USE OF VETIVER AND THREE OTHER GRASSES FOR RE-VEGETATION OF PB/ZN MINE TAILINGS AT LECHANG, GUANGDONG PROVINCE: A FIELD EXPERIMENT

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Abstract

The Lechang Pb/Zn mine is located in the north of Guangdong province in southern China. The tailing pond had been abandoned over five years, and re-vegetation was necessary to stabilize the bare surface of the pond in order to reduce its environmental impact. Chemical analysis indicated the tailings had a high content of heavy metals (Pb, Zn, Cu and Cd) and low levels of major nutrient elements (N, P and K) and organic matter. Heavy metal toxicity and extreme infertility were the main constraints on re-vegetation. A field experiment was conducted to compare the growth of vetiver grass *(Vetiveria zizanioides)* and three other grasses *(Paspalum notatum*, *Cynodon dactylon* and *Imperata cylindrica* var. *major)* on the tailings. The tailings were amended with four treatments, as follows: (i) 10-cm domestic refuse + complex (NPK) fertilizer (Tr.A), (ii) 10-cm domestic refuse (Tr.B), (iii) complex (NPK) fertilizer (Tr.C), and (iv) tailings without any amendment used as control (Tr.D). The six-month field experiment showed that both the domestic refuse and the NPK fertilizer could improve the growth of plants on tailings, and the combination of domestic refuse and NPK fertilizer (Tr.A) had the greatest benefits. After six months of growth, vetiver grass growing on Tr.A had a height of 220 cm, cover of 100 %, and a dry weight yield of 2 111 g/m^2. The height and biomass of vetiver grass were significantly greater than those of the other three grasses growing on the same treatment. Judging from the above results, vetiver grass was the best species among the four species used for the re-vegetation of Lechang Pb/Zn mine tailings, followed by *P. notatum*, *C. dactylon* and *I. cylindrica.*

Introduction

Metalliferous mining activities produce a large quantity of waste materials, such as tailings, which frequently contain excessive concentrations of heavy metals. These mining activities and waste materials have created pollution problems and caused a lot of land dereliction without vegetation cover. In China, there are over 8 000 national and 230 000 private mining companies currently operating, resulting in 200 000 km^2 of derelict land, with the loss of 370 000 km^2 of agricultural land (Young 1988). Re-vegetation of metalliferous mine tailings is necessary for long-term stability of the land surface. The success of reclamation schemes greatly depends upon the choice of plant species and their methods of establishment (Bradshaw 1987).

Vetiver grass (*Vetiveria zizanioides*), due to its unique morphological and physiological characteristics, is widely known for its effectiveness in erosion and sediment control (Greenfield 1995). It has been found to be highly tolerant to extreme soil conditions, including heavy-metal contamination (Truong and Baker 1998). In Australia, vetiver grass *(V. zizanioides)* has been successfully used to stabilize mining overburden and highly saline, sodic, magnisic and alkaline (pH 9.5) tailings of coal mines and highly acidic (pH 2.7) and highly arsenic tailings of gold mines (Truong and Baker 1998; Truong 1999). Bahia grass *(Paspalum notatum)* is also a widely used species for soil and water conservation, and has been proved to be tolerant to unfavourable soil conditions and heavy metal toxicity (Xia 1999; Xia and Ao 1997). Our previous studies also indicate that *Cynodon*

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dactylon and *Imperata cylindrica* are of the dominant species naturally colonizing the Lechang Pb/Zn mine tailings. A root elongation test demonstrates that the mine population of *C. dactylon* has evolved high tolerance to Pb, Zn and Cu (Shu 1997; Shu et al. 1998). Both native grasses may have the potential to be used in re-vegetation of Pb/Zn mine tailings. The present experiment aims at comparing the growth of the four grasses on Lechang Pb/Zn mine tailings with different amendments, for screening the most useful grass for Pb/Zn tailing re-vegetation and the most effective measure for establishing it on tailings. It is expected to develop a cost-effective method for re-vegetation of Pb/Zn mine tailings.

Material and Methods

Study Site Description

The Lechang Pb/Zn mine is located some 4 km east of Lechang City in the northernmost part of Guangdong province in China. The climate is subtropical and the annual rainfall is about 1500 mm. It is a conventional underground mining operation, covering an area of 1.5 km^2 and producing approximately 30 000 t of tailings annually, with a dumping area of 60 000 m^2 (Shu 1997).

Re-vegetation Experiment

The tailing pond was tilled to a depth of 20 cm, and then divided into 12 plots of 16 m^2 (4 m $\times$ 4 m). Each plot was further divided into four subplots of 4 m^2 (2m$\times$2m) for planting different grasses. There were four treatments (Table 1) with three replicates each, arranged in a completely randomized block. For Treatments A and C, NPK fertilizer (N:P:K = 15:15:15) was applied at a total amount of 225 kg N/hm^2 at three separate times, in April, July and September.

Table 1. Experimental design

	Treatment
A	Tailings + 10 cm domestic refuse + NPK *
B	Tailings + 10 cm domestic refuse
C	Tailings + NPK
D	Tailings (control)

* NPK fertilizer (15%N: 15%P: 15% K)

V. zizanioides and *P. notatum* were collected from the garden of the South China Institute of Botany for field experiment. Before planting on the experimental plots, the roots of *V. zizanioides* were cut about 20 cm below the surface and their leaves were cut about 30 cm above the roots. The clumps were broken into planting slips of about 3-5 tillers each. The clumps of *P. notatum* were divided into single tillers with about 5 cm root and 10 cm shoot. *C. dactylon* and *I. cylindrica* were collected from their natural populations of the mine tailings and treated with similar methods before planting. Sixteen slips or tillers for each species were planted on each subplot in April 1999. After planting, Treatments A and C received their first NPK fertilization, and all plots were watered for a week to improve the survival rate of the grasses.

The cover of four grasses and the height and tiller increments of *V. zizanioides* and *I. cylindrica* were investigated monthly. After six months' growth, a 0.25 m^2 quadrat (0. 5 m $\times$ 0. 5 m) was randomly placed on each subplot for sampling. Shoots of the plants were clipped 5 mm above ground and the roots were excavated out as thoroughly as possible. Plant materials were washed with distilled water, oven-dried at 80°C for 24 hours to determine dry weight.

Sample Collection and Chemical Analysis

Six mixture tailing samples and five mixture samples of domestic refuse were collected for chemical analysis. The tailing samples were collected from the top 20 cm of the Pb/Zn mine tailing pond before the field experiment, and domestic refuse samples were collected from a nearby landfill, which consisted of about 70% coal ash with an abandoned period of about one year. All samples were air-dried, ground to pass through a 2-mm sieve, and analysed for the following parameters: pH (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 metal (Zn, Pb, Cd, Cu) contents (conc. HNO_3, and conc. $HClO_4$ = 5:1) and extractable metal (Pb, Zn, Cd, Cu) contents (extracted by DTPA, atomic absorption spectrometry) (Page et al. 1982).

Statistical Analysis

The least significant difference was used to compare dry matter yields of the four grasses in the same treatment or the same species growing on different treatments.

Results and Discussion

The Properties of the Tailings and Domestic Refuse

The properties of the tailings and domestic refuse are listed in Table 2. Total Pb, Zn, Cu and Cd concentrations were 3 123, 3 418, 174 and 22 mg/kg, while extractable concentrations were 98, 101, 4.28 and 0.79 mg/kg, respectively. The tailings were slightly alkaline (pH 7.13) and their EC value was 2.09 dS/m. The total and extractable metal contents greatly exceeded the background values of normal soil nutrient contents were much lower than those of normal soil. Therefore, the toxic levels of heavy metals, deficiency of nutrients (N, P and K) and organic matter of the tailings were the main constraints for plant establishment and colonization. Our former studies on re-vegetation of Fankou Pb/Zn mine tailings also proved that the phyto-toxicity of heavy metals and extreme infertility were the main limiting factors for plant growth (Shu et al. 1997). Phyto-toxicity of tailings inhibited the root vitality of plants, prevented plants from absorbing inorganic nutrients, and significantly inhibited plant growth (Lan et al. 1997; 1998).

The domestic refuse was slightly acidic and had a low salinity. Compared with the tailings, domestic refuse contained higher levels of nutrients and lower levels of heavy metals. Therefore, domestic refuse could be used as an amendment to ameliorate the physico-chemical properties of the tailings.

Changes of Cover of the Four Grasses

Changes of covers of the four grasses grown on different treatments are illustrated in Fig. 1. From May to August, the covers of all the plants growing on Treatments A and B showed great increments and similar growth performance, the covers of the four grasses growing on Treatments A and B eventually reached 100% in October. For Treatment C, there were slight increments of covers from May to July. However, they increased rapidly after the second application of NPK fertilizer in July. The covers of *V. zizanioides* in Treatment C eventually reached 100% in October, and the covers of *C. dactylon*, *I. cylindrica* and *P. notatum* growing in Treatment C were 80, 50 and 80%, respectively. There were no increments of cover for plants growing in Treatment D from May to October, which even showed some decrement, except the cover of *V. zizanioides*, that showed a slight increment and reached 40% in October. The increment of covers of *V. zizanioides* growing on pure tailings without any treatment indicated that this species had higher tolerance to heavy metals than the three other species.

In general, all the plant species growing on the tailings amended with domestic refuse had the highest cover. This may be due to the relatively high nutrient contents of domestic refuse, and the application of domestic refuse also contributed to the improvement of the physical properties of the tailings.

Tiller number and plant height of *V. zizanioides* and *I. cylindrica*

The increment of tillers and plant height of *V. zizanioides* and *I. cylindrica* is illustrated in Figs. 2 and 3, respectively. From May to October, there were significant increments of tillers of the two grasses growing in Treatments A, B and C. However, those growing in Treatment D did not increase during the six-month period. The tiller numbers of *V. zizanioides* of Treatments B and C were similar, significantly more than those of Treatment D and less than those of Treatment A, while the tiller number of *I. cylindrica* followed the significantly descending order of Treatments A > B > C > D. This indicated that *V. zizanioides* and *I. cylindrica* had different responses to applications of domestic refuse and NPK fertilizer in the aspect of tiller formation; domestic refuse was more effective in improving the formation of tiller of *I. cylindrica*. In general, the combined use of domestic refuse and NPK fertilizer was best for tiller production of the two grasses. *V. zizanioides* growing in Treatment A in the present study had up to 20 tillers, an amount similar to those established in nursery (Xia et al. 1994), which indicated that the grass was well established on tailings amended with domestic refuse and NPK fertilizer.

Table 2. Physico-chemical properties of the tailings and domestic refuse used in the present experiment (mean ± sd, n = 6)

Parameter		Unit	Tailing	Domestic refuse
pH			7.13±0.11	6.65± 0.21
EC		DS/m	2.09±0.28	0.52± 0.07
Organic-C		%	0.57±0.17	1.58± 0.31
Total N		mg/kg	507±83	743± 129
Total P		mg/kg	619±75	2184± 363
Total K		mg/kg	2023±425	3035± 457
Pb	Total	mg/kg	3123±407	209± 57
	Extractable	mg/kg	98±24	4.88± 1.97
Zn	Total	mg/kg	3418±652	107± 20
	Extractable	mg/kg	101±35	3.26± 1.12
Cu	Total	mg/kg	174±31	53± 12
	Extractable	mg/kg	4.28±2.03	1.99± 0.42
Cd	Total	mg/kg	22±4.76	2.25± 0.42
	Extractable	mg/kg	0.79±0.26	0.12± 0.04

Biomass of the Four Grasses

The dry weight of the four tested grasses growing in each treatment is shown in Table 3 and Fig. 4. The total biomass of the four grasses were in the descending order of Treatment A > B > C > D ($p < 0.05$). *V. zizanioides* always had the highest biomass compared with the three other grasses in the same treatment, and *P. notatum* was only second to *V. zizanioides* and significantly ($p < 0.05$) higher than *C. dactylon* and *I. cylindrica*. The biomass of *C. dactylon* was slightly higher than *I. cylindrica* but not at a significant level ($p > 0.05$). The results presented here indicate that the applications of NPK complex fertilizer or domestic refuse significantly increased the dry weight yields of the four grasses, and the combination use of NPK complex fertilizer and domestic refuse had the best benefit for the growth of all grasses.

The overall results also indicate that *V. zizanioides* had the highest tolerance to the unfavourable edaphic conditions of the Pb/Zn tailings among the four tested species. Judging from the covers, height and dry weight yield, *V. zizanioides* was the best of the four species used for re-vegetation of the Lechang Pb/Zn mine tailings, followed by *P. notatum, C. dactylon* and *I. cylindrica*.

In fact, the population of *C. dactylon* used in this experiment had been proven to evolve higher tolerance to Pb, Zn and Cu by root elongation test (Shu 1997; Shu et al. 1998). It was also reported elsewhere that *C. dactylon* was a common species that could naturally colonize on toxic mine waste (Bradshaw and Chadwick 1980; Williamson et al. 1982; Johnson et al. 1994) and was a very useful species for re-vegetation of mine wastes (Ye et al. 1999). These authors also further proved that *V. zizanioides* had higher metal tolerance and great advantage in the re-vegetation of mine tailings.

It has long been recognized that *V. zizanioides* was tolerant of a wide range of pH, salinity, sodicity, acidity and heavy metals such as As, Cd, Cr,, Ni, Pb, Zn, Hg, Se and Cu (Xia 1999; Xia et al. 1999; Truong 1999). In Australia, *V. zizanioides* has been successfully used to stabilize mining overburden, coal mine tailings and gold mine tailings (Truong and Baker 1998). Results present here also indicated that the grass was very useful in the re-vegetation of Pb/Zn mine tailings. All the proofs suggest that the grass might have wide application in the restoration of mine waste and heavy-metal contaminated soil. The mechanisms of metal tolerance are of great scientific interest but still remain unclear and need further research. Furthermore, the distribution of heavy metals in the plant tissues should be clearly investigated to assess the risk of accumulation of heavy metals in the food chain.

Another major finding of the experiment was that the domestic refuse was a very useful ameliorative material for improving edaphic conditions of tailings. Domestic refuse not only contained high levels of NPK, but also helped to improve the poor physical properties and microbial activities of the tailings. Organic materials of domestic refuse also reduced heavy-metal toxicity to plants by complexing spoil metals (Lan et al. 1998). The application of domestic refuse may provide a cost-effective method for tailing rehabilitation, as well as an alternative for disposal of domestic refuse.

Table 3. Biomass of *Vetiveria zizanioides*, *Pasaplum notatum*, *Imperata cylindrica* and *Cynodon dactylon* growing on tailings with different treatment (Mean ± SD, n=3)

Treatment	A	B	C	D
V. zizanioides				
Shoot	1845± 192 a	1354± 165 b	975± 43 c	418± 12 d
Root	266± 43 a	218± 57 a	131± 19 b	56± 12 c
Total	2111± 227 a	1571± 202 b	1106± 60 c	474± 8.6 d
P. notatum				
Shoot	831± 153 a	490± 15 b	257± 91 c	136± 27 c
Root	259± 44 a	174± 51 bc	109± 15 cd	44± 8.3 d
Total	1090± 178 a	665± 47 b	366± 104 c	180± 36 c
I. cylindrica				
Shoot	645± 57 a	427± 82 b	180± 26 c	121± 11 c
Root	44± 7.7 a	31± 2.8 b	16± 2.7 c	12± 1.4 c
Total	689± 60 a	458± 84 b	196± 28 c	132± 12 c
C. dactylon				
Shoot	827± 73 a	502± 59 b	237± 75 c	54± 12 d
Root	71± 12 a	59± 8.3 a	24± 6.2 b	7± 1.5 c
Total	898± 74 a	562± 55 b	260± 72 c	61± 13 d

NB: Data in the same horizontal column with different letters indicate a significant difference at 5% level according to least-significant-difference test

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(Fig. 1)

(Fig.2)

(Fig.3)