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Characteristics of sewage sludge and distribution of heavy metal in plants with amendment of sewage sludge

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Abstract: In order to better understand land application of sewage sludge, the characterization of heavy metals and organic pollutants were investigated in three different sewage sludges in Shanghai City, China. It was found that the total concentrations of Cd in all of sewage sludge and total concentrations of Zn in Jinshan sewage sludge, as well as those of Zn, Cu, and Ni in Taopu sludge are higher than Chinese regulation limit of pollutants for sludge to be used in agriculture. Leachability of Hg in all of studied samples and that of Cd in Taopu sewage sludge exceed the limit values of waste solid extraction standard in China legislation. Based on the characteristics for three kinds of sewage sludge, a pot experiment was conducted to investigate the effect of soil amended with Quyang sewage sludge on the accumulation of heavy metal by *Begonia semperflorens-hybr*; *Ophiopogon japonicus* (L.F.) *Ker-Gaw*; *Loropetalum chindense-var. rubrum*; *Dendranthema morifolium*; *Viola tricolor*; *Antirrhinum majus*; *Buxus radicans Sieb*; *Viburnum macrocephalum*; *Osmanthus fragrans Lour*; *Cinnamomum camphora siebold* and *Ligustrum lucidum ait.* Results showed that 8 species of plant survived in the amended soil, and moreover they flourished as well as those cultivated in the control soil. The heavy metal concentration in plants varied with species, As, Pb, Cd and Cr concentration being the highest in the four herbaceous species studied, particularly in the roots of *D. morifolium.* These plants, however, did not show accumulator of As, Pb, Cd and Cr. The highest concentration of Ni and Hg was found in the roots of *D. morifolium*, followed by the leaves of *B. semperflorens-hybr.* Levels of Zn and Cu were much higher in *D. morifolium* than in the other plant species. *D. morifolium* accumulated Ni, Hg, Cu and Zn, which may contribute to the decrease of heavy metal contents in the amended soil. Treatment with sewage sludge did not significantly affect the uptake of heavy metals by the *L. chindense-var. rubrum*, however, it significantly affected the uptake of heavy metals by *D. morifolium.*

Keywords: sewage sludge; characteristic; lixiviation test; pot experiments; land application

Introduction

Sewage sludge is an unwanted but inevitable by-product of wastewater treatment process. Due to the tremendous increases in water consumption, the amount of wastewater treated and therefore the sewage sludge produced increase rapidly. Approximately more than 4×10^6 t (dry weight) of municipal sewage sludge is produced annually in China. Management of the ever-increasing volume of sewage sludge has been one of the prime environmental issues in China. The country has yet to adopt a practical, economic and acceptable approach in managing and disposing of sewage sludge. Present practice is either co-disposal of it with solid waste at landfill sites or direct disposal in shallow trenches.

Various methods have been proposed to dispose of the sludge either in the form of liquid slurry or dried sludge. The land application technique is one of the methods being considered and is thought to be very effective and efficient. Sludge may be applied to agricultural land, forest, disturbed land or dedicated disposal sites (Murphy *et al.*, 2000; Planquart *et al.*, 1999; Bhogal *et al.*, 2003; Scancar *et al.*, 2000; Alvarez *et al.*, 2003; During *et al.*, 2003; Walker *et al.*, 2003). Along with the rapid economic development, cities in China have been developing quickly. Modern cities should be made green and beautiful by planting trees, lawn and flowers. To serve horticulture in China, sludge has been used for ornamental plants such as the rose of Sharon (*Hibiscus syricus*), Chinese rose (*R. chinensis*), Chinese hibiscus (*Hibiscus rosa-sinensis* L.), evergreen euonymus (*Euonymus japonica* L. F.), kumquat (*Fortunella hindsii*), and Manila grass (*Zoysia matrella*) (Wang, 1997). Given the fact that most wastewater treatment plants are located in cities and transportation is expensive to sludge utilization, horticultural application in cities may be a good option of sludge disposal in China. However, any form of disposal need to be controlled in order to protect human health and the environment. In addition to high levels of nutrients and organic matter, sewage sludge also typically contains a wide range of organic and inorganic contaminants (Berti and Jacobs, 1998; Jones and Alcock, 1996; Schnaak *et al.*, 1997). As a matter of fact, pollution problems may arise from toxic heavy metals that are mobilized into the soil solution and are either taken up by plants or transported in drainage waters. Harmful organic compounds in sewage sludge may potentially get into other environmental media to which humans may be exposed. Concentrations of organic contaminants in sewage sludge and toxicological implications have been documented for the United States and elsewhere (Chaney *et al.*, 1996; Wilson *et al.*, 1997; Kester *et al.*, 2005). Within China, however, so far very limited published information exists on organic contaminants in sewage sludge.

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Many wastewater treatment plants receive discharges not only from residential area but also from industry. Sludge generated at these plants contains heavy metals and organic compounds at relatively high concentrations, which may vary considerably with time and mostly depend on industrial activities (Alloway and Jackon, 1991; Baveye *et al.*, 1999). Therefore, in this study was we investigated the total concentrations of heavy metals and characterization of organic contaminant in sewage sludge from three wastewater treatment plants, as well as the heavy metal content of plants in amended soil in pot experiments. The results obtained will be helpful for the proper application of sewage sludge into agriculture soils.

1 Experimental

1.1 Sampling and sample preparation

Sewage sludges were collected at three wastewater treatment plants within Shanghai City: Quyang Plant, Taopu Plant and Jinshan Plant. A summary of different wastewaters from these factories is shown in Table 1.

Table 1 Characterization of the overall influents generated in wastewater treatment plants (2000 Year)

Wastewater treatment plant	Average flows, $\times 10^4$ m^3/d	COD_{Cr}, mg/L	BOD_5, mg/L	NH_3-N, mg/L
Quyang	4.7	504.4	228.8	35.2
Taopu	4.1	629.0	309.2	37.9
Jinshan	12.8	440.9	206.3	36.3

1.2 Determination of total concentration of heavy metal

The sewage sludges were collected immediately after dewatering by the belt filter press. The samples were air-dried, grounded to sieve through 100 mesh for further analysis. The total concentration of heave metals in sludge samples was determined by ICP-AES (Thermo Jarrell Ash) following HNO_3+$HClO_4$ (70%) +HF acidic digestion (Scancar *et al.*, 2000). The detection limit of Cd, Cr, Cu, and Zn was 0.001 mg/L, Hg 0.0001 mg/L, As 0.0002 mg/L, Ni 0.005 mg/L and Pb 0.03 mg/L, respectively. Mercury was determined using F732-S Dual Beam Mercury Analyzer. Values were expressed as mg metal/kg of dry sludge. During the sample analysis, metal standard solution was checked every ten samples for quality control. For each sample, analysis was made in triplicate and differences between replications were kept lower than 3%.

1.3 Organic compounds in sewage sludge analysis

Analytical investigations of organic contaminants in sewage sludge adopt Soxhlet extraction technique followed by chromatographic clean-up and gas chromatography mass spectrometric analysis. The extract was conducted with a mixture of organic solvents (*n*-hexane/acetone 1:1 (v:v)) for Quyang sewage sludge, 4:1(v:v) for Taopu and Jinshan sewage sludge for 16 h. After the extraction step, the extract was clean-up using anhydrous sodium sulphate and magnesium silicate column, then evaporated with a rotary evaporator until 1—2 ml under nitrogen flow to dryness. After that, the extract was re-dissolved in 2 ml of *n*-hexane/acetone 1:1 (v:v) for GC-MS injection. Gas chromatograph mass spectrometer(GC-MS) (Finnigan Voyager) was equipped with a capillary HP-5 column (30 mm ×0.25 mm, 0.25 μm). The spectrometer was used in selected ion monitoring mode-SIM. The column temperature was 70℃ for 2 min, raised to 200℃ at 10℃/min, to 300℃ at 5℃/min. The final temperature was kept for 10 min. The injection temperature was 250℃. 1—2 μl samples were manually injected.

1.4 Lixiviation test of sewage sludge

The lixiviation test for sewage sludge was conducted according to solid waste extraction procedure for toxicity of solid waste horizontal vibration method (GB5086.2-1997). The sewage sludges (100 g, less than 4 mm) are extracted with an amount of extraction fluid equal to 20 times the weight of the solid phase with bottle of polytetrafluoroethylene. The extractions were conducted on a shaker with (110±10) r/mim at room temperature for 8 h, then placed 16 h. The extracants were deionized water, hydrochloride (pH 3.0), and sodium hydroxide (pH 10.0), respectively. Following extraction, the liquid extract is separated from the solid phase by filtration through a 0.45-μm glass fiber filter, and used to analyze for As, Cd, Cr, Hg, Ni, and Pb.

1.5 Pot experiments

A sandy clean soil was collected from Nanhui County near Yangtze River. The sewage sludge sample was obtained from Quyang wastewater treatment plant in Shanghai City. The soil and sewage sludge were air-dried and mixed with 4:1 of dry weight and placed in pots, which contained 4 kg each. Four replicates were conducted for each treatment and control. The vegetations obtained from a horticultural company in Shanghai City, were acclimated for 7 d before they were planted in the pot. The plant species studied in this experiment were herbaceous: *Begonia semperflorens-hybr*; *Ophiopogon japonicus* (L.F.) *Ker-Gaw*; *Loropetalum chindense-var. rubrum*; *Dendranthema morifolium*; *Viola tricolor*; *Antirrhinum majus*; shrub: *Buxus radicans Sieb*; *Viburnum macrocephalum*; tree: *Osmanthus fragrans Lour*; *Cinnamomum camphora siebold*; *Ligustrum lucidum ait*. The pot experiment was carried out in the glasshouse (with natural light and no supplementary heating) until harvest. Different parts of the plants were analyzed after growing for 12 weeks. After being washed with deionized water, dried at 80℃ for 48 h, then milled into powder, a portion of plant material was accurately weighed and dried at 550℃ for 6 h, with adding 5 ml nitric acid thereafter. The vessels were cooled and filtered as before, and made up to 50 ml with deionized water and stored for ICP-AES analysis. The detection limit of heavy metal was the same as above. Values were expressed as mg metal/kg wet weight tissues. For each sample, analysis was made in triplicate and differences between replications were kept lower than 3%.

2 Results and discussion

2.1 Heavy metal in sewage sludge

The concentrations of heavy metals expressed on a dry mass basis in sludge are given in Table 2. China legislation (GB18918-2002) prohibits the use of sewage sludge as fertilizer in agriculture that exceeds the maximum allowed values for total concentrations of heavy metals (Table 2). European legislation is less restrictive and permits higher contents of heavy metals in sludge used for agriculture. It is evident from the data of Table 2 that total concentrations of Cd in all of the sewage sludge, Cu, Ni and Zn in Taopu sewage sludge and those of Zn in Jinshan sewage sludge exceed the limit values for basic soil in China legislation. On the basis of total heavy metal concentrations from Table 2, the Jinshan and Taopu sewage sludge are not recommended for use in agriculture, particularly due to its high total Ni, Cu, Zn and Cd concentration in Taopu sewage sludge. However, Quyang sewage sludge can be used for basic soil according to China legislation standard. The high Zn and Cu concentration in sewage sludge may not only result from industrial source but also from leaching of pipes, including those in our homes (Wang, 1997). The main nutrients, i.e. potassium, phosphorus and total nitrogen are 7.1%, 22.7%, and 24.5% in Quyang sewage sludge, respectively, slightly lower than those in the other countries.

Table 2 Metal levels in sludges and their comparisons with standard (GB18918-2002)

Element	Metal level, mg/kg dry matter			Maximum permitted content used for soil pH, mg/kg dry matter	
	Quyang	Jinshan	Taopu	pH≥6.5	pH<6.5
Cd	17.33 ± 0.29^{B}	11.9 ± 0.47^{C}	81.2 ± 1.15^{A}	20	5
As	12.73 ± 0.18^{A}	5.28 ± 0.14^{B}	5.29 ± 0.10^{B}	75	75
Cr	28.07 ± 0.64	143 ± 4.16^{B}	460 ± 6.66^{A}	1000	600
Hg	0.99 ± 0.01^{A}	0.99 ± 0.04^{A}	0.97 ± 0.04^{A}	15	5
Ni	22.17 ± 0.38^{C}	97.7 ± 1.01^{B}	523 ± 4.58^{A}	200	100
Pb	63.52 ± 2.06^{B}	89.2 ± 1.37^{A}	56.9 ± 0.62^{B}	1000	300
Cu	156.40 ± 1.97^{C}	372 ± 7.09^{B}	3873 ± 68.39^{A}	1500	800
Zn	1658 ± 23.74^{C}	3532 ± 23.64^{B}	15890 ± 97.62^{A}	3000	2000

Note: The same letter after data in the row showed no significant difference at 0.01 level based on SPSS ANOVA test

2.2 Organic pollutants in three kinds of sewage sludge

Several techniques such as Soxhlet extraction, ultrasonication extraction and liquid-liquid extraction were tried for the extraction of organics from sewage sludge. The results showed that Soxhlet is the best extraction method for three sewage sludges. The optimization of extraction solvent is *n*-hexane/acetone (1:1) for Quyang sewage sludge, *n*-hexane/acetone (4:1) for Jinshan and Taopu sewage sludges, respectively. The optimization of extraction time is 16 h. The results of GC-MS analysis at the optimization of the experimental conditions showed that there is no priority pollutant in Quyang sludge. The priority pollutants in Jinshan sludge are benzene, toluene, *p*-xylene, phenol, naphthalene and anthracene. The priority pollutants in Taopu sludge are benzene, toluene, *p*-xylene, chlorobenzene, *o*-xylene, phenol, nitrobenzene and aniline.

The results showed that the alcohols, ketones and organic acids constitute about 63% of its organic compounds in the Quyang sewage sludge, and the number of carbon atom is between 16 and 25 (Table 3). The aromatic compounds are not found in the Quyang sewage sludge, which is in agreement with characteristic of Quyang wastewater treatment plant that treats 90% wastewater from the domestic area. There are a lot of alcohols and ethers in the domestic sludge, while aldehydes, ketones and organic compounds are degradation products of ethers. There are no priority pollutants in Quyang sewage sludge. Organic compounds and alcohols are biodegradable compounds during land application of sewage sludge.

There are a lot of alcohols and organic compounds (23% and 11%, respectively) in Jinshan sewage sludge, but monocyclic aromatics and polynuclear aromatics are 31% and 13% of the total organic compounds, reflecting that the aromatics could not be biodegradated completely and absorbed into solids. In contrast to the Quyang sewage sludge, Jinshan and Taopu sewage sludge contained some priority organic pollutants, which were probably because the Jinshan sewage sludge comes from a petrochemical wastewater treatment plant as raw

Table 3 Organic pollutants in three kinds of sludge

Organic chemical group	Numbers of organic chemicals tested		
	Quyang	Jinshan	Taopu
Monocyclic aromatics	2	18	9
Polynuclear aromatic hydrocarbons (PAHs)	ND	7	ND
Heterocyclic compounds	1	ND	2
Organic acid	10	6	8
Alcohols	6	13	5
Ketones	7	4	5
Aldehydes	ND	ND	1
Ethers	ND	1	ND
Phenols	1	2	1
Aliphatics	3	ND	ND
Alkenes	4	4	6
Aromatic and alkyl amines	1	ND	4

Note: ND. not detectable

material, while Taopu sewage sludge is from complicated wastewater discharged from dyeing industry, tannery industry and pharmaceutical industry. These industrial activities would release some organic matter to the sludge. On the basis of priority pollutants in Jinshan and Taopu sewage sludge, these two kinds of sewage sludge are not recommended for use in agriculture. Organic pollutants in sewage sludge have been studied for many years in some other countries (Miege *et al.*, 2003; Alcock *et al.*, 1999; Chaney *et al.*, 1996; Molina *et al.*, 2000; Bright and Healey, 2003), but in China little work has been done in this area. As merely supplementary work to wastewater analysis, some azotic-aromatic compounds in sewage sludge from Beijing Gaobeidian sewage treatment plant were also measured. A total of 35 azotic aromatic compounds were identified and seven were quantitatively determined (Ke and Lei, 1993).

2.3 Lixiviation test of sewage sludge

It is considered that the lixiviation test allow an assessment of the pollution risks due to the solubilization of the pollutants in percolating water (Bekaert *et al.*, 2002). Results of lixiviation tests for Quyang, Jinshan and Taopu sewage sludge performed according to Standard for Hazardous Waste Lixivation Test (GB5086.2-1997) are shown in Table 4. It is evident that the fractions of heavy metal extractable in water and hydrochloride (pH=3.0) are very low for Cr, Ni, Pb and As (0.08%—1.4%) and high for Hg (17%). The concentrations of 0.308 mg/L Cd and 0.156 mg/L Hg in this fraction of Taopu sewage sludge are much higher than that allowed for waste solid extraction standard by the relevant legislation for sludge to be used in agriculture. Except for concentration of Hg, the concentrations of other heavy metals in fraction of Taopu sewage sludge are higher than those in Jinshan and Quyang sewage sludge. Taking into consideration the high mobility and potential bioavailability of heavy metals in this fraction and their total concentrations, it can be concluded that Taopu sewage sludge cannot be used in agriculture due to the potentially hazardous effects of Cd and Hg on the terrestrial environment.

Table 4 Lixiviation test of sewage sludges (mg/L)

Heavy metal	Quyang			Taopu			Jinshan			Maximum permitted content for the test
	Acid	Base	H_2O	Acid	Base	H_2O	Acid	Base	H_2O	
As	0.10	0.07	0.06	0.08	0.06	0.04	0.05	0.06	0.07	1.5
Cd	0.05	0.09	0.07	0.07	0.29	0.31	ND	ND	ND	0.3
Cr	0.06	0.10	0.07	0.37	1.91	1.04	0.29	0.26	0.18	10
Hg	0.18	0.18	0.16	0.17	0.17	0.16	0.19	0.17	0.14	0.05
Ni	0.39	0.31	0.26	1.93	7.75	2.74	0.71	1.59	2.03	10
Pb	0.17	0.25	0.18	0.32	1.38	0.72	0.10	0.21	0.19	3

Note: ND. not detectable

2.4 Metal uptake patterns in plants

The sludge treatment significantly elevated Zn, Cu, Cd and Hg concentrations in soil, compared with the untreated control soil (Table 5). Among 11 plant species studied, 8 species (*B. semperflorens-hybr*; *O. japonicus* (L. F.) *Ker-Gaw*; *L. chindense-var. rubrum*; *D. morifolium*; *B. radicans Sieb*; *V. macrocephalum*; *O. fragrans Lour*; *C. camphora siebold*) survived in the amended soils, and they flourished as well as those cultivated in control soil. The uptake of heavy metals by plants exposed to the amended soils for 12 weeks is presented in Fig.1.

The concentrations of heavy metals in plants vary widely between 0 and 9.90 mg As/kg, 0 and 1.71 mg Cd/kg, 0 and 35.15 mg Cr/kg, 0 and 47.71 mg Ni/kg, 0 and 3.14 mg Hg/kg, 0 and 19.22 mg Pb/kg, 0 and 198 mg Cu/kg, 0 and 1539 mg Zn/kg, taking into account all the plant samples analyzed. The highest As concentration was found in the four herbaceous species studied, particularly in the roots of *D. morifolium* and *L. chindense-var. rubrum*. The concentration of As in roots is 13 times higher than that in leaves of *D. morifolium*. In the shrub species studied, *B. radicans Sieb* exhibits higher As concentration in stems than in leaves. Nevertheless, As concentration in *V. macrocephalum*, *O. fragrans Lour* and *C. Camphora siebold* is even below the detection limits. All plant species studied do not appear to accumulate As.

The highest concentration of Cd was found in roots of *B. semperflorens-hybr*, followed by *D.*

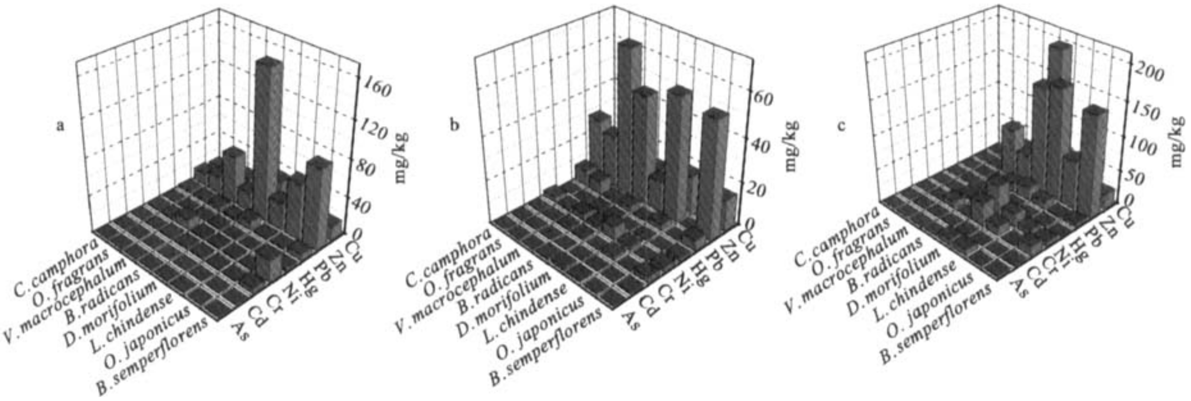

Fig.1 Metal concentration of plant studied
a. leaves; b. stems; c. roots

Table 5 Concentration of heavy metals in the amended and control soil (mg/kg)

Element	Amended soil	Control soil
As	19.32±0.48	12.1
Cd	4.35±0.12	<0.001
Cr	39.23±1.41	54.9
Cu	39.81±1.01	10.3
Hg	0.24±0.01	<0.0001
Ni	22.14±0.66	136
Pb	21.19±1.06	28.9
Zn	571.01±14.28	104

morifolium. Except for tree species of *O. fragrans* and *C. camphora siebold*, the concentration of Cd in the leaves of herbaceous and shrub species are below the detection limits. The highest concentration of Cr was found in the four herbaceous species studied, particularly in the roots *D. morifolium*, followed by *B. semperflorens-hybr*. The concentration of Cr in the plant part tested of *O. fragrans Lour* and *C. Camphora siebold* is below the detection limits. The concentration of Cr in *L. chindense-var. rubrum* follows the sequence of root > stem > leaf, whereas the opposite trend was observed for *B. radicans Sieb*. Similarly, the plants studied do not appear to accumulate Cd and Cr.

The highest concentration of Ni was found in the roots of *D. morifolium*, followed by the leaves of *B. semperflorens-hybr*. The concentration of Ni in roots is 26 times higher than that in leaves of *D. morifolium*, indicating that Ni is accumulated in the roots of this species, whereas *B. semperflorens-hybr* and *V. macrocephalum* exhibit higher Ni concentration in leaves than in roots. *O. fragrans* and *C. camphora siebold* contain similar amounts in leaves and stems, whereas Ni concentration in their roots is below the detection limits. The root Ni concentration in *D. morifolium* is 2 times higher than soil Ni concentration of 22.1 mg/kg. Therefore, this species accumulates Ni, which may contribute to its removal from the solid fraction of soil.

The concentration of Hg in plants varies widely. Of the plants studied, the highest Hg concentration was found in the roots *D. morifolium*, followed by the leaves of *B. semperflorens-hybr*. The root Hg concentrations in *D. morifolium* is 13 times higher than 0.24 mg/kg in amended soil (Table 5). Therefore, this species accumulates large amounts of Hg, which may contribute to its removal from the solid fraction of soil.

The highest concentration of Pb was found in the roots of *D. morifolium*, followed by *B.radicans Sieb*. *O. fragrans Lour* and *C. Camphora siebold* exhibit higher Pb concentration in stems than in leaves, whereas the Pb concentration in roots is below the detection limits. *B. semperflorens-hybr* contains similar amounts in all parts. Table 5 shows that the total concentration of Pb in amended soil is 19.22 mg/kg, while all the plant species studied exhibit Pb concentration well below this value, therefore, plants studied do not appear to accumulate Pb.

Levels of Zn in *D. morifolium* are much higher than those in the other plant species (Fig. 1c). The same species accumulates most Zn in roots. *B. radicans sieb* and *V. macrocephalum* contain similar amounts in three parts tested. *O. fragrans Lour* and *C. Camphora siebold* exhibit higher Zn concentrations in stems than in leaves, whereas the Zn concentration in roots is below the detection limits. The concentration of Zn in the amended soil is 571 mg/kg, and the root Zn concentration in *D. morifolium* is 3 times higher than this. Therefore, this species accumulates large amounts of Zn, which may contribute to its removal from the solid fraction of soil. The Zn concentrations in plant samples are within the range (between 27 and 150 mg/kg), which is considered as normal by Kabata-Pendias and Pendias (1984), except those of *D. morifolium* in root contents were excessive or toxic as defined by these authors. Zn concentration in this species is also higher than the normal values reported by Baker *et al.* (2000) for plants growing in metal-enriched soil (20—400 mg/kg).

The highest concentration of Cu was found in the herbaceous plants: *D. morifolium*, followed by *V. macrocephalum*, with the shrub and tree species showing much lower levels. In *O. fragrans Lour* and *C. Camphora siebold*, the Cu concentration in leaves and stems are similar, and below the detection limits in roots. All the plant samples exhibit Cu concentrations higher than 20 mg/kg, considered by Kabata-Pendias and Pendias (1984) as the limit for toxicity and also higher than the normal values of Baker *et al.* (2000) for plants growing in Metalliferous soils (5—25 mg/kg). As reported above, the total Cu in the amended soil also indicates toxicity of this element. The concentration of Cu in the amended soil is 39.7 mg/kg, and the root Cu concentration in *D. morifolium* is 5 times higher than this. Therefore, this species accumulates large amounts of Cu, which may contribute to its removal from the solid fraction of soil.

According to McNair *et al.* (1999), most plants growing in environments containing high concentrations of heavy metals take up large quantities of these elements through their roots but translocate only very small amounts to the above-ground parts. Hyperaccumulators are an exception to this, however, and they translocate significant amounts of these elements. Baker *et al.* (2000), for example, have identified a large number of such species which hyperaccumulate heavy metals in their roots and shoots. Baker and Walker (1998) reported exceptional values, therefore indicative of hyperaccumulation, of: 100 mg/kg for Cd; 1000 mg/kg for Cu and Pb; and 10000 mg/kg Zn. In the present study, it appears *D. morifolium* accumulates Hg, Ni, Cu and Zn, but these elements are not hyperaccumulated by any of the species, since the levels found are much lower than those reported by Baker and Walker (1998). However, the fact that these species are capable of growing in an environment containing high levels of certain heavy metals and of accumulating some of them is important for stabilizing the soil and for recovering the biogeochemical cycles in this system.

It can be seen from Fig. 2 that treatment with sewage sludge does not significantly affect the uptake of heavy metals by the *L. chindense-var. rubrum*. The concentration of As, Cr, Hg and Pb in all the parts studied produced on amended and control soil are similar. The concentration of Ni in all the parts studied produced on the amended soil is lower than those found produced on the control soil. For amended soils, roots of *L. chindense-var. rubrum.* accumulate higher amounts of Cu than leaves and stems. The concentrations of Cu and Zn in stems and leaves produced on the amended soil are lower than those found in leaves and stems produced on the control soil. The concentration of Cu in roots produced on the amended soil is higher than those found produced on the control soil, whereas the opposite is true for Zn in roots. The mobility of Cu is controlled by soluble organics in the amended soils. However, the low pH of the soil tends to favor the destabilization of metal-soluble organic complexes and consequently tends to increase Cu bioavailability since it is well-known that the free metal ion is more easily taken up by plants.

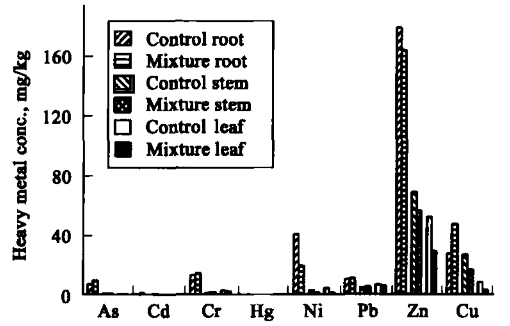

Fig.2 The concentration of heavy metals in *L. chindense-var. rubrum* produced on amended and control soil

It can be seen from Fig.3 that treatments with sewage sludge significantly affect the uptake of heavy metals by *D. morifolium*. The concentrations of all the elements studied in roots produced on the amended soil are higher than those produced on the control soil, especially Zn concentration in roots produced on amended soil is 28 times higher than that produced on the control soil. The concentrations of Cd, Cr and Hg in stems and leaves produced on the amended and control soils are similar. The concentration of Ni in stems and leaves produced on the amended soils is higher than those produced on the control soil. The concentrations of Pb, Zn and Cu in stems produced on the amended soil are lower than those produced on the control soil, whereas the opposite trend was observed in leaves. The present study does not support the data obtained by Pinamonti *et al.* (1997), which revealed that sewage sludge did not cause any significant increase of heavy metal levels in leaves.

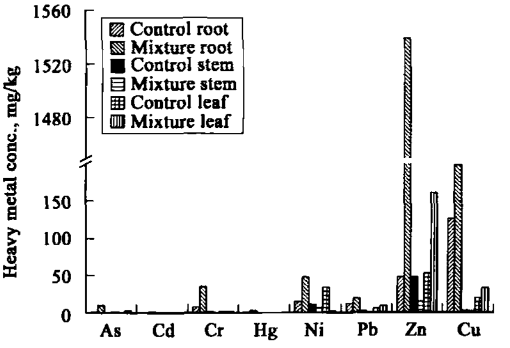

Fig.3 The concentration of heavy metals in *D. morifolium* produced on amended and control soil

3 Conclusions

The total concentrations of Zn in Quyang and Jinshan sewage sludge and those of Zn, Cu, Cd and Ni in Taopu sludge far exceed China regulatory limits for sludge to be used in agriculture. Jinshan and Taopu sewage sludge are not recommended for use in agriculture, particularly due to its extremely high levels of Ni and Cd concentration. However, Quyang sewage sludge can be used for agriculture according to USA and European standards. The results of GC-MS analysis showed that there is no priority organic pollutant present in Quyang sludge, but Jinshan and Taopu sludge contain some priority organic pollutants, i.e. benzene, toluene, *p*-xylene, phenol, naphthalene anthracene, chlorobenzene, *o*-xylene, nitrobenzene and aniline. The results of lixiviation tests showed that the concentration of Hg in all the samples studied and the concentration of Cd in Taopu sewage sludge are much higher than that allowed for waste solid extraction standard by the relevant legislation for sludge to be used in agriculture. A pot experiment showed that among 11 plant species studied, 8 species survived in the amended soils and they flourished as well as those cultivated in control soil. The highest As, Pb, Cd and Cr concentrations were found in the four herbaceous species studied, but these plants did not show accumulator of As, Pb, Cd and Cr. *D. morifolium* accumulated Ni, Hg, Cu and Zn, which may contribute to the decrease of the heavy metal contents in the amended soil. Treatment with sewage sludge significantly affects the uptake of heavy metals by *D. morifolium*, but less effect was found on the uptake of heavy metals by the *L. chindense-var. rubrum*.

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