Growth and Metal Accumulation in Vetiver and two *Sesbania* Species on Lead/Zinc Mine Tailings

Bing Yang[1], Wensheng Shu[1], Zhihong Ye[2], Chongyu Lan[1], Minghong Wong[2*]

[1] *School of Life Science, Sun Yatsen (Zhongshan) University, Guangzhou, 510275, China*
[2]*Institute for Natural Resources and Environmental Management, and Department of Biology,*
Hong Kong Baptist University, Kowloon Tong, Hong Kong, China

Abstract: The lead (Pb)/zinc (Zn) tailings contained high concentrations of heavy metals (total Pb, Zn, Cu and Cd concentrations 4164, 4377, 35 and 32 mg kg^{-1}, respectively), and low contents of major nutrient elements (N, P, and K) and organic matter. A field trial was conducted to compare growth performance, metal accumulation of Vetiver (*Vetiveria zizanioides*) and two legume species (*Sesbania rostrata* and *Sesbania sesban*) grown on the tailings amended with domestic refuse and/or fertilizer. It was revealed that domestic refuse alone and the combination of domestic refuse and artificial fertilizer significantly improved the survival rates and growth of *V. zizanioides* and two *Sesbania* species, especially the combination. However, artificial fertilizer alone did not improve both the survival rate and growth performance of the plants grown on tailings. Roots of these species accumulated similar levels of heavy metals, but the shoots of two *Sesbania* species accumulated higher (3-4 folds) concentrations of Pb, Zn, Cu and Cd than shoots of *V. zizanioides*. Most of the heavy metals in *V. zizanioides* were accumulated in roots, and the translocation of metals from roots to shoots was restricted. Intercropping of *V. zizanioides* and *S. rostrata* did not show any beneficial effect on individual plant species, in terms of height, biomass, survival rate, and metal accumulation, possibly due to the rather short experimental period of 5 months.

Key words: growth performance, intercropping, Pb/Zn mine, *Sesbania rostrata*, *Sesbania sesban*, tailings amendment, *Vetiveria zizanioides*

Contact: Wensheng Shu ls53@zsu.edu.cn

1 INTRODUCTION

Exploitation of mineral resource has resulted in the destruction of vast amounts of land. This has caused very serious environmental problems, which have received much attention from most countries in the world, including China. Revegetation of metalliferous mine tailings is necessary for long-term stability of the land surface. A good vegetation cover is beneficial in the restoration of contaminated land and results in enhanced amenity values as well as prevention of surface soil erosion (Baker *et al.*, 1994). However, adverse factors such as acidity, nutrient deficiencies, toxic heavy metal ions, and poor physical structure, and their interactions of most mine tailings inhibit plant establishment and growth on the tailings (Pichtel and Salt, 1998). The toxicity of heavy metals and deficiency of major nutrients are often the limiting factors for plant establishment on mine tailings, therefore, the success of reclamation schemes should overcome the two major problems (Bradshaw, 1987).

In general, amendments such as applications of organic materials (such as sewage sludge, domestic refuse) or inorganic fertilizer are necessary for establishment of plants on mine tailings. For long-terms remediation, metal tolerant species are commonly used for revegetation of mine tailings (Lan *et al.*, 1997; Sahi *et al.*, 1999), and herbaceous legumes can be used to as pioneer species solve the problem of nitrogen

---

[*] Author for correspondence. This paper has been published on Chemosphere, 2003, 52:1593-1600

deficiencies in mining wastelands because of their N_2-fixing ability (Archer *et al.*, 1988).

The genus *Sesbania* consisting of about 500 species pantropically distributed, is placed in the family *Leguminosae*, sub-family *Papilionoideae*. The majority of *Sesbania* species are annuals, and some are relatively short-lived perennials. Because of the ability of *Sesbania* species to grow in heavy metal soils, withstand waterlogging, and tolerate soil salinity, they are often the preferred green manure crop for rice and wheat (Evans and Rotar, 1987). *Sesbania rostrata*, native to tropical West Africa, is an annual species which bears stem as well as root nodules associated with *Azorhizobium caulinodans*, a specialized fast-growing strain of *Rhizobia* which can fix nitrogen in its free-living form (Somasegaran and Hoben, 1994). The formation of stem nodules in *S. rostrata* is considered as an unusual feature of harboring root primordial being formed along the stem (Tomekpe et al., 1996). *S. rostrata* is possibly the most rapid nitrogen-fixing plant known as it can fix 270 kg N/ha in 52 days (Manguiat *et al*., 1987; Yang *et al*., 1998). Our previous study also demonstrated that *S. rostrata* could successfully grow on Pb/Zn mine tailings amended with domestic refuse or sewage sludge (Ye *et al*., 2001). Vetiver grass (*Vetiveria zizanioides*), due to its fast growth, strong root system, high biomass, has been used to rehabilitate coal and gold tailings and mining overburden related to the mining industry (Truong and Baker, 1996).

Intercropping (IC) is a practice which can improve the utilization of available resources and cause yield advantage and increase yield stability compared to sole cropping (SC). Yield advantages occur when intercrop components compete only partly for the same plant growth resources. It is important of difference in competitive ability for growth factors between intercrop components (Ofori and stern, 1987). Legumes have been important crop plants with benefit of including improved soil quality, and reduced weed occurrence (Chris and Christopher, 2000). Ideally, cultivars suitable for IC should enhance the complementary effects between species (Vandermeer, 1989).

The objectives of the present field trial conducted at Lechang Pb/Zn mine tailings of Guangdong Province, southern China, were to: (i) compare the growth performance, heavy metal accumulation of *V. zizanioides* and two legume species, *S. rostrata* and *S. sesban*; (ii) evaluate the effects of domestic refuse and inorganic fertilizer amendment on the revegetation of Pb/Zn mine tailings; and (iii) evaluate whether IC of *V. zizanioides* with *S. rostrata* on the growth and heavy metal accumulation of these species on Pb/Zn mine tailings.

2 MATERIALS AND METHODS

2.1 Study Site

The Lechang Pb/Zn Mine is located at about 4 km east of Lechang City in the northern part of Guangdong Province, PR China. The climate is subtropical and the annual rainfall is about 1,500 mm. It is a conventional underground mining operation covering an area of 1.5 km^2, and produces approximately 30,000 t of tailings annually, with a dumping area of 60,000 m^2 (Shu, 1997). The tailings pond studied had been abandoned for about a year; the tailings surface of the pond was dry and completely devoid of vegetation.

Table 1 Experimental design for spot trial

	Treatment
A	Tailings (control)
B	Tailings amended with inorganic fertilizer*
C	Tailings amended with domestic refuse#
D	Tailings amended with domestic refuse and inorganic fertilizer

*inorganic fertilizer (15%N: 15%P: 15%K): 150 kg/ha;
#domestic refuse: 37.5 t/ha.

2.2 Plant Growth Experiment

A portion of the tailings pond was tilled to a depth of 20 cm, and defended with wire netting to prevent tested plants from animals. A ditch of 30 cm×30 cm was constructed outside the wire netting for drainage and separated the experiment area from surroundings. Sixteen plots (2 m×4 m) were set up within this area, and each plot was further divided into four subplots (1 m×2 m), with each subplot planted with *V. zizanioides*, *S. sesban*, or *S. rostrata* as SC respectively, or *V. zizanioides* and *S. rostrata* as mixed IC using a replacement design (50:50), at the rate of 32 individual plants per square meter. There were four treatments with four replicates each (Table 1). Healthy seedlings of *V. zizanioides* (about 20 cm in height), *S. rostrata* and *S. sesban* (about 10 cm in height) were collected from Guangzhou and transplanted to the experiment plots. Before planting, the seedlings of *S. rostrata* and *S. sesban* were soaked with theirs inoculants (isolated from the root nodules *A.caulinodans and Sesbania caulinodans*), respectively. After planting, treatments B and D received their first inorganic fertilization (N : P : K=15:15:15) at a rate of 150 kg/ha monthly, treatment A and C were remained still. All the plots were watered daily, except for rainy days, at the first two months to improve the survival rate of plants. The survival rate and height of each species was recorded shortly before harvest, after a growth period of 20 weeks.

2.3 Chemical Analysis

Tailings samples were excavated from the tailings pond (0-20 cm) before the field trial in March 2001. Domestic refuse samples were collected from a nearby landfill which has been abandoned for about a year. All samples were air-dried and sieved through a 2-mm mesh and mixed well, for the following parameters were determined: pH, electric conductivity (EC), water soluble N, P, K (solid: distilled water=1:2 w/v); total organic carbon (H_2SO_4+$KCrO_4$), total nitrogen (N) (indophenol-blue method), total phosphate (P) (molybdenum blue method), total Zn, Pb, Cd, Cu, and K (digested with conc. HNO_3, and conc. $HClO_4$=5:1) and extractable Zn, Pb, Cd, and Cu extracted by diethylene triaminepentaacetic acid (DTPA), by atomic absorption spectrometry, AAS) (Page *et al.*, 1982).

2.4 Plant Samples

After a growth period of 20 weeks, shoots of the plants were clipped at 5 mm above ground, and roots were excavated as completely as possible to determine number of nodules for Legumes species. Plant materials were washed with distilled water, oven-dried (80 □) to constant weight to determine dry weight, and then milled, divided into shoot and root portion, and passed through a 2 mm sieve. Approximately 0.5 g milled plant material was placed into a 100 ml digesting tube, and then digested at 180 □ with 5 ml 16 M HNO_3 and 1 ml 12 M $HClO_4$, until the samples were completely clear. The concentrations of Zn, Pb, Cu, and Cd in the digestates were determined by AAS (Allen, 1989).

2.5 Statistical Analysis

The data were analyzed using a SPSS statistical package by one-way analysis of variance (ANOVA) to compare the means of different treatments. Where significant *F* values were obtained, differences between individual means were tested using LSD tests at 0.05 significance level.

3 RESULTS

3.1 General Physio-chemical Properties of Tailings and Domestic Refuse

The general properties of tailings and domestic refuse are presented in Table 2. The tailings were slightly alkaline (pH=8.55), with an EC value of 0.41 dS m^{-1}, while the domestic refuse was near neutral (pH=7.56), with an EC value of 1.05 dS m^{-1}. The domestic refuse contained high levels of total N, P, and K, which were about 40, 4 and 4 times respectively higher than those in the tailings. In terms of heavy metals, concentrations of the total and DTPA-extractable Zn, Pb and Cd in the tailings were significantly higher, while total and DTPA-extractable Cu significantly lower than those in domestic refuse.

Table 2 General physio-chemical properties of tailings and domestic refuse (Mean ± SE, n=5)

Parameters		Units	Tailings	Domestic refuse
pH			8.55 ± 0.12	7.56 ± 0.07
EC		dS m^{-1}	0.41 ± 0.07	1.05 ± 0.06
Organic Carbon		%	1.4 ± 0.13	3.6 ± 0.15
N	Total	mg kg^{-1}	52.3 ± 5.89	2356 ± 212
	Water-soluble	mg kg^{-1}	0.11±0.01	0.18 ± 0.002
P	Total	mg kg^{-1}	550 ± 30.0	2245 ± 178
	Water-soluble	mg kg^{-1}	0.07 ± 0.01	0.52 ± 0.04
K	Total	mg kg^{-1}	1525 ± 192	6865 ± 486
	Water-soluble	mg kg^{-1}	0.25 ± 0.03	2956 ± 134
Zn	Total	mg kg^{-1}	4377±1700	1080 ± 177
	DTPA-extractable	mg kg^{-1}	187 ± 48	73 ± 4.95
Pb	Total	mg kg^{-1}	4164 ± 554	297 ± 50.1
	DTPA-extractable	mg kg^{-1}	331 ± 57	62 ± 5.73
Cu	Total	mg kg^{-1}	35 ± 4.44	48 ± 3.03
	DTPA-extractable	mg kg^{-1}	2.6 ± 0.17	5.5 ± 1.41
Cd	Total	mg kg^{-1}	32 ± 3.12	10 ± 1.14
	DTPA-extractable	mg kg^{-1}	0.77 ± 0.18	0.32 ± 0.02

3.2 Growth Performance of The Three Plant Species

The growth performance (survival rate, height, and biomass) of *V. zizanioides* and two *Sesbania* species are listed in Table 3. In general, the plants grown on treatment D had the best growth performance. The height and biomass of the three plants were in the descending order of D>C>B>A. *S. rostrata* grown under the treatment D had the highest biomass (1379 g m^{-2}) and height (216 cm), which were significantly higher than those of *V. zizanioides* (1111 g m^{-2} and 174 cm, respectively) and *S. sesban* (455 g m^{-2} and 155 cm, respectively) growing under the same treatment.

Table 3 Survival rate (%), height (cm), and biomass (g dry weight m^{-2}) (Mean±SE, n=4) of *Vetiveria zizanioides, Sesbania rostrata,* and *S. sesban* grown on Lechang Pb/Zn mine tailings under different treatments for a period of 20 weeks.

	Treatment	*V. zizanioides*	*S. rostrata*	*S. sesban*
Survival rate	A	90 ± 1.2 a*-a#	18 ± 1.4 c-b	6.3 ± 1.6 b-c
	B	90 ± 3.7 a-a	27 ± 4.5 c-b	7.0 ± 0.59 b-c
	C	95 ± 3.3 a-a	59 ± 5.1 b-b	85.2 ± 5.1 a-a
	D	93 ± 1.2 a-a	86 ± 2.3 a-a	87 ± 3.7 a-a
Height	A	91 ± 1.2 d-a	12 ± 1.4 b-bc	14 ± 0.66 d-b
	B	113 ± 1.9 c-a	13 ± 0.37 b-c	23 ± 0.58 c-b
	C	154 ± 2.0 b-bc	210 ± 6.0 a-a	103 ± 5.0 b-d
	D	174 ± 3.5 a-b	216 ± 19 a-a	155 ± 2.6 a-b
Biomass	A	213 ± 5 c-a	29 ± 2 c-b	26 ± 2 c-b
	B	331 ± 18 c-a	57 ± 2 c-b	40 ± 1 c-b
	C	782 ± 84 b-a	891 ± 44 b-a	169 ± 10 b-b
	D	1111 ± 144 a-a	1379 ± 42 a-a	455 ± 25 a-b

Refer to Table 1 for the explanation of treatment. Data with different letters (*) in the same column, or (#) in the same row indicate a significant difference at 5% level according to LSD test.

Survival rates (%) of *V. zizanioides* were similar in the all treatments, but survival rates of *S. rostrata* and *S. sesban* grown in treatments C and D were significantly higher than their counterparts grown in treatments A and B. *S. sesban* seedlings grown in treatments A and B were almost dead at the end of experiment and with extremely low survival rates (6.25% and 7.03%, respectively) (Table 3).

There were no significant differences in growth performance (biomass, height and survival rate) between the SC *S. rostrata* (*V. zizanioides*) and IC *S. rostrata* (*V. zizanioides*) under the same treatment (data not shown).

3.3 Nodulation of Two *Sesbania* Species

The biomass and number of nodules of two *Sesbania* species grown in D subplots were significantly higher than in A and B subplots. The biomass and nodule number of *S. rostrata* were significantly higher than those of *S. sesban* under the same treatment (Table 4). There were no significant difference in biomass and number of nodules between SC *S. rostrata* and IC *S. rostrata* under the same treatment (data not shown).

Table 4 Number (/plant) and biomass (g dry weight/plant) of root nodulation per plant of *Sesbania rostrata* and *S. sesban*, grown on tailings under different treatments.

	Treatment	*S. rostrata*	*S. sesban*
Number of nodules	A	12 ± 2 d*- a#	7 ± 1 d-b
	B	54 ± 18 c-a	30 ± 9 c-b
	C	193 ± 19 b-a	143 ± 12 b-b
	D	420 ± 28 a-a	224 ± 20 a-b
Biomass of nodules	A	0.06 ±0.02 c-a	0.04 ± 0.01 d-a
	B	0.30 ± 0.14 b-a	0.18 ± 0.08 c-b
	C	0.64 ± 0.04 b-a	0.41 ± 0.04 b-a
	D	1.22 ± 0.12 a-a	0.59 ± 0.08 a-b

Refer to Table 1 for the explanation of treatments. Data with different letters (*) in the same column, or (#) in the same row indicate a significant difference at 5% level according to LSD test.

3.5 Metal (Zn, Pb, Cu, and Cd) Concentrations in Plant Tissues

The concentrations of Zn, Pb, Cu, and Cd in tissues of *V. zizanioides* and two *Sesbania* species are presented in Table 5. Metal concentrations exhibited similar trends among species, tissues and treatments. In general, plants accumulated high concentrations of Pb and Zn, and low concentrations of Cu and Cd; and roots always accumulated significantly higher heavy metals than shoots. The metal concentrations in same tissues (shoot or root) of plants under different treatments were generally in the descending order of D≈C>B≈A. However, the two *Sesbania* species under different treatments accumulated similar concentrations of Zn ($P > 0.05$). Among the three species, *V. zizanioides* always accumulated the lowest concentrations of Pb, Zn, Cu and Cd (Table 5). The metal accumulations in IC *V. zizanioides* and *S. rostrata* were similar with those of their counterparts (SC) grown under the same treatment (data not shown).

4 DISCUSSION

Many factors such as poor physical structure, low water and nutrient holding capacity, deficiency of major nutrients (N, P, K), acidity and alkaline, water supply, toxic materials, salinity, stability, surface temperature are known to affect plant establishment on mine tailings (Bradshaw and Chadwick, 1980). Results presented in Table 2 indicated that Lechang Pb/Zn mine tailings contained high levels of total and DTPA-extractable Pb and Zn, and low levels of major nutrients (N, P, K) and organic materials. The total

Table 5 Concentrations (mean±se, n=4, mg kg^{-1}) of Zn, Pb, Cu, and Cd in plants of *V. zizanioides*, *Sesbania rostrata*, and *S. sesban* grown on tailings under different treatments

		V. zizanioides		*S. rostrata*		*S. sesban*	
	Treatment	Shoot	Root	Shoot	Root	Shoot	Root
Zn	A	57±14 ab	1162±620 a	216±72 a	605±235 a	209±30 a	383±119 a
	B	64±19 a	911±324 a	186±66 a	374±55 a	225±15 a	348±154 a
	C	37±4.6 c	351±44 b	192±58 a	562±125 a	237±83 a	309±94 a
	D	43±5.9 bc	316±56 b	157±69 a	448±148 a	158±57 a	505±199 a
Pb	A	18±4.0 a	720±213 a	33±14a b	227±122 a	13±2.3 b	100±25 ab
	B	13±5.4 ab	456±54 b	46±17 a	156±19 a	27±9.1 a	109±53 ab
	C	7.9±1.8 b	146±28 c	23±13 b	217±87 a	14±1.9 b	91±32 b
	D	8.0±2.9 b	141±31 c	17±4.1 b	197±25 a	12±5.5 b	158±51 a
Cu	A	3.7±1.9 a	58.7±17.7 a	11±4.3 ab	30±9.8 a	12.4±1.1 b	57±17 ab
	B	4.7±1.42 a	58.1±9.51 a	12±0.33 a	29±3.9 a	16±1.0 a	47±4.4 b
	C	5.0±2.0 a	30±3.9 b	7.9±1.8 b	36±7.9 a	10±2.5 bc	68±16 a
	D	7.90±4.62 a	28.2±3.14 b	8.2±1.0 b	39±14 a	8.3±3.2 c	57±16 ab
Cd	A	n. d.	4.98±1.82 a	1.6±0.48 a	2.5±0.98 a	0.87±0.2 ab	1. 8±0.85 a
	B	n. d.	3.7±0.46 ab	1.8±0.81 a	1.4±0.37 a	0.75±0.4 ab	1.3±0.52 a
	C	n. d.	2.5±0.33 b	1.1±0.43 a	2.1±0.40 a	1.08±0.33 a	1.3±0.46 a
	D	n. d.	3.0±1.9 ab	0.99±0.50 a	1.95±1.14 a	0.52±0.09 b	1.71±0.19a

*Different letters in the same column and in the same metal (Zn, Pb, Cu, or Cd) indicate a significant difference at $p < 0.05$ according to the LSD test.
n. d.: Not detect.

and extractable concentrations of Pb and Zn greatly exceeded the background values of normal soil (Pb 22.50, Zn 29.00 mg kg^{-1})(Xu and Liu, 1996), and nutrient contents and organic matter were much lower than those of normal soil (N, P, K, and organic matter 1240, 870, 21600, and 23500 mg kg^{-1}, respectively)(Liu, 1993), although pH and EC values were in the normal range for plant growth. Therefore, the toxic levels of heavy metals, deficiency of nutrients (N, P, K) and low organic matter in the tailings might be the major constraints for plant establishment on Lechang Pb/Zn mine tailings pond. Our previous study also demonstrated that phyto-toxicity of heavy metals and extreme infertility of the Fankou Pb/Zn mine tailings in northern Guangdong Province were the major limiting factors for plant growth (Lan *et al.*, 1998; Shu *et al.*, 1997). Therefore, application of inorganic fertilizer or organic materials is necessary for successful revegetation of these tailings. Results in the present experiment demonstrated that domestic refuse and the combination of inorganic fertilizer and domestic refuse greatly enhanced the growth of *V. zizanioides*, *S. rostrata*, and *S. sesban* and the nodulation of the two *Sesbania* species on Lechang Pb/Zn mine tailings, especially the combination. On the contrary, using inorganic fertilizer alone could not effectively improve plant growth on the tailings (Table 3). A number of studies showed that domestic refuse resulted in successful revegetation of mine spoils (Ye *et al.*, 1999, 2000). Besides having high level of NPK, domestic refuse could also improve the poor physical properties and microbial activities of the tailings. Organic materials of domestic refuse could also reduce heavy metal toxicity to plants by complexing metals (Wong and Lau, 1985). There has been a long history in using domestic refuse as soil amendment in rural areas of China. However, due to the increased use of artificial fertilizer in recent years, domestic refuse has been disposed of in rural areas and cities without any treatment, which resulted in serious environmental problems (Jiang, 2000). The application of domestic refuse for revegetating derelict land may not only provide a cost-effective method for land rehabilitation, but also provide an alternative for refuse disposal.

It was commonly known that *V. zizanioides* tolerates wide range of pH, salinity, sodicity, acidity and heavy metals such as As, Cd, Cu, Pb, and Zn (Kantawanichkul *et al.*, 1996; Xia and Shu, 2001). In Australia, *V. zizanioides* has been successfully used to stabilize mining overburden, coal and gold mine tailings (Truong and Baker, 1996). The present results also showed that *V. zizanioides* has better growth performance (survival rate, height, and biomass) than the two legume species under the same treatment (Table 3). Accumulation and distribution of heavy metals in plant tissues are important aspects to evaluate the role of plant in remediation of metalliferous soils (Friedland, 1989). In terms of stabilizing metal contaminated sites, a lower metal concentration in shoot is preferred, in order to prevent metal from entering the ecosystem through food chain (Pichtel *et al.*, 2000; Taylor *et al.*, 2001). Among the three species studied, the shoot of *V. zizanioides* accumulated the least concentrations of Pb, Zn, Cu, and Cd (Table 5), and is therefore, more suitable for revegetation of mine tailings. Similar results were also observed in our previous study of growth and accumulation of heavy metals in four grasses grown on Pb/Zn mine tailings (Shu *et al.*, 2002). The restriction of metal translocation from root to shoot in *V. zizanioides* might be one of its metal tolerance strategies (Shu et al., 2002). All these evidences suggested that *V. zizanioides* has higher tolerance to metals (e.g. Pb and Zn) than the two legume species. In addition, *V. zizanioides* also possess an extensive root system (the maximum diameter of root scale and height 30, 70 cm, respectively) to stabilize tailings particles and avoid arosion.

Although previous studies showed that *Sesbania* was able to grow on tin (Sn) (Radziah and Shamsuddin, 1990) and complete its life cycle and produced seeds on Pb/Zn tailings within about nine month (Yang *et al.*, 1997), which suggested that *S. rostrata* might possess a certain degree of heavy metal tolerance. The results presented that *S. rostrata* and *S. sesban* grown in C and D subplots had significantly better growth performance than in A and B subplots. The results also showed that the biomass of *S. rostrata* was higher than that of *V. zizanioides* when grown in the same C and D subplots (Table3). Root nodules of *S. rostrata* might also contribute to N accumulation in the substrate. Therefore, this plant could be used as a pioneer species to improve edaphic conditions of mine tailings. However, organic amendment such as the use of domestic refuse is necessary for enhancing plant growth on tailings. Although the stem nodulation of the species was emphasized (Tomekpe *et al.*, 1996; Ye et al., 2001), where nitrogen application stimulated nodulation and N_2 fixation in stems of *S. rostrata*, also heavy metals tend to reduce the nodulation rate of *S.rostrata*, especially at low pH (Ibekwe *et al.*, 1995). No stem nodule was observed during the present study. Failure of nodulation on stem of *S. rostrata* growing on tailings might due to the degradation of bacteria strain or the stem nodule bacteria was more susceptible by high metal toxicities.

IC of grasses and legumes are recommended in revegetation of wasteland in order to ensure a long-term stability of vegetation, due to contribution of N by legume species (Bradshaw and Chadwick, 1980). However, present results did not show any competitive and beneficial effects on growth performance of *S. rostrata* and *V. zizanioides* growing in the same subplot. This may be due to the relatively short experimental period (20 weeks) and the beneficial effect of legume species was not clearly manifested. Therefore, the long-term role of legume species in IC system for mine tailings revegetation needed further investigation. The effects of decomposition of *S. rostata* on the growth of grasses on the tailings are being studied.

5 CONCLUSION

Lechang Pb/Zn mine tailings contained higher concentrations of Pb and Zn and lower contents of major nutrients. The combination of domestic refuse and inorganic fertilizer was more effective than inorganic fertilizer or domestic refuse alone in supporting plant growth on the tailings.

V. zizanioides had the highest tolerance to metal toxicities and accumulated the lowest concentrations of heavy metals in shoot among the three species tested. This species was considered more suitable for stabilizing mine tailings, and the danger of transferring toxic metals to grassing animals was minimal.

6 ACKNOWLEDGMENTS

The author would like to thank Ms. Zhou Mi for technical assistant. Financial support from the NSFC (No. 30100024), GDNSF (No. 990259), and the Research Grants Council of University Grants Committee of Hong Kong is gratefully acknowledged.

7 REFERENCES

Allen SE. 1989. Chemical Analysis of Ecological Materials, 2nd ed. Blackwell Science Publishers, Oxford

Archer IM, Marshman NA, Salomons W. 1988. Development of a revegetation programme for copper and sulphide-bearing mine waste in the humid tropic. In: Salomons W, Forstner U (eds.), Environmental management of solid waste, Overseas Typographers, Makati. 166-184

Baker AJM, McGrath SP, Sidoli CMD, *et al.* 1994. The possibility of in situ heavy metal decontamination of polluted soils using crops of metal-accumulating plants. Resour., Conserv. Recycl., 11: 41-49

Bradshaw AD, Chadwick MJ. 1980. The Restoration of Land: The Ecology and Reclamation of Derelict and Degraded Land. University of California Press, Berkeley Los Angeles. pp.302

Bradshaw D. 1987. Recalmation of land and ecology of ecosystem. In: William, R.J., Gilpin, M.E., Aber, J.D. (Eds.), Restoration Ecology, Cambridge University Press, Cambridge. pp. 53-74

Evans DO, Rotar PP. 1987. Sesbania in agriculture Boulder, CO: Westview Press

Friedland AJ. 1989. The movement of metals through soils and ecosystems. In: Shaw AJ (ed.), Heavy metal tolerance in plants: Evolutionary aspects. CRC Press, Inc, Boca Raton. 7-20

Ibekwe AM, Angle JS, Chaney RL, *et al.* 1995. Sewage sludge and heavy metal effects on nodulation nitrogen fixation of legumes. J. Environ. Qual., 24: 1199-1204

Jiang BL. 2000. Pollution ecology on leachate from municipal landfill, Ph. D. Thesis, Zhongshan University, China

Kantawanichkul S, Pilaila S, Tanapiyawanich W, *et al.* 1999. Wastewater treatment by tropical plants in vertical-flow constructed wetlands. Wat. Sci. Tech., 40: 173-178

Lan CY, Shu WS, Wong MH. 1997. Revegetation of Pb/Zn mine tailings: phytotoxicity of the tailings. pp. 119-130 in Wise, D. L. (ed.), Global environmental biotechnology, Elsevier Science, London

Lan CY, Shu WS, Wong MH. 1998. Reclamaton of Pb/Zn mine tailings at Shaoguan, Guangdong Province, PRC: the role of river sediment and domestic refuse. Biores. Technol., 65: 117-124

Liu AS. 1993. Soils in Guangdong Province. Science Press, Beijing, China. 325-339

Manguiat IJ, Sebiano AG, JAlolon AT, *et al.* 1987. Biofertizer and nitrogen fixation potential of *Sesbania rostrata* under flooded and nonflooded conditions as affected by inoculation and nitrogen application. J. Crop Sci., 12: 325

Ofori F, Stern WR. 1987. Cereal-legume intercropping systems. Adv. Agron., 41: 41-90

Page AL, Miller RH, Keeney DR. 1982. Methods of Soil Analysis, Part 2. Chemical and Microbiological Properties, 2nd Ed. Agronomy, No. 9, ASA, SSSA, Madison, Wisconsin

Pichtel J, Kuroiwa K, Sawyerr HT. 2000. Distribution of Pb, Cd and Ba in soils and plants of two contaminated sites. Environmental Pollution, 110: 171-178

Pichtel J, Salt CA. 1998. Vetegative growth and trace metal accumulation on metalliferous wastes. J. Environ. Qual., 27: 618-642

Radziah O, Shamsuddin H. 1990. Growth and *Sesbania rostrata* on different components on tin tailings. Pertanika, 13: 9-15

Sahi SV, Fasion V, Bryant NL, *et al*. Accumulation of heavy metals by *Sesbania* species. Proceedings of the 5th International Conference on the Biogeochemistry of Trace Elements, Vienna. 582-583

Shu WS. 1997. Revegetation of Lead/Zinc Mine Tailings, Ph. D. thesis, Zhongshan University, China

Shu WS, Lan CY, Zhang ZQ. 1997. Analysis of major constraints on plant colonization at Fankou Pb/Zn Mine tailings. Chinese Journal of Applied Ecology, 8(3): 314-318

Shu WS, Xia HP, Zhang ZQ, *et al*. 2002. Growth and accumulation of heavy metals in four grasses grown on Pb/Zn mine tailings at Lechang of Guangdong Province, China. Int. J. of Phytoremediation, 4: 47-57

Somasegaran P, Hoben HJ. 1994. Handbook for Rhizobia: methods in legume-Rhizobium technology, Springer-Verlag, New York

Taylor MD, Percival HJ. 2001. Cadmium in soil solutions from a transect of soils away from a fertilizer bin. Environmental Pollution, 113: 35-40

Tomekpe K, Dreyfus B, Holsters M. 1996. Root nodulation of *Sesbania rostrata* suppresses stem nodulation by *Sinorhizobium teranga* but not *Azorhizobium caulinodans*. Can. J. Microbiol., 42: 187-190

Truong PN, Baker D. 1996. Vetiver grass for the stabilization and rehabilitation of acid sulfate soils. Proc. Second National Conf. Acid Sulfate Soils, Coffs Harbour, Australia. 196-198

Vandermeer J. 1989. The ecology of intercropping. Cambridge University Press, Cambridge, UK

van Kessel C, Hartley C. 2000. Agricultural management of grain legumes: has it led to an increase in nitrogen fixation. Field Crop Res. 65: 165–181

Wong MH, Lau WM. 1985. The effects of applications of phosphate, lime, EDTA, refuse compost and pig manure on the Pb contents of crops. Agric. Wastes, 12: 61-75

Xia HP, Shu WS. 2001. Resistance to and uptake of heavy metals by *Vetiveria zizanioides* and *Paspalum notatum* form lead/zinc mine tailings. Acta Ecologica Sinica, 21(7): 1121-1129

Xu LF, Liu TH. 1996. The zonal differentiation of soil environmental background values and critical contents in Guangdong. Journal of South China agricultural University, 17(4): 58-62

Yang ZY, Yuan JG, Xin GR, *et al*. 1997. Germination, growth and nodulation of *Sesbania rostrata* grown in Pb/Zn tailings. Environ. Manage., 21: 1-6

Yang ZY, Yuan JG., Zhang HD. 1998. Growth, nodulation, N-fixing and seed production of *Sesbania rostrata-Azorhizobium caulinodans* symbiosis in South China. Journal of Applied Ecology, 9: 91-95

Ye ZH, Wong JWC, Wong MH, *et al*. 2000. Revegetation of Pb/Zn mine tailings, Guangdong Province, China. Restoration Ecology, 8: 87-92

Ye ZH, Wong JWC, Wong MH, *et al*. 1999. Lime and pig manure as ameliorants for the revegetation on lead/zinc mine tailings: a greenhouse study. Biores. Technol., 69: 35-45

Ye ZH, Yang ZY, Chan GYS, *et al*. Growth response of *Sesbania rostrata* and *S. cannabina* to sludge-amended lead/zinc mine tailings: A greenhouse study. Environ. Inter., 26: 449-55

A Brief Introduction to the First Author

Bing Yang, as a doctorate student, is studying in School of Life Science, SunYat-Sen University, Guangdong, PRC. He has been engaged in using the Vetiver System for the purpose of mine tailings rehabilitation and wetland construction over 3 years and has 4 academic papers in these aspects published.