中山大学学报（自然科学版）
第 39 卷　第 4 期　　ACTA SCIENTIARUM NATURALIUM UNIVERSITATIS SUNYATSENI　　Vol. 39　No. 4
2000 年　7月　　Jul.　2000

文章编号：0529-6579（2000）04-0094-05

Use of Tolerant Population of *P. distichum* for Revegetation of a Pb/Zn Mine Tailings at Lechang: Field Experiment*

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Abstract: A field trial was conducted on Lechang Pb/Zn mine tailings at Shaoguan, Guangdong Province, to evaluate the growth of a metal tolerant population of *Paspalum distichum* on Pb/Zn tailings amended with soil and domestic refuse. Chemical analysis indicated that the toxic level of heavy metals (Pb, Zn, Cu and Cd) and deficiency of major nutrients (N, P, K and organic materials) were the major constraints of the tailings for plant establishment. In the first three months, *P. distichum* could successfully grow on pure tailings, but the addition of soil and domestic refuse significantly improved growth of the grass, the application of limestone not only improved plant growth, but also inhibited the uptake of heavy metals by plants. The second harvest after one-year growth indicated that there was significant increase of biomass in TDL treatment (tailings+domestic refuse+limestone) compared with the first harvest. Generally, there were evident decreases of heavy metals contents in plant in the second harvest. Results presented here demonstrated that use of tolerant species together with waste materials might be a cost-effective method for revegetation of mine tailings.

Keywords: Pb/Zn mine tailings; metal tolerance; revegetation; *Paspalum distichum*

CLC number: X753　　**Document code:** A

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. Therefore, it is essential to restore the productivity of these derelict or damaged lands. Tolerant plants can withstand adverse conditions other than those associated with toxic metals, such as drought, saline, low levels nitrogen, calcium and phosphate, direct seeding of tolerant species on mining wastes is a low input approach for revegetation[1]. Our previous study indicated that *Paspalum distichum* was one of the dominant species naturally colonizing on the Lechang Pb/Zn mine tailings, and the species had evolved high multi-tolerance to Pb, Zn and Cu and had the potentiality to be used in revegetation of Pb/Zn mine tailings[2]. Therefore, the experiments presented here aimed at assessing the growth of *P. distichum* on Lechang Pb/Zn mine tailings with different amendments. It is expected to develop a cost-

* 基金项目：国家自然科学基金资助项目（39870145，39770154）；广东省自然科学基金资助项目（990259）；广东省博士启动基金资助项目（984130）
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effective method for revegetation of Pb/Zn mine tailings.

1 Materials and Methods

1.1 Study site description and sample collection

The Lechang Pb/Zn Mine is located at about 4 km east of Lechang City in the northern part of Guangdong Province, China. The climate is sub-tropical 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 tons of tailings annually, with a dumping area of 60 000 m^2. Surface tailings samples of the top 20 cm were collected from the Pb/Zn mine tailings pond in October 1995, before the field experiment, domestic refuse was collected from a nearby landfill, surface soil (red-yellow podzolic soil) was collected from an uncultivated area far away from the mining area.

1.2 Revegetation experiment

The tailings pond was roto-tilled to a depth of 20 cm, and then divided into plots (2 m×2 m). There were six treatments (Table 1) with four replicates each arranged in a completely randomized block. All plots received a N, P, K fertilizer (w(N)∶w(P)∶w(K) = 15∶15∶15) at a rate of N 150 kg/hm^2.

Tab 1 Experimental design

	Treatment
TA	Tailings (control)
TL	Tailings+ limestone
TD	Tailings+5 cm domestic refuse
TDL	Tailings+5 cm domestic refuse+ limestone
TS	Tailings + 5 cm soil
TSL	Tailings + 5 cm soil + limestone

Note: Limestone was applied at the rate of 10 t·hm^{-2}.

P. distichum growing naturally on the waterlogged area of the Pb/Zn tailings was transplanted into the experimental plots in August 1996. After 3 months' growth, a 0.022 5 m^2 quadrat (0.15 m×0.15 m) was randomly placed on each plot for sampling. Shoots of the plant 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 ℃ for 24 h for determining dry weight and contents of Pb, Zn, Cu and Cd[3]. After one year's growth, the second harvest was conducted using the same method as the first harvest.

1.4 Chemical analysis

Air-dried tailings, soil, domestic refuse samples were ground to pass through a 2-mm sieve and analyzed for the following parameters: pH (w(solid)∶V(distilled water)=1∶2); total organic carbon (H_2SO_4+$KCrO_4$), total nitrogen (N) (indophenol-blue method), total phosphate (P), (molybednum blue method); total metal (Zn, Pb, Cd, Cu) contents (c(HNO_3)∶c($HClO_4$)=5∶1) and extractable metal (Pb, Zn, Cd, Cu) contents (extracted by DTPA, atomic absorption spectrometry)[3].

2 Results and Discussion

2.1 The properties of the tailings and amendment materials

The properties of the tested materials are listed in Table 2. The tailings possessed high concentrations of total and DTPA extractable heavy metals. Total Pb, Zn, Cu, Cd concentrations were 3 051, 3 655, 160 22 mg/kg, while extractable concentrations were 196, 79, 5.04, 0.83 mg/kg respectively. The tailings are slightly acidic with a pH of 5.47. EC values of the tailings ranged from 1.33 to 8.37 dS/m, with an average of 4.09 dS/m. Tailings were generally low in N, P and organic matter contents. Toxic levels of heavy metals, deficiency of nutrients (N, P and K) and organic matter of the five tailings were the major constraints to plant establishment and colonization.

Tab 2 **Properties of the tailings ($n = 18$), soil and domestic refuse ($n = 4$) used in present experiment**

		Tailings	Soil	Domestic refuse
pH		5.47	6.62±0.12	6.43±0.23
EC/(dS·m^{-1})		4.09	0.32±0.04	0.45±0.06
Organic-C/%		0.69±0.38	1.12±0.14	1.35±0.21
Total N/(mg·kg^{-1})		429±93	1434.68±142.17	534.43±101.21
Total P/(mg·kg^{-1})		552±79	298.22±43.56	2015.38±259.83
Total K/(mg·kg^{-1})		1562±402	3318.61±549.21	3222.91±483.26
Pb	Total/(mg·kg^{-1})	3051±604	127.04±25.74	291.63±83.24
	Extractable/(mg·kg^{-1})	196±176	8.10±0.94	6.88±2.13
Zn	Total/(mg·kg^{-1})	3655±1696	75.63±19.47	65.23±20.18
	Extractable/(mg·kg^{-1})	79.29±65	3.30±0.06	3.26±1.12
Cu	Total/(mg·kg^{-1})	160±54	2.52±0.43	65.94±10.17
	Extractable/(mg·kg^{-1})	5.04±4.50	0.57±0.07	2.85±0.52
Cd	Total/(mg·kg^{-1})	21.96±10.71	0.94±0.09	2.17±0.32
	Extractable/(mg·kg^{-1})	0.83±0.86	0.06±0.04	0.10±0.08

The surface soil and domestic refuse were also slightly acidic and had a low salinity. Compared with the tailings, both the soil and refuse contained higher levels of nutrients and lower levels of heavy metals. In all the three materials, soil had the highest N and K contents, while domestic refuse had the highest P and organic-C contents.

2.2 Biomass of *P. distichum*

The dry weight yields of *P. distichum* grown on each treatment are shown in Table 3. In the first harvest, the total dry weight yields in different treatments generally followed the descending order of TDL (tailings + refuse + limestone) ≈ TSL (tailings + soil + limestone) > TD (tailings + refuse) ≈ TS (tailings + soil) > TL (tailings + limestone) ≈ TA (tailings alone).

There were no significant differences between the root dry weight yields among the treatment of TD, TDL, TS and TSL ($P > 0.05$), but the shoot in treatments of TDL and TSL were significantly higher than the other treatments. The highest yields of *P. distichum* were obtained when grown in the tailings amended with refuse or soil + limestone, might be due to the improved nutrient conditions and the role of limestone.

Tab 3 **Biomass (g·m^{-2}, dw) of *Paspalum distichum* grown on the tailings**[1)]

Treatment	First harvest (3 months)			Second harvest (1 year)		
	Shoot	Root	Total	Shoot	Root	Total
TA	138±42^{b}	112±78^{c}	250±94^{c}	23±11^{f*}	56±25^{d*}	79±21^{e*}
TL	144±42^{b}	165±61^{bc}	309±102^{c}	58±13^{e*}	89±21^{d*}	147±18^{d*}
TD	356±48^{b}	423±119^{ab}	778±122^{ab}	339±41^{c}	352±86^{bc}	690±89^{c}
TDL	490±102^{a}	556±151^{a}	1047±148^{a}	693±129^{a*}	599±105^{a}	1292±116^{a*}
TS	339±41^{b}	352±86^{bc}	690±89^{b}	220±32^{d*}	301±79^{c}	521±54^{c*}
TSL	501±124^{a}	471±83.11^{a}	974±126^{ab}	487±82^{b}	510±143^{ab}	997±106^{b}

1) ($\bar{x}$ ± sd, $n = 4$); Different letters (within the same column) indicate a significant difference at 5% level LSD test; * indicates a significance between the first and second harvest at 5% level according to student *t*-test.

In the second harvest after one-year growth, there were significant decrease ($P < 0.05$) of biomass in treatments of TA, TL and TS compared with the firth harvest, and no significant changes of biomass in TSL and TD. However, there was significantly increase ($P < 0.05$) of biomass in TDL.

Tab 4　Heavy metal contents ($mg \cdot kg^{-1}$, dw) of *P. distichum* grown on the tailings with different amendments[1)]

Treatment	Shoot Pb	Shoot Zn	Shoot Cu	Shoot Cd	Root Pb	Root Zn	Root Cu	Root Cd
First harvest (3 months)								
TA	289.01±105.29^{a}	1091.61±487.39^{ab}	47.34±15.59	11.39±3.83	1857.74±162.08^{a}	4208.48±500.92^{a}	151.61±22.01^{a}	38.54±10.47^{a}
TL	303.47±174.95^{a}	1288.44±737.54^{a}	59.84±23.87	10.63±4.26	1717.13±144.02^{ab}	3097.57±323.44^{b}	115.96±19.13^{b}	26.93±5.17^{b}
TD	122.42±42.56^{b}	480.91±121.84^{c}	30.25±2.03	5.59±1.14	1639.95±165.38^{ab}	2826.24±497.01^{b}	99.85±17.49^{b}	24.21±2.66^{b}
TDL	98.27±18.92^{b}	380.55±151.68^{c}	34.30±3.43	5.57±2.23	1221.24±205.18^{c}	3093.49±472.66^{b}	103.91±28.45^{b}	22.73±5.83^{b}
TS	281.00±76.67^{a}	642.22±147.55^{bc}	42.88±20.74	9.84±5.21	1595.57±407.74^{a}	3346.79±744.28^{b}	115.26±27.24^{b}	24.06±4.86^{b}
TSL	133.05±41.03^{b}	678.33±133.95^{bc}	34.60±7.46	7.28±3.67	1509.12±234.73^{b}	3279.72±402.96^{b}	129.31±11.32^{ab}	26.91±2.51^{b}
Second harvest (1 year)								
TA	253.21±44.27^{a}	892.45±223.48^{a}	33.26±10.15^{ab}	10.58±3.29^{a}	2015.48±223.94^{a}	4415.23±606.63^{a}	123.25±29.24^{a}	30.23±6.26^{a}
TL	202.62±39.59^{ab}	779.43±121.68^{a}	40.35±10.13^{a}	8.25±2.17^{ab}	1759.13±354.62^{ab}	3201.45±403.26^{b}	143.48±39.12^{a}	25.24±4.83^{ab}
TD	81.00±26.67^{cd}	302.57±79.18^{cd}	28.12±9.34^{ab}	5.72±2.23^{bc}	1020.31±203.15^{ab}	2258.13±403.27^{c}	64.13±15.96^{c*}	13.78±2.49^{b*}
TDL	58.26±21.54^{d*}	228.54±65.43^{d*}	15.28±4.51^{c*}	4.23±1.08^{c}	818.27±204.59^{c*}	2004.15±303.28^{c*}	37.28±7.23^{d*}	15.42±4.41^{b}
TS	185.54±34.27^{b}	432.19±79.53^{b}	32.43±3.57^{ab}	6.23±1.87^{abc}	1413.26±303.87^{a}	2993.55±403.52^{b}	103.54±11.32^{ab}	15.58±4.97^{b*}
TSL	101.43±17.65^{c}	397.14±82.25^{bc*}	25.43±4.25^{b}	5.63±1.98^{bc}	1383.75±229.12^{b}	3132.58±503.41^{b}	82.54±28.45^{bc*}	17.95±4.28^{b*}

1) (x ± sd, $n = 4$); To each harvest, data within the same column of with different letters indicate a significant difference at 5% level according to the LSD test; Data followed by * indicate a significant difference between the first and second harvest at 5% level according to Student t-test

Our previous studies revealed that the Lechang mine tailings contained high level of pyrite, when the pyrite exposed to air and water, it would be oxidized quickly and produced large amount of acidity, the lowest pH of acidity tailings at Lechang was 1.69[4]. Therefore, the degradation of vegetation after one－year growth might be due to the acidification of the tailings. The highest and increased biomass obtained at TDL might be due to two factors: firstly, the high P content in domestic refuse (Table 2) not only provided enough P for plant growth, but also inhibited the acidification process of the pyritic tailings[5], secondly, the application of limestone could neutralize the acidity produced from the tailings, and reduce the phytotocixity of heavy metals.

2.3　Heavy metal contents in *P. distichum*

Heavy metal contents in roots and shoots of *P. distichum* are listed in Table 4. Cu and Cd contents in shoots of the grasses did not show any significant difference ($P > 0.05$), while Pb and Zn contents in shoots of the plants grown on the control and tailings amended with limestone were higher than those of the other treatments ($P < 0.05$). It was observed that roots of *P. distichum* grown on all treatments accumulated very high amounts of Pb and Zn, such as the concentrations of Pb and Zn in the roots of TA treatment were 1 858 and 4 208 mg/kg, respectively. Metal accumulation has been recognized as an extreme type of physiological response in heavy metal tolerance. In general, the concentrations of Zn and Pb in roots were higher than in aerial parts of *P. distichum* by many folds. The results also indicated that *P. distichum* exhibited the ability to exclude the metal from aerial parts. Compared with the first harvest, there were no evident changes of metal contents in plants. However, metal contents (Pb, Zn, Cu and Cd) in root and shoot of *P. distichum* in TDL treatment were significantly decreased ($P < 0.05$) in the second harvest (Table 4). This might be due to the growth dilution, because plants grown on TDL had significant higher biomass in the second harvest than that in the first harvest.

3 Summary

Lechang Pb/Zn mine tailings contained high levels of total and extractable heavy metals (Pb, Zn, Cu and Cd) and low levels of N, P, K and organic materials. The toxicity of heavy metals and deficiency of macro－nutrients were the major constraints for plant establishment. The result from the first harvest demonstrated that *P. distichum* had satisfactory growth on tailings without any amendment, and also indicated that *P. distichum* had high heavy metal tolerance. Tailings amended with surface soil and domestic refuse great improved the growth of *P. distichum* on the tailings, due to the relative higher nutrient contents of soil and domestic refuse. Application of limestone aided to increase plant growth, and inhibit the uptake of heavy metal by plant. The overall results demonstrated that using tolerant ecotype of *P. distichum* together with domestic refuse and limestone treatment was an ideal approach for revegetation of Pb/Zn mine tailings.

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双穗雀稗重金属耐性种群在铅锌尾矿生长的野外实验研究

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摘　要：利用双穗雀稗（*Paspalum distichum*）的重金属耐性生态型，结合土壤、垃圾和石灰改良尾矿，在广东乐昌进行了为期一年的尾矿植被重建的野外试验．重金属毒性和极端贫瘠是乐昌铅锌尾矿植物定居的限制因子．野外试验第 1 次收割结果表明（3 个月），双穗雀稗可以在乐昌铅锌尾矿正常生长，而尾矿覆盖 5 cm 的土壤或垃圾则可大幅度提高它的生物量．施用石灰不仅促进植物的生长，同时可抑制植物对重金属的吸收．第 2 次收割结果表明（1 年），除了 TDL 处理（尾矿＋5 cm 垃圾＋石灰）双穗雀稗的生物量较第 1 次收割有着极显著的提高，但各处理组（尤其是 TDL 处理）植物体内的重金属含量普遍有所降低．实验证明利用耐性植物可在经轻度改良的尾矿上成功定居．

关键词：双穗雀稗；重金属耐性；植被重建；铅锌尾矿
中图分类号：X753

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