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Phytoremediation Potential of Populus Alba and Morus alba for Cadmium, Chromuim and Nickel Absorption from Polluted Soil

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ABSTRACT: Metal pollution has become one of the most serious environmental problems resulting from human activity. Phytoremediation utilizes plants to uptake contaminants and can potentially be used to remediate metal-contaminated sites. The present study investigates heavy metal uptake (Cd, Cr, and Ni) from soil by different organs of *Populus alba* and *Morus alba.* For this purpose, Cd (40, 80, and 160 mg/kg), Cr (60, 120, and 240 mg/kg) and Ni (120, 240, and 480 mg/kg) were added to the soil in pot experiments over the course of a growing season in open air. The total concentration of these metals was measured in the roots, stems, green leaves, fallen leaves, and the corresponding soil. Our results show that the highest accumulation of all studied metals was found in the leaves. Furthermore, the fallen leaves had higher concentrations of Cd and Cr in *P. alba* and Cr and Ni in *M. alba* when compared to the green leaves. In the two species, Cd and Ni did not transport from the leaves to the roots and stems, or vice versa, in the fall season, but Cr was transported from the roots and stems to the leaves in the 240 and 480 mg/kg treatments.In addition, the determination of a bioconcentration factor and a translocation factor showed that *P. alba* and *M. alba* were suitable for phytoextraction of Cd and Ni in all treatments respectively; however, none of the plants was suitable for phytostabilization.

Key words: Heavy metal, Bioconcentration, Phytostabilization, Phytoextraction, Phytoremediation

INTRODUCTION

The term "heavy metal" refers to any metallic element with an atomic density greater than 6 g/cm^3. These metals are ubiquitous, highly persistent and non-biodegradable. (Torresday *et al*., 2005). The concentration of heavy metals increases as a result of the natural weathering of rocks, the disposal of waste, and the use of fertilizers, pesticides, and industrial effluent that can contaminate the soil (Abdullahi *et al*., 2007 ; Abdullahi *et al*.,2009). Although traditional methods for cleaning contaminated soil, such as ion-exchange and ultra-filtration, have proven to be efficient, they may not be economically feasible because of their relatively high cost, particularly when used for the removal of heavy metals at low concentrations (<100 mg/L) (sangi *et al*., 2007; Torresday *et al*., 2005).

Phytoremediation, or the use of green plants to extract, sequester, and detoxify pollutants, has shown considerable promise as a low-cost technique and has received much attention in recent years. Additionally, this method can be accomplished in situ, it is environmentally friendly and the soil can be utilized immediately after treatment (Pulford *et al*., 2001). Phytoremediation of heavy metals can be divided into three groups: phytoextraction, which is the use of plants to remove heavy metals from soil by concentrating the metal in aboveground plant organs

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(Sebastini *et al*., 2004); phytostabilization, in which the plants are used to stabilize the soil surface by retaining the metals in the roots [Marques *et al*., 2008]; and rhizofiltration, which is the use of plant roots to ab/adsorb metals from water and aqueous waste streams (Erakhrumen and Agbontalor, 2007).

The uptake and accumulation of pollutants can vary from plant to plant and among species within a genus. The proper selection of plant species for phytoremediation plays an important role in the development of remediation methods, especially for low or medium polluted soil (Fischerova *et al*., 2005). Fast-growing tree species could be suitable to treat heavy metal-polluted soil and to produce economically valuable non-food biomass that is exploitable for energy production. These trees, such as Poplar, have additional advantages, including high biomass production, rapid growth, easy propagation and deep root growth, which make them possible candidates for application in phytoremediation approaches (Castiglion *et al*., 2006; Sebastini *et al*., 2004).

In this paper, we consider the mulberry plant (*Morus alba*) and poplar (*Populous alba*) because both have a relatively high environmental adaptability; they are inexpensive and easily found in Iran. There is also no risk of livestock poisoning because they are not a food source for livestock.

The responses of these plants to heavy metals (especially for Cd and Zn) have been investigated for *Populous alba* (Robinson *et al*., 2000; Madejon *et al*., 2004; Borghi *et al*., 2007; Dominguez *et al*., 2007; Robinson *et al*., 2007; Dominguez *et al*., 2008) and less so for *Morus alba* (Prince *et al*., 2000; Wang, 2002; Wang *et al*., 2003; Ashfagh *et al*., 2009).

The main goal of this study was to determine the accumulation of heavy metals, such as Cd, Cr and Ni in different sections of studied plant, including the roots, stems, green leaves and fallen leaves grown in contaminated soil.

The detailed objectives of this screening were as follows:

- To assess the transport trend of the studied elements from the leaves to other organs in the fall season.
- To introduce suitable plant species for phytoextraction and phytoremediation based on the bioconcentration factor (BCF) and translocation factor (TF) indicators.

MATERIALS & METHODS

The two species, *Morus alba* and *Populus alba*, were planted in pots under natural conditions. This experiment was performed using one-year seedlings between February and December 2009. No significant differences were observed between trees of the same age in terms of their structure (i.e., they had identical diameters along the entire length of nodes and had similar root systems), and at the onset of this experiment, they had no foliage, and their lengths ranged from 80±5 cm for *M. alba* to 110±5 cm for *P. alba*.

The seedlings were catched from the Alborz farm nursery in Karaj, Iran, and the pots were filled with 10 kg soil derived from the same place. This soil was mixed well with sand and animal fertilizer manure in a 3:1:1 (v/v/v) ratio before being placed in the pots. Five samples of this soil were taken before planting and analyzed for physico-chemical characteristics.

The pots were placed outdoors with tap water irrigation (three times in a week) and were partially covered to protect them from rainfall. Two months after planting and after the leaves had budded, 40, 80, and 160 mg/kg of Cd; 60, 120, and 240 mg/kg of Cr; and 120, 240, and 480 mg/kg of Ni in the forms of $CdN_2O_6.4H_2O$, $CrN_3O_9.9H_2O$ and $NiN_2O_6.6H_2O$, respectively, were added to the pots over a three week period (1/3 of the total solution each week instead of one irrigation turn).This treatments amounts came from literature review such as Prince *et al.*, 2000; Sebastiani *et al.*, 2004; Zacchini *et al.*, 2008 and normal range of this metals in Kabata Pendias, 1985. Each pot was treated with one metal to prevent interaction effects. One control (with no treatment) was also performed.

The first sampling of leaves was conducted in August. At this time, the green leaves were collected randomly from different parts of the tree crown and were bulked into a homogenous sample. During the falling time of the leaves in November, the second sampling was performed. The yellow leaves from each tree stand that were ready to fall were collected in the manner stated above. All leaf samples were placed in polythene bags, labeled and taken to the laboratory for the next analysis.

For each tree, one soil sample was taken at 0-25 cm (root zoon) at the time when all leaves had fallen. At the end of September, the entire structures of all of the plants were dug out, and the Cd, Cr, and Ni contents of the different parts were determined.

Soil samples from each pot were homogenized and air dried in an oven at 30°C overnight to a constant weight and were then passed through a 2 mm sieve [Uba *et al*., 2009] before analysis. Approximately 0.25 g of soil sample was digested with 6 mL of H_2So_4:15 mL H_2O_2 in a closed Digesdahl system (Hach Co., USA) at 440°C to obtain a total extraction of heavy metals. The samples were then filtered and diluted with deionized water to 50 mL (Brainina *et al*.,2004). The total concentrations of Cd, Cr, and Ni were determined by ICP-OEC (Inductively Coupled Plasma Emission Spectroscopy, GBC, Australia).

After the plants were harvested, they were washed with tap water to remove any residual soil or dust and separated into roots and stems. All of the plant parts (green leaves, stems, roots and fallen leaves) were rinsed with distilled water to remove surface contamination, oven dried at 70°C for 48 h (to a constant weight, and the dry weight was recorded before grinding), and grinded and sieved to <1 mm. The resulting sample (0.5 g) was digested using a mixture of 4 mL H_2SO_4:13 mL H_2O_2 in a closed Digesdahl system at 440°C (Hach Co., USA). Samples were filtered and diluted with deionized water to 50 mL. These final solutions were analyzed for Cd, Cr and Ni using ICP-OEC (Brainina *et al*., 2004; Unterbrunner *et al*., 2006). The bioconcentration factor (BCF) and translocation factor (TF) indicate the ability of plants to tolerate and accumulate heavy metals. These factors were calculated using the ratio of metal concentration in the plant roots to the soil (root BCF), the ratio of total metal concentration in plant shoots (stem + leaves) to the soil (shoot BCF) and the ratio of metal concentration in plant shoots to the roots (TF) (Sarawet and Rai, 2007; Zacchiini *et al*.,2008).

All chemicals used were of analytical grade (Anala R), and chemical analyses were validated by blanks (one blank for every 20 samples), duplicate samples and reference materials.

All data presented are the mean values, and measurements were taken with three independent replicates for metal concentration. The statistical analysis was performed with SPSS (v.17.0) software. One-way ANOVA was used to compare the trace element concentration in the plant structures and in the soils between treated and untreated soils. Additionally, the Games-Hawel test was used for mean comparison at a significance level of pd”0.05.

RESULTS & DISCUSSION

The main characteristics of the primary soil and heavy metals (before treating) are shown in Table 1. The soil in the pots had a loamy texture, with an average EC and CEC of approximately 12 ms/m and 16.5 meq/100 g, respectively, and they were slightly alkaline (pH=7.5), which means the pH conditions were suitable for plant growth.

After the treatment with the heavy metals and the removal of the plants, the total concentrations of Cd, Cr, and Ni were measured. The results in Table 2 show that the total concentrations for the three heavy metals were significantly different between the treated and control soils at some of the tested levels in the two species. In treated *P. alba*, the Cd concentration in treated soils was significantly different at the 80 and 160 levels compared to the control. In treated *M. alba*, the Cd concentrations in treated soils were significantly different at the 40 and 160 levels compared to the control for Cd, and at the 240 and 480 levels compared with the control for Ni. Furthermore, there were no significant differences between Ni and Cr concentrations in the treated soil of *P. alba* and no difference in the Cr concentration in the treated soil of *M. alba* compared to the control.

Table. 1 Primary soil characteristics

Characteristics	value
pH	7.5
EC (ms/m)	1.2
CEC (meq/100gr)	16.5
Texture	Loam
O.C%	1.2
Total N%	0.15
P (ppm)	9.8
K (ppm)	340

Values are mean (n= 5)

Because the sampling times were different for different organs (green leaves in August and fallen leaves, roots and stems in December), a comparison between heavy metal uptake was conducted in organs that had simultaneous sampling times (roots, stems and yellow or fallen leaves). Therefore, the uptake amounts in green leaves were only mentioned to analyze plant interactions with the heavy metals in the fall season.

In plants, heavy metals can play different roles that can be roughly divided into the following: (a) essential (i.e., Zn, Cu, and Ni), which are required for a variety of metabolic processes; and (b) non-essential (i.e., Cr and Cd). However, Cr (III) is an essential element at low levels, as seen in a few references such as Sahmone *et al*., 2008. Independent from their biological function, both essential and non-essential heavy metals can be toxic above a certain threshold (Sebastini *et al*., 2004; McGee *et al*., 2006).

Table2. Total heavy metals concentrations in soil

Element	Treatments (mg/kg)	Populus alba	Morus alba
Cd	0 (control)	3.60 ± 0.34 c	3.70 ± 0.20 c
	40	6.58 ± 0.96 ac	7.24 ± 0.13 a
	80	9.84 ± 1.24 a	8.65 ± 1.71 ac
	160	18.58 ± 0.39 b	16.17 ± 1.66 b
Cr	0 (control)	40.87 ± 0.85 ab	35.41 ± 4.66 a
	60	64.42 ± 1.56 ab	38.55 ± 3.46 a
	120	43.73 ± 4.06 a	38.98 ± 2.95 a
	240	55.38 ± 4.64 b	51.11 ± 5.68 a
Ni	0 (control)	45.89 ± 10.50 a	38.73 ± 5.36 c
	120	111.14 ± 9.20 a	109.62 ± 8.75 ac
	240	24.91 ± 2.54 a	25.96 ± 4.65 a
	480	22.44 ± 3.72 a	57.54 ± 3.52 b

Values are mean ± standard deviation (n=3), Units are mg/kg. Means in columns fallowed by different letters (a-c) are significantly different at *P*=0.05 level (Games-Hawel test)

Based on this information, there are three different paradigms related to the falling time in plants: (a) the movement of metals from the leaves into the stems and roots (essential elements, such as K) to prevent their loss in the fall, (b) the movement of metals from the stems and roots into the leaves (i.e., Ca), and (c) the loss of the same amount of metals in the fall that were taken up by green leaves (Hassanzadeh, 2008).

The highest metal concentrations among treated *P. alba* samples were seen in fallen leaves for Cd (13.97 mg/kg at level 80), Cr (15.39 mg/kg at level 240) and in green leaves for Ni (85.54 mg/kg at level 120) (fig 1).These findings coincide with the results of other studies that described a higher concentration of Cd in poplar leaves than in other organs (Fischerova *et al.*, 2005; Dominguez *et al.*, 2007; Martens *et al.*, 2007); but in contrast with Pulford *et al.*, 2001 who found that the roots contained the highest level of Cr in *P. euroamericana* and *P. trichocarpa*. Moreover, Golovatyi *et al.*, 1999 have shown that Cr distribution in crops is stable and does not depend on soil properties and concentrations of this element; the maximum quantity of Cr was always contained in the roots, and the lowest concentrations were found in the vegetative and reproductive organs. This finding was in contrast with our results too.

The fallen leaves in treated *P. alba* contained, on average, 2.5 and 3.2 times the amount of Cd, 5.5 and 28.9 times more Cr and 4.5 and 4.8 times more Ni than the roots and stems, respectively. There is evidence in the literature that poplar leaves typically have higher metal concentrations than the stems or roots, particularly for Cd and Zn (Robinson *et al.*, 2000; McGee *et al.*, 2006).

Fig. 1 illustrates the rates of accumulation of Cd, Cr, and Ni in various organs of *P. alba*.

Based on these results (Fig. 1a), in the control *P. alba* and in those treated with 40, 80 and 160 mg/kg, there was no significant difference between the Cd uptake rates in green and fallen leaves. The reason for this is that the green leaves retained their accumulated Cd until the fall season. Therefore, the accumulated Cd was not transported to the stem and root. The difference between these three doses was that there was a significant difference between the accumulated Cd in yellow leaves when compared to the roots in the 160 mg/kg treatment, while in the 40 and 80 mg/kg treatments, the amount of accumulated Cd in the yellow leaves showed no significant difference in comparison to the stems and roots.

In *P. alba*, there was no significant difference in the amount of Cr accumulation between the fallen leaves and the green leaves in the control plant (Fig. 1b).However, there was a difference when comparing the stem and root concentrations, in which the amount of Cr in the yellow leaves was higher than that found in the stems and roots. In the 60 mg/kg treatment of Cr, there was a significant difference between the roots and stems, with higher amounts in the roots. However, the trend of Cr uptake in the 120 and 240 mg/kg treatments differed from the control and 60 mg/kg doses, and the trend was the same when compared with each other. In both treatments, the largest content of Cr was found in the fallen leaves, which was significantly different when compared to the green leaves. This revealed that in addition to the accumulated Cr in green leaves, Cr was also transported to the yellow leaves through the roots and stems. Another possibility is that the difference in time affected the high uptake of Cr in yellow leaves in comparison to the green leaves because, in this study, the sampling time of the yellow leaves was three months later than that of the green leaves. However, because the maximum metabolic interactions of the plant occurred in August and leaf activity declined by forming callus during this time, this explanation is less probable. In both of these treatments, Cr transportation from the roots and stems to the fallen leaves did not result in a significant difference in the amounts of this element seen in the root and stem.

In treated *M. alba*, the highest values for Cr (6.25 mg/kg in level 60) and Ni (110.18 mg/kg in level 120) were found in the fallen leaves, while Cd was highest in the green leaves (4.60 mg/kg in level 40) (fig. 2). These results are in contrast with Wang, 2002 and Prince, 2000 who showed that Cd in *M. alba* accumulates more in roots, with limited transport to the leaves. Only Zn was found to accumulate in the leaves of *M. alba* in previous studies (Ashfagh *et al*., 2009). Also, fallen leaves values in treated *M. alba* reached to 1.9 and 2 times Cd, 6.8 and 3.3 times Cr and 11.1 and 9 times Ni more than the roots and stems, respectively.
Fig. 2 illustrates the concentrated amount of Cd, Cr and Ni in different organs of *M. alba*.

As can be seen in Fig. 2a, in the control *M. alba*, the Cd content in the yellow leaves was significantly higher than the green leaves, roots and stems. With time, more uptake of Cd occurred in the yellow leaves in comparison to the green leaves (as discussed for the data shown in Fig. 1b). Alternatively, during the falling period of the leaves, a portion of this element entered the fallen leaves through the roots and stems of the plant. Yet, time had a greater effect on the higher uptake in the yellow leaves in *M. alba* than in *P. alba* because the falling time of *P. alba* is sooner than that of *M. alba*. Additionally, Cd transportation from the roots and stems to the fallen leaves did not induce a significant difference in the amounts of this element in the root and stem. The trend of Cd concentration in the falling leaves was the same in the 40, 80, and 160 mg/kg treatments. The same amount of Cd in the green leaves was removed from the plant in the fall, with no transport from the root and stem to the yellow leaves. However, in the 40 and 80 mg/kg doses, the concentrated amount of Cd in the yellow leaves displayed significant differences when compared to the content of Cd in the stems and roots; at the 160 mg/kg dose, the Cd content in the yellow leaves was only significantly different from that found in the roots. The comparison of Cr uptake in various organs of *M. alba* (Fig. 2b) revealed that there was no significant difference between the control level and the 60 mg/kg dose among the different organs. In addition, in the 120 and 240 mg/kg treatments, the fallen leaves retained high levels of Cr that was significantly different when compared to the green leaves because of either the transport of this element from the roots and stems to the yellow leaves or the long uptake time in yellow leaves (as discussed for the data shown in Fig. 1b). In both of these treatments, Cr transportation from the root and stem to the yellow leaves showed no significant difference to the levels of Cr in the roots and stems.

The amount of Ni uptake in the fallen leaves of the control *M. alba* (Fig. 2c) followed the same trend of Cd uptake in the control soil for this plant. Also, there was no significant difference between the concentrated Ni in green and yellow leaves in the 120, 240 and 480 mg/kg treatments. The only difference among these doses was a higher concentration of Ni in the stem in comparison to the root in the 120 mg/kg treatment, and a higher accumulation of Ni in yellow leaves in comparison to the stem and root in the 480 mg/kg treatment.

The interaction of *M. alba* and *P. alba* species in the control soil and the tolerance trends to heavy metals were important because these plants were not exposed to the contamination stress and were instead located in ordinary conditions. The changes seen when comparing treatments may be attributed to a variety of items and needs to be further investigated. But, under conditions in which these species were exposed to contaminants, they displayed the same reaction to heavy metals, such as Cd, Cr and Ni. In both species, these three elements are not considered as essential elements for the plants that would be transported from the leaves to the root and stem in the fall season. Consequently, *M. alba* and *P. alba* have the tendency to remove these metals in the fall season. Both species

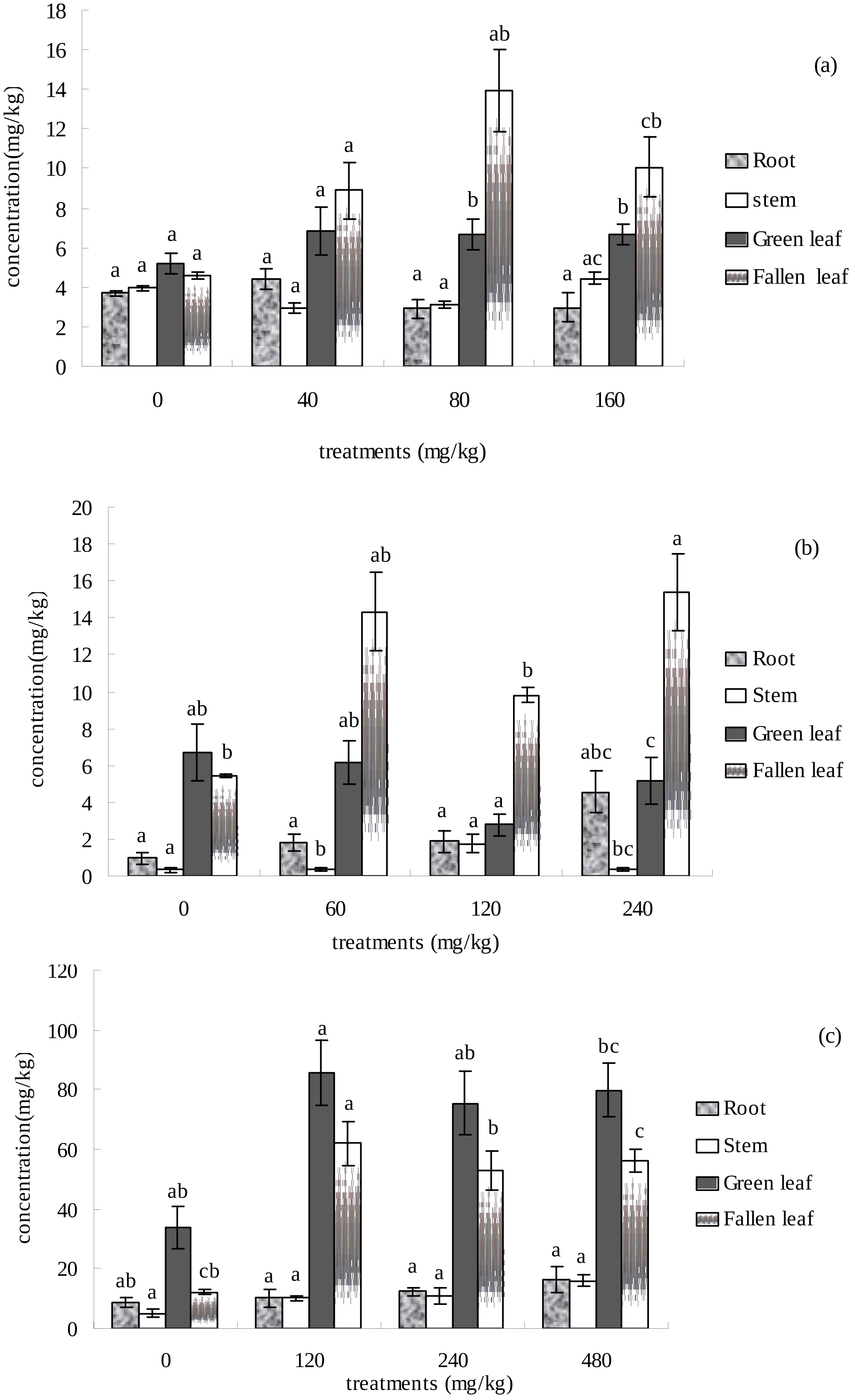

Fig. 1. A comparison among Cd (a), Cr (b), Ni (c) concentrations in different organs of *Populus alba*. Data indicate means ± SD(n=3).Different letters in the same treatment indicate significant differences ($p<0.05$)

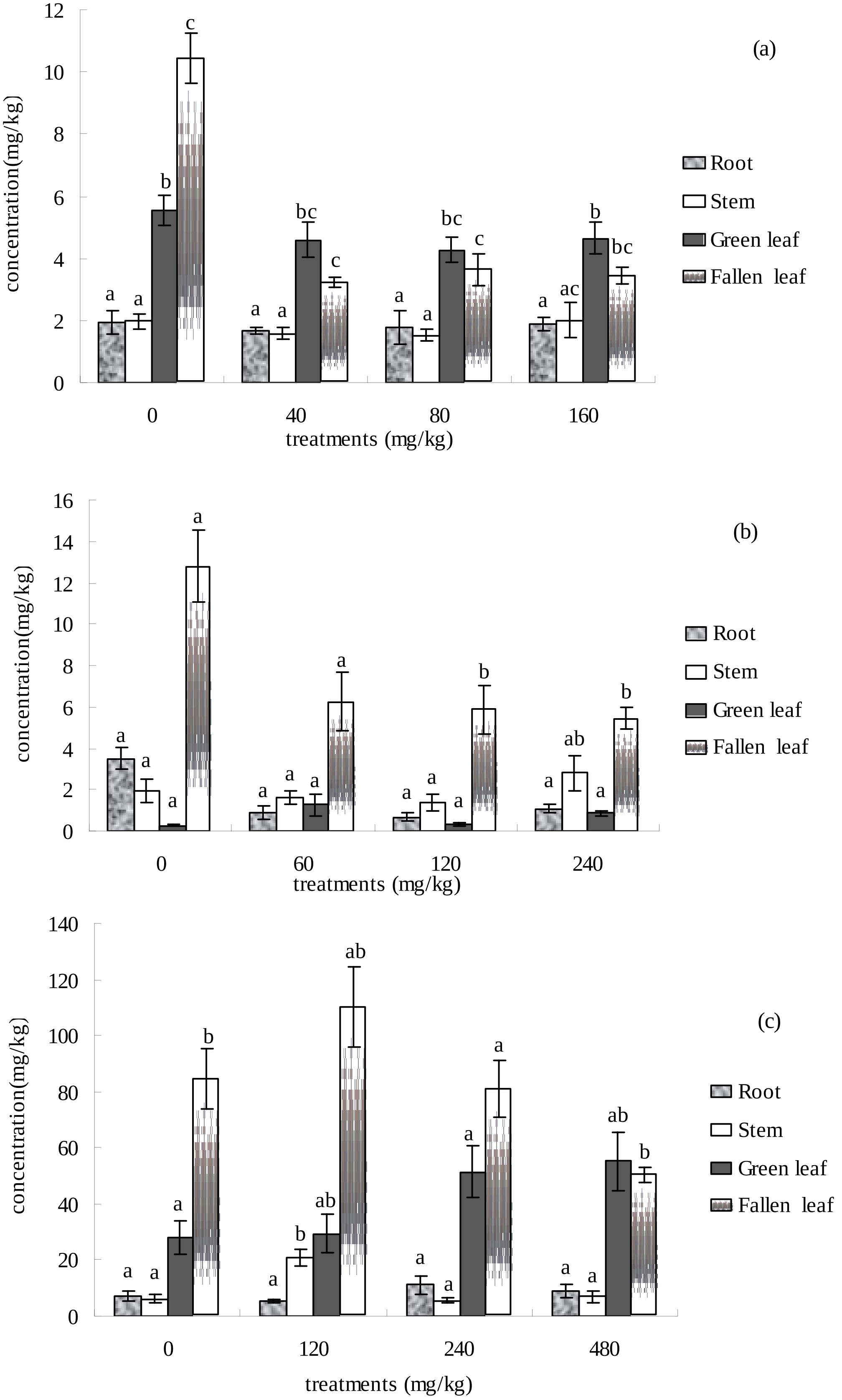

Fig. 2. A comparison among Cd (a), Cr (b), Ni (c) in different organs of *Morus alba*. Data indicate means ± SD (n=3). Different letters in the same treatment indicate significant differences ($p<0.05$)

remove the same amounts of Cd and Ni in green leaves in the fall season (there was no significant difference between yellow and green leaves in taking up these elements), which could be due to two things: the levels of treatments were not high enough to force the plants to react and transport the extra Ni and Cd from the root and stem to the leaves in the fall season, or these two plant species are highly resistant to Ni and Cd because they retain a certain amount of these heavy metals in their stems and roots. However, in these species, in addition to the Cr uptake in the green leaves for the 240 and 480 treatments, Cr was transported to the leaves from the roots and stems. This could take place because of the high range of toxicity to Cr in these species at higher concentrations. Therefore, they have tendency to reduce the maximum amount of Cr in the fall season, which is accomplished by Cr transportation from the roots and stems to the leaves of the plants.

The results presented in Table 3 show the BCFs and TFs for different heavy metals. These factors are key values that are needed to estimate a plant's potential for phytoextraction and phytostabilization. Plants exhibiting a shoot BCF >1 are suitable for phytoextraction, and plants with a root BCF >1 and TF<1 have the potential for phytostabilization (Sarawet and Rai, 2007; Zacchiini *et al*.,2008).

The results show that the two plant species at the different levels (treatments and control) had TFs>1 and root BCFs<1 for Cd, Cr and Ni; therefore, they were not suitable for phytostabilization of these metals. The TF results are similar to the findings of Zacchini *et al*., 2008 who reported high TF values (approximately 10) for Cd in *P. alba*. However, *P. alba* had a shoot BCF>1 for Cd at the 40, 80, and 160 levels (3.9, 4.7 and 2.2, respectively) and a shoot BCF>1 for Ni at the 240 and 480 levels (2.5 and 3.2, respectively) and were thus suitable for phytoextraction of Cd and Ni in these treatments. These results for Cd are in agreement with the findings of Dominguez *et al*., 2007 (BCF of the leaves was approximately 2 in *P. alba*) and Zacchini *et al*., 2008 (aerial BCFs were 2.5 and 4 for *P. alba* L. clone 6K3 and *P. alba* L. clone 14P11, respectively). Additionally, Migeon *et al*., 2009 identified three poplar hybrids that were considered Cd accumulators; these were P. *deltoides* × *P. nigra*, P. *tremula* × *P. tremuloides*, P. *trichocarpa* × *P. deltoids*, with a leaves BCF of approximately 1.39, 2.26 and 1.98, respectively.

P. alba was capable of phytoextracting in all the treatment conditions of Cd and in the high concentration of Ni added to the soil. Whether this species is able to phytoextract at higher and lower levels of Cd in the soil and concentrations higher than 480 mg/kg Ni is still unanswered. Additionally, the appropriate plant concentration threshold for Ni between the 120 and 240 mg/kg treatments needs to be determined in future investigations.

In *M. alba*, the shoot BCF for Ni at all levels (values were 2.3, 1.2, 3.3, and 1 for 0, 120, 240, and 480 mg/kg, respectively) and the shoot BCF for Cd in the control (3.3) had values greater than 1, which indicates that

Table 3. Bioconcentration (BCF) and translocation factors (TF) for Cd, Cr and Ni in *Populus alba* and *Morus alba*

		Populua alba			Morus alba		
Element	Treatments (mg/kg)	Root BCF	Shoot BCF	TF	Root BCF	Shoot BCF	TF
Cd	0 (control)	0.2	0.46	2.08	0.53	3.36	3.76
	40	0.94	3.98	3.36	0.23	0.66	3.44
	80	0.81	4.75	4.57	0.21	0.6	3.87
	160	0.45	2.2	4.31	0.12	0.34	3.48
Cr	0 (control)	0.02	0.1	4.57	0.06	0.27	5.63
	60	0.03	0.23	6.25	0.02	0.2	10.84
	120	0.04	0.26	5.95	0.02	0.19	9.12
	240	0.08	0.28	2.48	0.02	0.16	5.53
Ni	0 (control)	0.13	0.26	1.82	0.19	2.34	15.42
	120	0.09	0.65	5.8	0.05	1.2	9.41
	240	0.49	2.56	3.99	0.43	3.34	5.3
	480	0.73	3.22	3.17	0.15	1.02	3.93

this plant has the potential for phytoextraction of Ni and Cd at these levels.

M. alba is capable of phytoextracting Ni at all levels of Ni in the soil but can only extract a slight portion of Cd from the soil. Whether or not this species has the capability to phytoextract in doses higher than 480 mg/kg still needs to be investigated. Additionally, finding the appropriate plant concentration threshold for Cd between the amount of the control soil (3.70 mg/kg) and in the 40 mg/kg treatment requires further study. For Cr, none of the plants had a shoot BCF >1, indicating there is no potential in *P. alba* and *M. alba* for phytoextraction of Cr.

CONCLUSION

The aim of this study was to evaluate the potential of *P. alba* and *M. alba* to uptake Cd, Cr, and Ni from the soil. Plants differ in their uptake of heavy metals and the subsequent distribution of metals within plant organs. Comparing the plant organs in this study showed that leaves accumulate higher concentrations of Cd, Cr, and Ni than other organs. Furthermore, Cd and Cr in *P. alba* and Cr and Ni in *M. alba* had higher values in fallen leaves than green leaves. This accumulation in leaves resulted in the redistribution of metals from deeper soil layers to the topsoil, thereby increasing these elements' concentration in the soil surface via leaf decomposition, which may represent a risk to the food chain. This knowledge is important for the selection of the most appropriate technology for processing metal-enriched plant material after harvest and can help in phytoremediation management.

Phytoextraction is a phytoremediation strategy in which plants are used to uptake and accumulate heavy metals in above-ground biomass, which can be harvested and removed from the soil. This study shows that *P. alba* can accumulate Cd and Ni (in high values in soil), but *M. alba* can only accumulate Ni in their shoots; therefore, both species can be considered as an accumulator. The highest Cd and Ni values in *P. alba* leaves (13.97 and 85.54 mg/kg) were within the phototoxic range of these two metals for the leaves of plants (5-30 and 10-100 mg/kg, respectively,) but the highest amount of Ni in *M. alba* leaves (110.18 mg/kg) exceeded the phototoxic range of this element for the leaves of plants (Awofolu, 2005).

This is an additional reason why the accumulation of these metals in the shoots of *P. alba* and *M. alba* did not result in any toxicity symptoms. Also high biomass production, rapid growth, easy propagation and establishment and a developed root system make these two plants suitable for the phytoextraction of Cd and Ni from contaminated soils.

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