Use of Vetiver and Other Three Grasses for Revegetation of a Pb/Zn Mine Tailings at Lechang, Guangdong Province: A Field Experiment

W S Shu[1], H P Xia[2], Z Q Zhang [1], C Y Lan[1] and M H Wong[3]

[1] School of Life Sciences, Zhongshan University, Guangzhou 510275, China
[2] South China Institute of Botany, The Chinese Academy of Sciences, Guangzhou 510650, China
[3] Institute for Natural Resources and Waste Management and Department of Biology, Hong Kong Baptist University, Kowloon Tang, Hong Kong, China

Abstract: The Lechang Pb/Zn mine is located at the north of Guangdong Province, South of China. The tailings pond had been abandoned over five years, and revegetation was necessary for stabilizing the bare surface of the pond to reduce its environmental impact. Chemical analysis indicated the tailings contained high content of heavy metals (Pb, Zn, Cu and Cd) and low level of major nutrient elements (N, P and K) and organic matter, heavy metal toxicity and extreme infertility were the major constraints on revegetation. A field experiment was therefore conducted to compare the growth of *Vertiveria zizanioides, Paspalum notatum, Cynodon dactylon* and *Imperata cylindraca* var. *major* on the tailings. The tailings was amended with 10 cm domestic refuse + complex fertilizer (NPK) (Treatment A), 10 cm domestic refuse (Treatment B) and complex fertilizer (NPK) (Treatment C) respectively, and tailings without any amendment used as control (Treatment D). The six months field experiment demonstrated both the domestic refuse and NPK fertilizer could improve the growth of plants on tailings, and the combination use of domestic refuse and NPK fertilizer (Treatment A) had the greatest benefits. After six months growth, *V. zizanioides* growing on treatment A had a height of 220 cm, cover of 100% and a dry weight yield of 2111 g m^{-2}. The height and biomass of V. zizanioides were significantly greater than other thress grasses growing on the same treatment. Judging from the above results, *V. zizanioides* was the best species among the four species used for revegetation of Lechang Pb/Zn mine tailings, followed by *P. notatum, C. dactylon* and *I. cylindraca* in turn.

Key words: Pb/Zn tailings; revegetation; *Vertiveria zizanioides*; *Paspalum notatum*; *Cynodon dactylon*; *Imperata cylindraca* var. *major*

1 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 problem and caused a lot of land dereliction without vegetation cover. In China, there are over 8,000 national and 230,000 private mining companies presently operating, resulting in 200,000 km^2 of derelict land, which includes the loss of 370,000 hm^2 of agricultural land (Young, 1988). Revegetation of metalliferous mine tailings is necessary for long-term stability of the land surface. The success of reclamation schemes is greatly dependent upon the choice of plant species and their methods of establishment (Bradshaw, 1987)

Vetiver grass (*Vetiveria zianioides*), due to its unique morphological and physiological characteristics, which has been widely known for its effectiveness in erosion and sediment control (Greenfield, 1995), has also been found to be highly tolerant to extreme soil conditions including heavy metal contamination (Truong and Baker, 1998). In Australia, *V. zizanioides* has been successfully used to stabilize mining overburden and highly saline, sodic, magnisic and alkaline (pH 9.5) tailings of coal mine and highly acidic (pH 2.7) and high arsenic tailings of gold mines (Truong and Baker, 1998; Truong, 1999). Bahia grass, *Paspalum notatum* is also a wide use species for soil and water conservation, and has been proved to be tolerant to unfavorable soil conditions and heavy metal toxicity (Xia, 1999; Xia and Ao, 1997). Our previous studies also indicate that *Cynodon dactylon* and *Imperata cylindraca* are of the dominant species naturally colonizing on the Lechang Pb/Zn mine tailings. Root elongation test demonstrates that the mine population of *C. dactylon* has evolved high multi-tolerance to Pb, Zn and Cu (Shu, 1997; Shu et al., 1998). Both the native grasses may have the potentiality to be used in revegetation of Pb/Zn mine tailings. Therefore, the experiment presented here 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 tailings revegetation and the most effective measure for establishing it on tailings. It is expected to develop a cost-effective method for revegetation of Pb/Zn mine tailings.

2 MATERIALS AND METHODS

2.1 Study site description

The Lechang Pb/Zn Mine is located at about 4 km east of Lechang City in the most northern part of Guangdong Province, PR China. The climate is sub-tropical and the annual rainfall is about 1500 mm. It is a conventional underground mining operation covering an area of 1.5 km^2, and produces approximately 30,000 tons of tailings annually, with a dumping area of 60,000 m^2 (Shu, 1997).

2.2 Revegetation experiment

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

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 South China Institute of Botany for field experiment. Before planting on the experiment plots, the roots of *V. zizanioides* were cut about 20 cm below the surface and there leaves were cut about 30 cm above the roots, and broke the clump into planting slips of about 3-5 tillers. The clumps of *P. notatum* were divided into single tiller with about 5 cm root and 10 cm shoot. *C. dactylon* and *I. cylindraca* 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 respectively in April 1999. After planting, treatment A and C received their first NPK fertilization, and all the 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. cylindraca* were investigated monthly. After 6 months' growth, a 0.25 m^2 quadrat (0. 5 m × 0. 5 m) was randomly placed on each subplot for sampling. Shoots of the plants were clipped at 5 mm above the ground, then excavated out the roots as completely as possible. Plant materials were washed with distilled water, oven-dried at 80 °C for 24 h for determining dry weight.

2.3 Sample collection and chemical analysis

Six mixture tailings samples and five mixture samples of domestic refuse were collected for chemical analysis. The tailings samples were collected from the top 20-cm of the Pb/Zn mine tailings 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. Samples were air-dried, ground to pass through a 2-mm sieve and analyzed 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) (molybednum blue method), total metals (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).

2.4 Statistical analysis

Least significant difference (LSD) was used to compare dry matter yields of the four grasses in the same treatment or the same species growing on different treatments.

3 RESULTS AND DISSCUSSIONS

3.1 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 3123, 3418, 174 and 22 mg kg^{-1}, while extractable concentrations were 98, 101, 4.28 and 0.79 mg kg^{-1} respectively. The tailings were slightly alkaline (pH 7.13), and its EC value was 2.09 dS m^{-1}. 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 major constraints for plant establishment and colonization. Our former studies on revegetation of Fankou Pb/Zn mine tailings also proved that the phyto-toxicity of heavy metals and extreme infertility were the major 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 amendment to ameliorate the physic-chemical properties of the tailings.

3.2 Changes of cover of the four grasses

Changes of cover of the four grasses grown on different treatments are illustrated in Fig. 1. From May to August, the cover of all the plants growing on treatment A and B showed great increments and similar growth performance, the covers of the four grasses growing on treatment A and B eventually reached 100% at October. For treatment C, there were slight increments of cover from May to July, however, they increased rapidly after the second application of NPK fertilizer in July. The cover of *V. zizanioides* on treatment C eventually reached 100% in October, while the covers of *C. dactylon*, *I. cylindraca* and *P. notatum* growing on treatment C were 80%, 50% and 80% respectively. There were no increments of covers for plants growing on treatment D from May to October, and even showed somewhat decrement, except the cover of *V. zizanioides* had 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 other three species.

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

Parameters		Units	Tailings	Domestic refuse
pH			7.13±0.11	6.65± 0.21
EC		dS m^{-1}	2.09±0.28	0.52± 0.07
Organic-C		%	0.57±0.17	1.58± 0.31
Total N		mg kg^{-1}	507±83	743± 129
Total P		mg kg^{-1}	619±75	2184± 363
Total K		mg kg^{-1}	2023±425	3035± 457
Pb	Total	mg kg^{-1}	3123±407	209± 57
	Extractable	mg kg^{-1}	98±24	4.88± 1.97
Zn	Total	mg kg^{-1}	3418±652	107± 20
	Extractable	mg kg^{-1}	101±35	3.26± 1.12
Cu	Total	mg kg^{-1}	174±31	53± 12
	Extractable	mg kg^{-1}	4.28±2.03	1.99± 0.42
Cd	Total	mg kg^{-1}	22±4.76	2.25± 0.42
	Extractable	mg kg^{-1}	0.79±0.26	0.12± 0.04

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

3.3 Tiller numbers and plant heights of *V. zizanioides* and *I. cylindraca*

The increments of tillers and plant heights of *V. zizanioides* and *I. cylindraca* are illustrated in Fig. 2 and 3 respectively. From May to October, there were significant increments of tillers of the two grasses growing on treatment A, B and C. However, those growing on treatment D didn't increase during the six months. The tiller numbers of *V. zizanioides* of treatment B and C were similar, and significantly more than those of treatment D and less than those of treatment A, while the tiller numbers of *I cylindraca* followed the significantly descend order of treatment A > B> C > D. This indicated that *V. zizanioides* and *I. cylindraca* 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. cylindraca*. In general, the combination use of domestic refuse and NPK fertilizer was best for tiller production of the two grasses. *V. zizanioides* growing on treatment A in present study had up to 20 tillers, was similar amount with 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.

3.4 Biomass of the four grasses

The dry weight of the four tested grasses growing on each treatment are 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 other three 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. cylindraca*. The biomass of *C. dactylon* was slightly higher than *I. cylindraca* but not at significant level ($p > 0.05$). Results presented here indicated that the applications of NPK complex fertilizer or domestic refuse significantly increased the dry weight yields of four grasses, and the combination use of NPK complex fertilizer and domestic refuse had the best benefit for all the grasses growth.

The overall results also indicated that *V. zizanioides* had the highest tolerance to the unfavorable edaphic conditions of the Pb/Zn tailings among the four tested species. Judging from the cover, height and dry weight yield, *V. zizanioides* was the best species among the four species used for revegetation of Lechang Pb/Zn mine tailings, followed by *P. notatum*, *C. dactylon* and *I. cylindraca* in turn.

In fact, the population of *C. dactylon* used in this experiment had been proved 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 revegetation of mine wastes (Ye et al., 1999). Those also further proved that *V. zizanioides* had higher metal tolerance and great advantage in revegetation of mine tailings.

Table 3 Biomass of *Vetiveria zizanioides*, *Pasaplum notatum*, *Imperata cylindraca* 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. cylindraca				
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

Note: Data in the same horizontal column with different letters indicate a significant difference at 5% level according to LSD test.

It was long recognized that *V. zizanioides* was tolerance to 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 stailise minings overburden, coal mine tailings and gold mine tailings (Truong and Baker 1998). Results present here also indicated that the grass was very useful in revegetation of Pb/Zn mine tailings. All the proofs suggest that the grass might have wide application in the restoration of mine wastes and heavy metal contaminated soil. However, the mechanisms of metal tolerance is of great scientific interest but still remain unclear and need for further research, furthermore, the distributions of heavy metals in the tissues should be clearly investigated to assess the risk of accumulation of heavy metals in food chain.

An 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 level of NPK, but also helping to improved 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 tailings rehabilitation, moreover, it provides an alternative for disposal of domestic refuse.

ACKNOWLEDGEMENT

The authors would like to thank colleagues of the Lechang Lead/Zinc Mine Company for their assistance in the field experiment. Financial support from the Natural Science Foundation of China (No. 39870155, 39770154) and Guangdong Natural Science Foundation (No. 980147, 990259) are gratefully acknowledged.

REFERENCES

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

Greenfield J C, 1995. Vetiver grass (*Vetiveria* spp.), the ideal plant for vegetative soil and moisture conservation. In: Grimshaw R G and Helfer L eds. Vetiver Grass for Soil and Water Conservation, Land Rehabilitation, and Embankment Stabilization. The World Bank, Washington DC, pp. 3-38.

Johnson M S, Cooke J A and Stevenson J K W, 1994. Revegetation of metalliferous wastes and land after metal mining. In: Hester and Harrison R M (Eds.), Mining and Its Environmental Impact. pp. 31-48.

Lan C Y, Shu W S and Wong M H, 1997. Revegetation of Pb/Zn mine tailings: phytotoxicity of the tailings. In: Wise D L (ed.) Global Environmental Biotechnology. Elsever Science B.V., pp.119-130.

Lan C Y, Shu W S and Wong M H, 1998. Revegetation of Pb/Zn mine tailings: the role of river sediment and domestic refuse. Bioresource Technology, 65: 117-124

Page A L, Miller R H and Keeney D R, 1982. Methods of Soil Analysis, Part 2. Chemical and Microbiological Properties, 2nd Ed. Agronomy, No.9, ASA, SSSA, Madison, Wisconsin.

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

Shu W S, Lan C Y and Zhang Z Q, 1997. Analysis of major constraints on plant colonization at Fankou Pb/Zn mine tailings, Chinese Journal of Applied Ecology, 8(3): 314-318

Shu W S, Lan C Y, Zhang Z Q, Wong J W C and Wong M H, 1998. Lead, zinc and copper tolerance in populations of *Cynodon dactylon* and *Paspalum distichum*, International Conference on Environmental Contamination Toxicology and Health, Hong Kong. p6.

Truong P N V and Baker D E, 1998. Vetiver grass for the stabilization and rehabilitation of acid sulfate soils. Proceedings of Second National Conference on Acid Sulfate Soils. Coffs harbour, Australia. pp. 196-198.

Truong P N V, 1999. Vetiver Grass technology for mine tailings rehabilitation. In: Proceedings of the first Asia-Pacific Conference on Ground and Water Bioengineering for Erosion Control and Slope Stabilization, Manila, The Philippines.

Williamson N A, Johnson M S and Bradshaw A D, 1982. Mine Wastes Reclamation. Mining Journal Books Ltd, London.

Xia H P, 1999. Comprehensive Studies on Ecological Characteristics and Applications of Vertiver, Ph.D. Thesis, Shenyang Institute of Applied Ecology, The Chinese Academy of Sciences, China.

Xia H P, Ao H X and He D Q, 1994. Effects of environmental factors on Vetiver grass growth. Chinese journal of Ecology, 13(2): 23-26.

Xia H P, Ao H X, 1997. Bahia grass – a new, excellent species for protecting slopes and used as lawn, Journal of Guangdong Landscape Architecture, 4: 33-34.

Xia H P, Ao H X, Liu S Z and He D Q, 1999. Application of the Vetiver eco-engineering for the prevention of highway slippage in South China. In: Proceedings of the first Asia-Pacific Conference on Ground and Water Bioengineering for Erosion Control and Slope Stabilization, Manila, The Philippines, pp. 522-527.

Xia H P, Wang Q L and Kong G H, 1999. Phyto-toxicity of garbage leachates and effectiveness of plant purification for them, Acta Phytoexologia Sinica, 23(4): 289-301.

Ye Z H, Wong J W C, Wong M H, Baker A J M, Shu W S and Lan C Y, 1999. Revegetation of Pb/Zn mine tailings: field trials to compare different waste materials and plant species. Restoration Ecology (in press).

Young K, 1988. Destruction of ecological habitats by mining activities. Agricultural Ecology, 16:37-40.

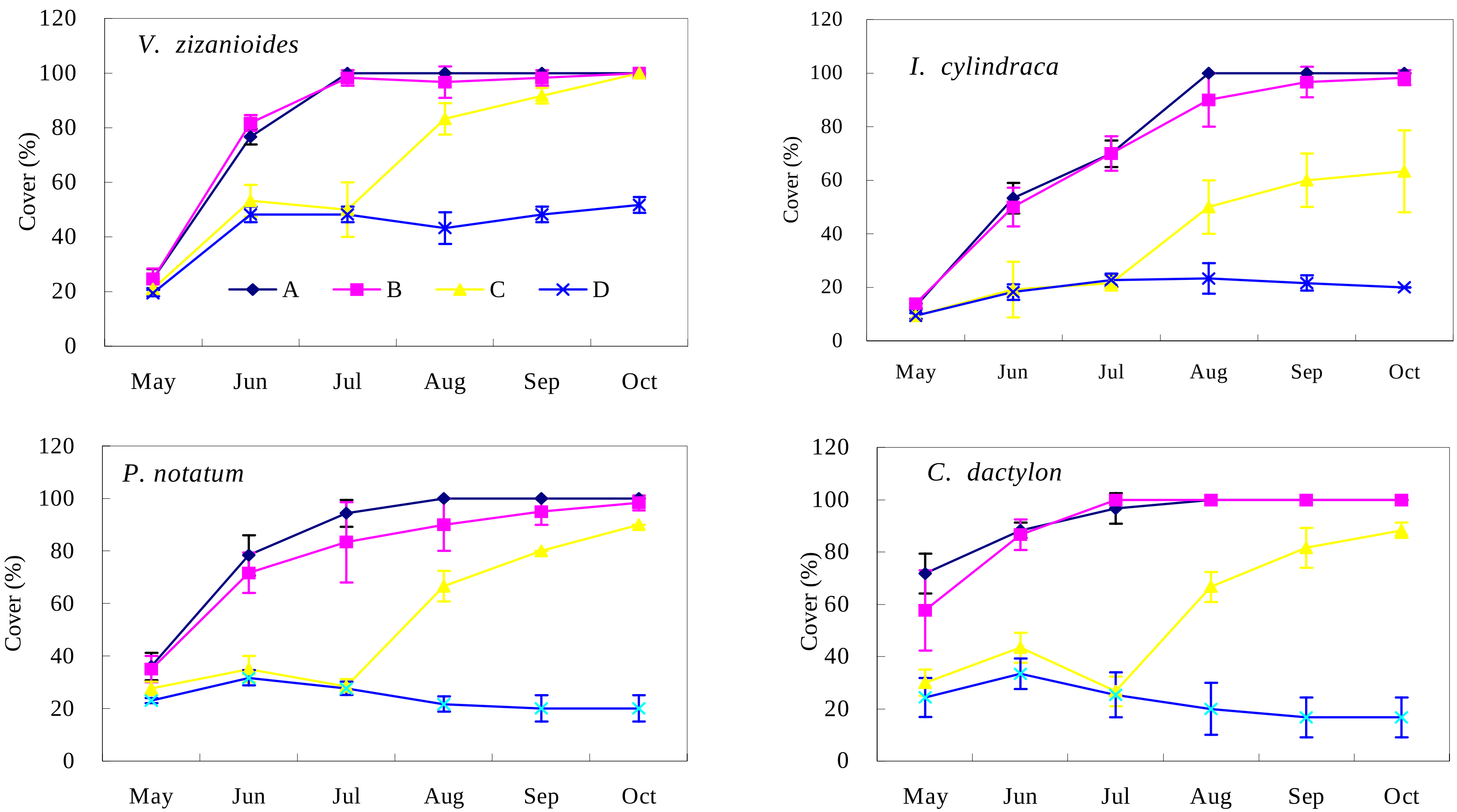

Fig. 1 The increments of cover of *Vetiveria zizanioides*, *Paspalum notatum*, *Imperata cylindraca* and *Cynodon dactylon* growing on tailings with different treatments. (A: tailings + 10 cm domestic refuse + NPK; B: tailings + domestic refuse; C: tailings + NPK; D: tailings).

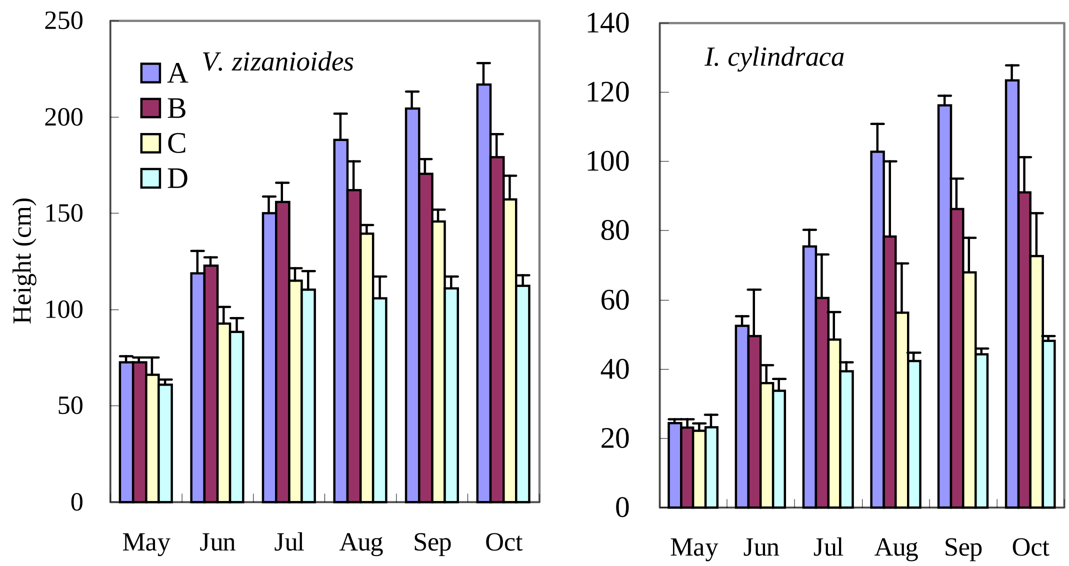

Fig. 2 The increments of heights of *Vetiveria zizanioides* and *Imperata cylindraca* growing on tailings with different treatments (Please refer to Fig. 1 for treatment explantation).

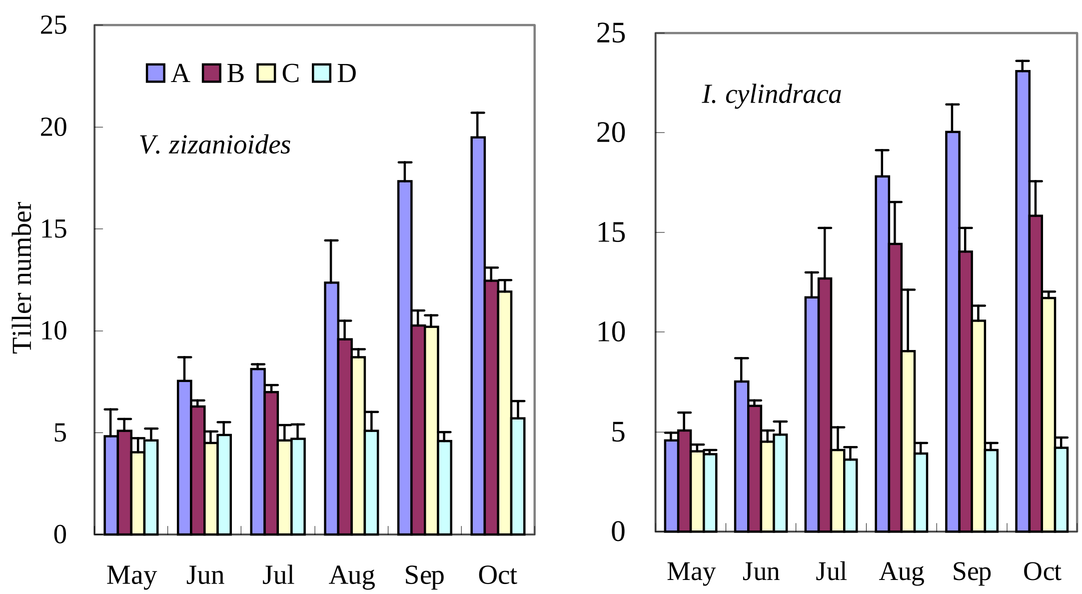

Fig. 3 The increments of tiller numbers of *Vetiveria zizanioides* and *Imperata cylindraca* growing on tailings with different treatments (Please refer to Fig. 1for treatment explantation).

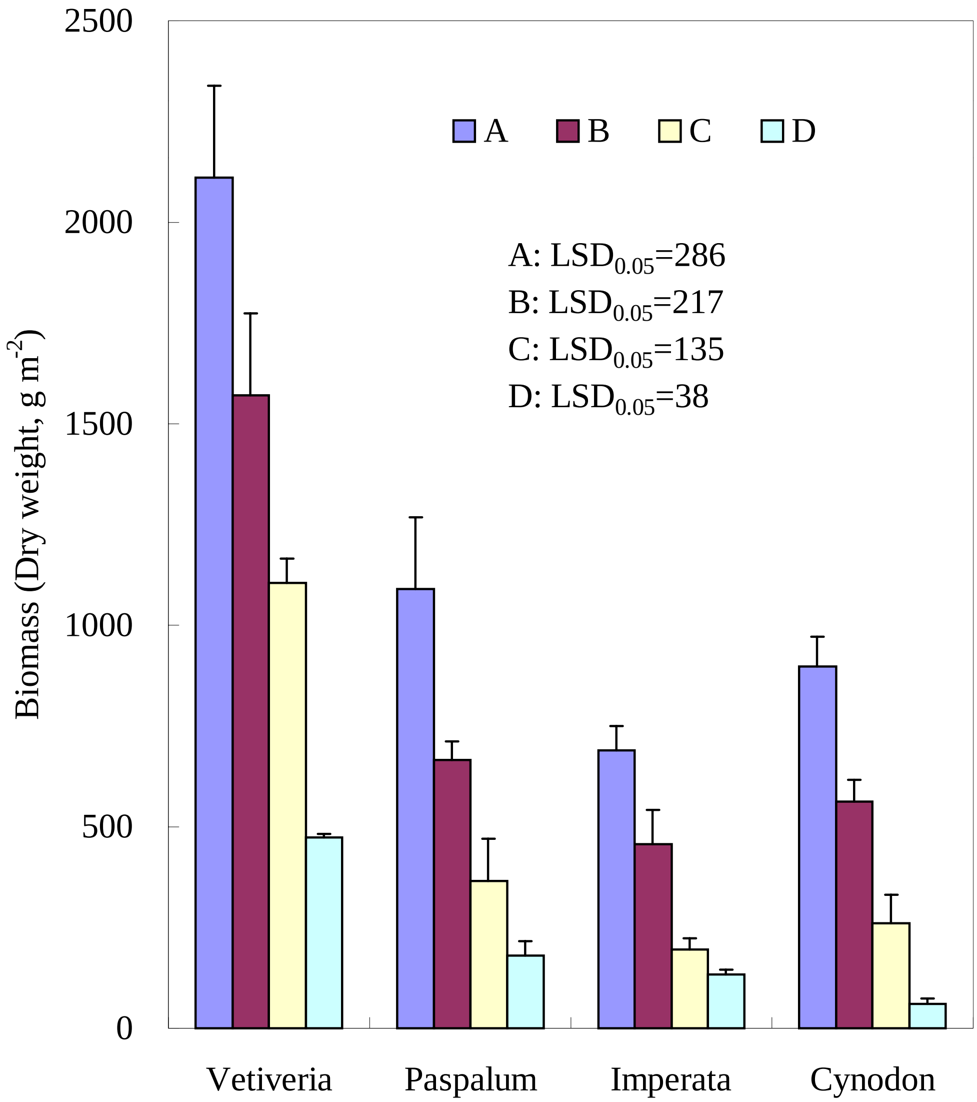

Fig. 4 Biomass of *Vetiveria zizanioides, Paspalumn potatum, Imperata cylindraca* and *Cynodon dactylon* growing on tailings with different treatments (Please refer to Fig. 1 for treatment explantation).