavy metal in the plant. The dry biomass of plant is also considered to be a very influential factor. Large dry biomass is the indispensable requirement for an efficient phytoremediator, as a plant with low biomass production could hardly possess excellent capability for accumulating the elevated amount of heavy metal though the metal concentration in the plant would be very high. Besides, to be an efficient phytoremediator, the plant species, even though sharing a large dry biomass and high concentration of heavy metal, should also satisfy another requirement that a considerable metal amount accumulate in the easily harvestable plant organs (e.g., shoots). For screening the native plant species with phytoremediation potentials in the investigated area, the individual phytoremediation factor (IPF), reflecting the remediating capability per a single plant, was used to compare metal removing capabilities of the 13 plant species. This factor refers to the ratio of the metal amount accumulated in plant shoot to the metal concentration in soil. The IPF values of 13 plant species were calculated and listed in Table 8. As provided in Table 8, the IPF value of *S. viridis* for Cu and Pb was obviously higher than that of the other plant species. *M. falcata* showed the highest IPF value for Cd, while *S. viridis*, *C. eragrostis* and *C. japonicum* also had relatively high IPF values for Cd. Considering that the soils in the investigated area were strongly contaminated by Cd and moderately contaminated by Cu (Table 5), the above 4 screened plant species with excellent remediating capability per a single plant can be preferentially taken as the candidates for further examining, since the plant biomass per unit area and the growth cycle of different plant species are not taken into consideration in the present study.

CONCLUSION

According to the results of this study, obvious accumulation of heavy metals, especially Cd and Cu, were found in the soils around Taoyuan coal gangue dump compared to the background values. Heavy metal concentrations in the plant of different species varied greatly. For most plant species, the accumulated amounts of Cu, Cd, Pb and Cr mainly existed in the aerial part. Among the 13 native plant species, none of them satisfied the concentration criteria of hyperaccumulator, but two high Cd-enriched species of *M. falcata* and *C. japonicum* with both BCF and TF values greater than one were recorded. Finally, based on the individual phytoremediation factor (IPF), four species of *M. falcata*, *S. viridis*, *C. eragrostis* and *C. japonicum* with strong remediating capability per a single plant were screened and proposed to be further studied for restoring Cd and Cu contaminations of the soils in the mining area.

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