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Cadmium accumulation and growth responses of a poplar (*Populus deltoids* × *Populus nigra*) in cadmium contaminated purple soil and alluvial soil

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ABSTRACT

To characterize the phytoextraction efficiency of a hybrid poplar (*Populus deltoids* × *Populus nigra*) in cadmium contaminated purple soil and alluvial soil, a pot experiment in field was carried out in Sichuan basin, western China. After one growing period, the poplar accumulated the highest of 541.98 ± 19.22 and 576.75 ± 40.55 μg cadmium per plant with 110.77 ± 12.68 and 202.54 ± 19.12 g dry mass in these contaminated purple soil and alluvial soil, respectively. Higher phytoextraction efficiency with higher cadmium concentration in tissues was observed in poplar growing in purple soil than that in alluvial soil at relative lower soil cadmium concentration. The poplar growing in alluvial soil had relative higher tolerance ability with lower reduction rates of morphological and growth characters than that in purple soil, suggesting that the poplar growing in alluvial soil might display the higher phytoextraction ability when cadmium contamination level increased. Even so, the poplars exhibited obvious cadmium transport from root to shoot in both soils regardless of cadmium contamination levels. It implies that this examined poplar can extract more cadmium than some hyperaccumulators. The results indicated that metal phytoextraction using the poplar can be applied to clean up soils moderately contaminated by cadmium in these purple soil and alluvial soil.

1. Introduction

Owing to the rapid expansion of industrialization and the heavy use of chemical fertilizer, pesticides and herbicides in agriculture, cadmium pollutant has been considered as one of the most serious environmental problems worldwide [1,2]. Compared with other heavy metals, cadmium is not an essential nutrient in higher plants [3–5], and the exposure to relatively low concentrations results in high toxicity to plant and animal [3,6]. Moreover, the heavy metal can enter human diet and accumulate gradually in the human body [4,7], resulting a number of adverse health effects, such as nephrotoxicity and osteotoxicity [8,9]. Thus, there is an urgent and imperative need to develop efficient techniques for cadmium removal from the environment.

Fortunately, a variety of the engineering and biology technologies have been developed to remedy the contaminated ecosystems [10,11]. Including others, phytoremediation, the use of plants to extract, sequester and/or detoxify hazardous heavy metal from medium (soil, water and air), is regarded as a tangible alternative with great potential for affordable remediation of polluted sites [12–14]. According to the previous studies, four indicators have been often used to define a cadmium hyperaccumulator: (1) the threshold value of cadmium accumulated in the plant (>100 mg kg^{-1} dry weight) [15,16]; (2) bioaccumulation coefficient (BC), the ratio of metal concentration in the plant to medium (>1.0) [16]; (3) transport factor from metal concentration (TF), the quotient of metal concentration in shoots to roots (>1.0), which is used to measure the effectiveness of the plant in transferring a metal from roots to shoots; (4) tolerance index (Ti), the hyperaccumulator should not decrease significantly at the concentration of the critical value, which is a key endpoint index for judging it as a hyperaccumulator [14]. It is obvious that the former three factors were calculated mainly from metal concentration in plant tissue and medium. Although the phytoextraction amount of metal was determined by both biomass production and metal concentration in plant, the biomass production of plant was ignored [17]. Consequently, the actual efficiency of plant remediation was at least partly concealed. In addition, it is well-known that metal concentration in plant tissue and the growth of plant rely greatly on the metal concentration in medium and other medium characters [18,19]. Many previous studies have focused on the cadmium accumulation and growth responses of plant in controlled experiment with relative higher cadmium concentration [6,19,20] compared with that in field condition. Accordingly, the plant with higher biomass production but relative lower metal concentration as fast-growing plant might employ the higher remediation efficiency in cadmium contaminated soil compared with the plant with lower biomass production although higher metal concentration in tis-

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Table 1
Height, basic radius and leaf area of poplar (means ± SD) in respond to different cadmium supplies in purple soil and alluvial soil.

Cadmium supplies (mg kg^{-1})	Purple soil			Alluvial soil		
	Height (cm)	Basic radius (mm)	Leaf area (m^2)	Height (cm)	Basic radius (mm)	Leaf area (m^2)
0.00	161.52 ± 26.87a	1.60 ± 0.20a	0.35 ± 0.03a	199.33 ± 1.89a	1.85 ± 0.03a	0.58 ± 0.03a
0.50	142.47 ± 12.73b	1.36 ± 0.00b	0.28 ± 0.02b	194.00 ± 7.79a	1.90 ± 0.06a	0.50 ± 0.01b
1.00	124.38 ± 2.83c	1.32 ± 0.02b	0.24 ± 0.02bc	194.33 ± 8.14a	1.88 ± 0.01a	0.50 ± 0.02b
1.50	124.09 ± 12.73c	1.26 ± 0.01c	0.21 ± 0.02c	192.00 ± 14.40a	1.86 ± 0.06a	0.47 ± 0.02b

Different letters within a column indicate the significant differences among the treatments ($P < 0.05$, $n = 5$).

sue. However, only a little information has been available on the cadmium extraction efficiency of fast-growing plants in cadmium contaminated soil [18].

Furthermore, cadmium uptake and accumulation efficiency of plants could be altered by a number of soil factors. Including others, soil cadmium speciation [21], soil pH [22], other metals [4,5] and soil fertility [23] are the factors most frequently observed to affect cadmium availability to plants. At the same time, soil characters also play crucial roles in plant growth, and subsequently in cadmium accumulation. Thereby, the use of hyperaccumulator in remedying contaminated soil should take the soil characters into consideration. However, most previous studies have carried out in a single type of soil or in the nutrient solution when defined the hyperaccumulator [6,24], which have limited the remediation application of hyperaccumulator in the contaminated field condition.

Purple soil and alluvial soil are two representative soil types in Sichuan basin, western China [25]. Due to the soil background and human activities, these soils have been contaminated by cadmium in many areas [26,27], resulting potential risk to local human health and the environment. According to model forecast by Guo et al. [28], the cadmium contamination level is increasing in this region with the increasing tendency in the global scale owing to human activities [29]. Thus, the stopping of the serious aggravating tendency and the cleanup of cadmium contaminated soils is emergent. A kind of hybrid poplar (*Populus deltoids* × *Populus nigra*) has been acknowledged as a hardy, perennial, fast growing, easily propagated, highly tolerance, and widely adaptation plant in both purple soil and alluvial soil in this region [30], which could be potentially used as phytoremediation tools in the cadmium contaminated soil. However, no information is available concerning the cadmium extraction effect of fast-growing trees as poplar in these cadmium contaminated areas.

This study was conducted in a typical cadmium contaminated area of Sichuan basin, Ya'an of Sichuan province, western China. The objective was here to understand the cadmium phytoextraction efficiency of poplar in the cadmium contaminated condition with different contamination levels using a pot experiment in the field. It was hypothesized that fast-growing plant had the higher remedying efficiency compared with the known slow-growing hyperaccumulators. It was also predicted that the phytoremediation of poplar could be used in both cadmium contaminated purple soil and alluvial soil.

2. Materials and methods

2.1. Field site and soil characterization

The field pot-culture experiment was located at the state key laboratory of forestry eco-engineering in Sichuan Agricultural University (102°59′E, 29°58′N, a.s.l. 620 m). It belongs to the subtropical zone with a warm and moist climate, 16 °C average annual temperature, 1732 mm average annual precipitation, 838 mm average transpiration, and 294 days frostless duration per year [31]. Samples of purple soil and alluvial soil were collected from the surface (0–20 cm) in a field near the university and near the Qingyi River, respectively. The sampled purple soil and alluvial soil were measured with 4.85 and 8.02 for pH, 20.03 and 8.73 g kg^{-1} for organic carbon, 1.28 and 0.32 g kg^{-1} for total nitrogen, 0.45 and 0.62 g kg^{-1} for total phosphorus, 3.05 and 3.59 g kg^{-1} for total potassium, 2.95 and 2.87 g kg^{-1} for cadmium, respectively.

2.2. Experimental design

The porcelain pots with 25 cm height and 36 cm in diameter were used in this experiment. Air-dried soil of 20 kg was sieved by a 4-mm plastic sieve, and then placed into each pot after mixed with Cd solution. Based on the investigation in the cadmium contaminated soil of this region and the model forecast by Guo et al. [28], the content of soil cadmium in this region would be gradually increased. As the result of it, four levels of cadmium (0.00, 0.50, 1.00, 1.50 mg Cd kg^{-1} dry soil) were supplied as $CdCl_2 \cdot 2.5H_2O$ to simulate the future application. Thus, the cadmium content was 2.95, 3.33, 3.81 and 4.35 g kg^{-1} in purple soil, and 2.87, 3.23, 3.70 and 4.27 g kg^{-1} in alluvial soil, respectively. Meanwhile, 6 g urea and 3 g KH_2PO_4 were applied in each pot to avoid nutrient limitation. 1-year-old and 10-cm cuttings of poplar were collected from a non-contaminated field in the key laboratory of forestry eco-engineering in Sichuan Agricultural University before plant germination. The cuttings were transferred directly to porcelain pots on March 16, 2008, and the average dry mass of the used cutting was determined. The plants were grown outdoors to simulate field condition. Each treatment was arranged in ten replicates to ensure the sampling at the end of the experiment. The experiment was terminated just after completely leaf fell on November 2, 2008. The total growth time was 231 days.

2.3. Measurements and calculations

The fell leaves were collected every month during the experiment, and their area was determined immediately by a portable leaf-area recorder (CI-203). Their biomass was determined after oven-dried at least 36 h at 70 °C. The total area and biomass of leaf were the sum of the leaf area and leaf biomass in every month. Five plants with similar growth character were harvested in each treatment when experiment terminated, and their height and basic diameter were recorded. The harvested plants were rinsed with tap water, and the roots were immersed in 20 mM Na_2-EDTA for 15 min to remove cadmium adhered to the root surface [32,33], and then the whole plants were rinsed with deionized water. The roots and shoots were divided and dried in an oven for at least 48 h at 70 °C to constant weight for biomass determination. Average dry mass of the cuttings at the beginning was subtracted from final shoot dry mass for shoot biomass determination. Total plant biomass was the sum of the leaf, root and shoot. The oven-dried samples were ground finely by a porcelain mortar for cadmium analysis.

The powders of samples were digested with a concentrated acid mixture of HNO_3–$HClO_4$ (3:1, v/v) and heated at 160 °C for 5 h. After cooling, the extract was diluted, filtered, and made up to 25 ml with

Table 2
Poplar biomass and its components (means ± SD) in respond to different cadmium supplies in purple soil and alluvial soil.

	Cadmium supply (mg kg^{-1})	Leaf biomass (g)	Shoot biomass (g)	Root biomass (g)	Total (g)
Purple soil	0.00	18.08 ± 2.28a	33.32 ± 8.36a	69.42 ± 16.59a	120.82 ± 3.19a
	0.50	20.23 ± 5.93ab	25.54 ± 7.31a	52.37 ± 14.30ab	98.14 ± 26.32b
	1.00	21.67 ± 2.44b	27.49 ± 7.26a	61.62 ± 3.67a	110.77 ± 12.68b
	1.50	22.00 ± 2.87b	28.58 ± 5.95a	45.83 ± 8.41b	96.41 ± 17.03b
Alluvial soil	0.00	41.72 ± 1.31a	85.22 ± 2.17a	77.17 ± 12.40a	204.11 ± 15.69a
	0.50	40.75 ± 4.74ab	82.57 ± 10.01a	68.80 ± 6.87a	192.11 ± 21.33ab
	1.00	35.02 ± 4.61b	77.80 ± 5.38a	67.85 ± 12.00a	180.67 ± 18.54b
	1.50	42.69 ± 3.79a	80.85 ± 7.39a	79.00 ± 8.64a	202.54 ± 19.12a

Different letters within a column indicate the significant differences among the treatments ($P < 0.05$, $n = 5$).

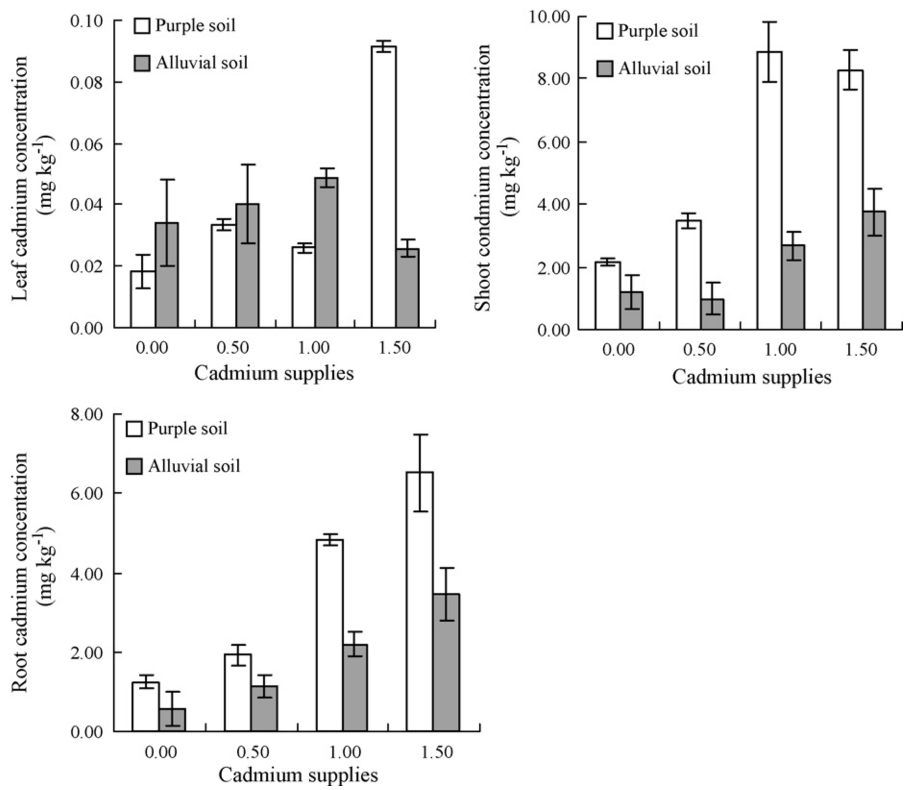

Fig. 1. Cadmium concentrations of leaf, shoot and root in respond to different cadmium supplies in purple soil and alluvial soil. Bars indicate SD, $n = 5$.

Table 3
Poplar cadmium accumulation and its components (means ± SD) in respond to different cadmium supplies in purple soil and alluvial soil.

	Cadmium supply (mg kg^{-1})	Cadmium accumulation (μg plant^{-1})			
		Leaf	Shoot	Root	Total
Purple soil	0.00	0.33 ± 0.01a	71.87 ± 1.99a	86.75 ± 3.06a	158.95 ± 1.05a
	0.50	0.68 ± 0.11b	89.21 ± 23.73b	100.61 ± 3.60b	190.50 ± 27.44b
	1.00	0.56 ± 0.09c	243.90 ± 6.84c	297.52 ± 26.15c	541.98 ± 19.22c
	1.50	2.01 ± 0.28d	237.01 ± 27.40c	299.25 ± 8.19c	538.27 ± 35.87c
Alluvial soil	0.00	1.43 ± 0.49a	103.03 ± 53.23a	43.18 ± 5.38a	147.63 ± 47.62a
	0.50	1.65 ± 0.60a	81.36 ± 5.07b	78.17 ± 8.88b	161.18 ± 5.09b
	1.00	1.71 ± 0.14a	208.24 ± 29.30c	148.42 ± 37.82c	358.37 ± 65.71c
	1.50	1.10 ± 0.11b	303.00 ± 42.46c	272.65 ± 57.59d	576.75 ± 40.55d

Different letters within a column indicate the significant differences among the treatments ($P < 0.05$, $n = 5$).

5% HNO_3 [20]. The cadmium concentration of the extract was determined by Inductive Coupled Plasma Atomic Emission Spectroscopy (ICP-AES IRIS Intrepid II XSP) (Thermo Electron Company, USA). The analysis was carried out in triplicate.

The bioaccumulation coefficient (BC), or enrich factor, was described as Liu et al. [33] and Tanhan et al. [34]: BC = the cadmium concentration in the whole plant/the cadmium concentration in the soil.

The translocation factor (TF) indicated the ability of plants to translocate cadmium from the roots to the shoots [35]. TF from cadmium concentration was calculated as Liu et al. [33]: TF = the cadmium concentration in shoots/the cadmium concentration in roots; TF from cadmium accumulation (TF′) = the cadmium accumulation in shoots/the cadmium accumulation in roots.

The tolerance index (Ti) was calculated to measure the ability of the plant to grow in the presence of a given concentration of

Table 4
Bioaccumulation coefficient (BC), transport factor from concentration (TF) and from accumulation (TF′), and tolerance index (Ti) of poplar (means ± SD) in respond to different cadmium supplies in purple soil and alluvial soil.

	Cadmium supply (mg kg^{-1})	BC	TF	TF′	Ti
Purple soil	0.00	0.45 ± 0.11a	1.73 ± 0.59a	0.83 ± 0.03a	1.00 ± 0.00a
	0.50	0.58 ± 0.12b	1.82 ± 0.91a	0.87 ± 0.27a	0.81 ± 0.22ab
	1.00	1.28 ± 0.24c	1.84 ± 0.13a	0.82 ± 0.03a	0.92 ± 0.10a
	1.50	1.28 ± 0.25c	1.27 ± 0.73b	0.79 ± 0.12a	0.80 ± 0.14b
Alluvial soil	0.00	0.25 ± 0.06a	2.16 ± 0.54a	2.39 ± 0.52a	1.00 ± 0.00a
	0.50	0.26 ± 0.07a	0.87 ± 0.39b	1.04 ± 0.06b	0.94 ± 0.10a
	1.00	0.54 ± 0.06b	1.22 ± 0.27c	1.40 ± 0.14c	0.89 ± 0.19a
	1.50	0.67 ± 0.10c	1.09 ± 0.16c	1.11 ± 0.14b	0.99 ± 0.09a

Different letters within a column indicate the significant differences among the treatments ($P < 0.05$, $n = 5$).

metal [2,36], calculated as: Ti = dry weight of the plants growing in cadmium supplies/dry weight of the plants growing in control.

2.4. Statistical analysis

Differences between treatments were tested by ANOVA followed by LSD test using the SPSS (Standard released version 11.5 for Windows, SPSS Inc., IL, USA) software package.

3. Results

3.1. Growth responses

A decreased tendency was observed in the height, basic radius and leaf area of poplar with the increase of cadmium concentration in both purple soil and alluvial soil, but the decreased tendency was more obvious in purple soil compared with that in alluvial soil (Table 1). The height, basic radius and leaf areas of poplar were lower in purple soil than those in alluvial soil.

Cadmium supplies also decreased shoot, root and total biomass of poplar, but increased leaf biomass in purple soil (Table 2). Alternatively, only cadmium supply with 1.00 mg kg^{-1} significantly ($P < 0.05$) decreased total biomass and leaf biomass of poplar, whereas the other treatments had insignificantly ($P > 0.05$) effects on poplar biomass and its components in alluvial soil.

3.2. Cadmium accumulation

Cadmium concentration in poplar components showed the same order (shoot > root > leaf) in both purple soil and alluvial soil (Fig. 1). However, cadmium concentrations in shoot and root were increased with the increase of cadmium supply in both purple soil and alluvial soil, but cadmium concentrations in leaf had no significant ($P > 0.05$) changes. In addition, cadmium concentrations in both shoot and root were higher in purple soil compared with those in alluvial soil.

Cadmium accumulation in poplar and its components increased with the increase of cadmium concentration in both soils (Table 3). Cadmium accumulation in plant components showed the order as root > shoot > leaf regardless of cadmium supplies in purple soil, but which showed the order as shoot > root > leaf in alluvial soil. Poplar cadmium accumulation was higher in purple soil than that in alluvial soil when treated with relative lower cadmium supplies (<1.00 mg kg^{-1}), but shoot and total cadmium accumulations were higher in alluvial soil compared with those in purple soil at the treatment with 1.50 mg kg^{-1} cadmium supply.

Additionally, BC of poplar was increased with the increase of cadmium concentration in both purple soil and alluvial soil, whereas BC was higher in purple soil than that in alluvial soil (Table 4). The highest cadmium supply significantly decreased TF, TF′ and Ti of poplar in purple soil, but all of the cadmium supplies decreased TF and TF′ in alluvial soil, although cadmium supplies showed few effects on Ti in alluvial soil. Although TF of poplar was higher in purple soil than that in alluvial soil when treated with cadmium supplies, TF′ was higher in alluvial soil than that in purple soil regardless of cadmium supplies. Ti of poplar was lower in purple soil compared with that in alluvial soil at the treatments with 0.50 and 1.50 mg kg^{-1} cadmium supplies.

4. Discussion

Previous studies have documented that plants can suffer toxic effects when the tissue cadmium concentration reaches 3–10 mg kg^{-1} dry weight [19,37]. The results of the present study indicated that the poplar has received the toxic effects from cadmium in these cadmium contaminated soils, because cadmium in poplar shoot was 8.29 and 3.75 mg kg^{-1} dry weight in both purple soil and alluvial soil (Fig. 1), respectively. Nonetheless, the poplar could still adapt to the contaminated soils with only a little decrease of morphological growth and biomass production as the cadmium contamination level increased. In addition, the poplar showed efficient cadmium extraction efficiency with the highest of 541.98 ± 19.22 μg cadmium plant^{-1} and 576.75 ± 40.55 μg cadmium plant^{-1} for purple soil and alluvial soil after one growing period, respectively. These findings implied that the examined poplar tree could be an efficient phytoextraction plant in these cadmium contaminated soils.

Adaptive responses in morphology and biomass production are the primary tolerance indicators by which the poplar can cope with the cadmium contaminated environment. According to the current results, although the reduced tendency of poplar growth was observed with the increase of cadmium concentration in both purple soil and alluvial soil, more significant reduced responses of poplar growth were observed in purple soil in respond to the increase of cadmium concentration, which suggested that poplar could have higher tolerance ability to cadmium in alluvial soil than that in purple soil. Including other soil characters, soil pH is essentially different between purple soil and alluvial soil. Higher metal activity and biology availability of cadmium have been widely documented under acid condition than that under alkaline condition [38]. Consequently, the toxicity of cadmium might be aggravated in acid condition in comparison with that in alkaline condition [22,39]. This is also the reason that the growth characters (height, basic radius, leaf area, biomass and its components) of poplar were lower in purple soil (pH 4.85) than those in alluvial soil (pH 8.02).

Exclusion and accumulation of metal are two main tolerance mechanisms of plants in respond to heavy metal pollution as declared by Baker [40]. Due to higher cadmium concentration in shoot compared with that in root (Fig. 1), poplar growing in cadmium contaminated purple soil and alluvial soil might employ the accumulation mechanism. This suggested that this hybrid poplar has efficiently translocation ability that transferred cadmium from root to shoot. Cadmium concentration in plant tissue was increased with the increase of cadmium concentration in medium, indicat-

Table 5
Comparison of Cd accumulation in some species of hyperaccumulator plants and the poplar.

Plant species	Biomass (g)	Cadmium accumulation (μg plant^{-1})	Cadmium content in medium (mg kg^{-1})	Reference
Arachis hypogaea	0.85	56.00	50	[19]
Arabidopsis halleri	0.50	84.00	12.5	[11]
Atriplex halimus	0.12	1.13	50	[6]
Bidens pilosa	5.00	291.20	5	[14]
Cannabis sativa	0.19	8.50	50	[19]
Echinochloa polystachya	15.96	310.00	10	[18]
Iris iactea var. chinensis	0.40	100.20	10	[20]
Iris tectorum	0.30	50.10	10	[20]
Linum usitatissimum	0.04	2.40	50	[19]
Lonicera japonica	4.06	494.99	5	[33]
Populus deltoids × *Populus nigra*	202.54	576.75	4.28	This study
Solanum nigrum	0.46	46	10	[24]
Solonum nelongena	0.22	11	10	[24]

ing poplar has potential cadmium phytoextraction ability, which agreed with many results from other plants [14,20]. Due to the higher cadmium activity in acid condition [38], cadmium concentrations of shoot and root were higher when poplar growing in purple soil compared with those in alluvial soil. Moreover, senesced leaves have relative lower cadmium concentration than other plant tissues, implying that cadmium could be reabsorbed by plant before leaf fall. This observation warrants further study of cadmium translocation.

Generally, cadmium accumulation was determined by its concentration in plant tissue and biomass production. Increased cadmium accumulation was found with the increase of the cadmium concentration in this study could be explained by two sides. On the one hand, poplar growth as morphological characters and biomass production was not sharply decreased with the increase of cadmium concentration in both purple soil and alluvial soil (Tables 1 and 2). On the other hand, cadmium concentrations of poplar tissue were significantly increased with the increase of the cadmium concentration in both soil mediums (Fig. 1). The results also imply that the poplar is an interesting candidate plants for phytoremediation application in these cadmium contaminated soils.

Many previous studies have suggested that four indicators (the threshold value of cadmium, BC, TF and Ti) could be used to define a cadmium hyperaccumulator [14–16]. The threshold value of cadmium here was not examined, the results from the BC, TF, TF′ and Ti were inconsistent between poplar growing in purple soil and in alluvial soil. Even so, the synthesized analysis implied that poplar could be a cadmium hyperaccumulator in both purple soil and alluvial soil with Ti > 0.8, TF > 1.0, and BC > 1.0 in purple soil, and increased with the increase of cadmium concentration in alluvial soil. However, phytoremediation efficiency depends on plant biomass and the ability of metal to be translocated to the shoots [19]. Thus, transport factor (TF′) from cadmium accumulation could be a better parameter in indicating metal transport efficiency than TF. The results indicated that poplar could transport more cadmium from root to shoot in alluvial soil, implying that the poplar might display relative higher phytoremediation efficiency in alluvial soil compared with that in purple soil. The results from Ti could also draw the similar conclusion that Ti was not significantly decreased with the increase of cadmium concentration in alluvial soil.

An ideal plant for phytoextraction application should have high metal tolerance and high accumulation capacity in its tissues (especially in harvestable parts) [19,41]. However, a lot of studies have focused on the metal tolerance and the accumulated concentration in hyperaccumulator [6,18,20], but ignored the biomass production of the plant, which limited the actual phytoextraction application in contaminated field. Fast-growing plant as the examined poplar exhibited higher phytoextraction efficiency with higher biomass production but relative lower cadmium concentration in comparison with some species of hyperaccumulator plants (Table 5). The results at least partly demonstrated the hypothesis that fast-growing plant had the higher remedying efficiency compared with the other slow-growing hyperaccumulators. Nevertheless, the results that the plant growing in purple soil accumulated more cadmium with lower biomass but higher cadmium concentration in tissues compared with the poplar growing in alluvial soil. This suggested that cadmium concentration in tissue is also the important factors determining phytoremediation efficiency.

In conclusion, the poplar had potential phytoremediation application as a good phytoextractor in both cadmium contaminated purple soil and alluvial soil with high tolerance ability and cadmium accumulation. Compared with the poplar growing in purple soil, the poplar growing in alluvial soil had higher phytoextraction ability with higher biomass production at higher soil cadmium concentration. It should be also noted that the soil characters play important roles in remedying efficiency of plant.

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