Application Vetiver and Three Other Grasses to Oil Shale Mine for Revegetation and Phytoremediation

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Abstract: Vetiver grass (*Vetiveria zizanioides*), bahia grass (*Paspalum notatum*), St. Augustinegrass (*Stenotaphrum secundatum*), and bana grass (*Pennisetum glaucum*_*P. purpureum*) were selected to rehabilitate the degraded ecosystem of an oil shale mined land of Maoming Petro-Chemical Company located in Southwest of Guangdong Province, China. Among them, vetiver had the highest survival rate, up to 98.6%, followed by bahia and St. Augustine, 96.5% and 90.9% respectively, whereas bana has the lowest survival rate of 61.7%. The coverage and biomass of vetiver were also the highest after six-month planting. Fertilizer application significantly increased biomass and tiller number of the 4 grasses, of which St. Augustine was promoted most, up to 70.1%, while vetiver was promoted least, only 27.4%. Two heavy metals, lead (Pb) and cadmium (Cd) tested in this trial had different concentrations in the oil shale residue, and also had different contents and distributions in the four grass species. Concentrations of Pb and Cd in the four grasses presented a disparity of only 1.6–3.8 times, but their uptake amounts to the two metals were apart up to 16–35 times, which was chiefly due to the significantly different biomasses among them. Fertilizer application could abate the ability of the four species to accumulate heavy metals, namely concentration of heavy metals in plants decreased as fertilizer was applied. The total amount of metals accumulated by each plant under the condition of fertilization did not decrease due to an increase of biomass. In summary, vetiver may be the best species used for vegetation rehabilitation in oil shale disposal piles.

Key words: oil shale mined land, phytoremediation to heavy metal, *Vetiveria zizanioides*; *Paspalum notatum*; *Stenotaphrum secundatum*; *Pennisetum glaucum*_*P. purpureum*

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1 INTRODUCTION

Opencast mining activities usually yield extremely harsh surroundings, including large quantities of waste materials, high concentrations of pollutants, and severely infertile soils. As a result, the kind of hard surroundings forms a lot of land dereliction without vegetation cover. Alone in China, for example, a total of 2.88 _10^6 ha of destroyed land has been produced in mined areas and furthermore a mean of 46 700 ha of destroyed land is increased annually (Shu *et al*., 2000). These destroyed lands are almost completely devoid of vegetation due to serious pollution, and eventually produce severe soil erosion and off-site pollution. Therefore, revegetation of mined lands is necessary for pollution control and the long-term stability of the soil surface. However, whether the success of restoration or not is greatly dependant on the choice of plant species and their methods of establishment (Bradshaw, 1997; Bradshaw and Huttl, 2001).

Compared to trees and shrubs, herbaceous plants, especially grasses have characteristics of rapid growth, large biomass, strong resistance, and effective stabilization to soils and, therefore, usually result in excellent restoration effects in degraded and mined lands, particularly in the tropics and subtropics with high temperature and precipitation (Xia *et al*., 1999; Gilbert, 2000; Ye *et al*., 2000; Loch, 2000). However, data on the application of herbs or grasses in oil shale mined land and on the effectiveness of this type for rehabilitation are lacking despite the fact that there have been a few examples about ecological restoration of oil shale minesites (Toomik and Liblik, 1998; Sydnor and Redente, 2000).

Vetiver grass (*Vetiveria zizanioides* (L.) Nash) has been well documented to have a strong resistance to the execrable environment and to be able to survive in high concentrations of heavy metals (Xia *et al.*, 1998; Truong, 1999). In Australia, vetiver has been used successfully to stabilize mined land, highly saline, alkaline (pH 9.5) coal mined land, and highly acidic (pH 2.7) gold mined land (Truong and Baker, 1998; Truong, 1999). Similar applications have been reported in China (Xia, 2001). Bahia grass (*Paspalum notatum* Flugge) is also an excellent species in the respect of ecological restoration and turf and forage application (Kalmbacher and Martin, 1998; Reynolds *et al.*, 1999; Xia and Shu, 2001). St. Augustine (*Stenotaphrum secundatum* (Walt.) Kuntze) is a newly introduced species used as turfgrass in Guangdong, and also used as forage in some countries. It has been reported that this species is tolerant to drought and salinity (Marcum and Murdoch, 1994; Carrow, 1996; Qian and Engelke, 1999). Bana grass (*Pennisetum glaucum* (L.) R. Br._*P. purpureum* schum.), very similar to elephant grass (*P. purpureum*), has just been used as forage in Guangdong in recent years, but its botanic and ecological features so far have been very poorly documented (Koester *et al.*, 1992a, b; Van De *et al.*, 1999). The performance of the four grasses and their rehabilitation effects applied in oil shale mined lands remain to be documented. Therefore, the present study aims at investigating and evaluating the impacts of oil shale waste on growth of the above four grass species, and their efficiency for the revegetation of oil shale soil under the influence of fertilization/non-fertilization. The objective is to identify one or two species of plants that have the resistance to adverse conditions of oil shale dump and have the ability to accumulate and remove heavy metals.

2 MATERIALS AND METHODS

2.1_Study Location

Maoming City is located in the southwest of Guangdong Province, situated in between 21°25_–22°42_N and 110°21_−111°46_E. Its geographical position is transitioning from the tropics through the low-subtropics, near to South China Sea. The climate of the area is marine monsoon; the mean annual temperature is 23.2 _, and the mean monthly maximum and minimum temperatures are 28.4 _ (July) and 15.5 _ (January), respectively. The mean annual precipitation rainfall is 1567 mm, with distinctly dry (from October to March) and wet (from April to September) seasons, never snow or frost. Rainfall and heat in here are abundant and coincident, which are beneficial to growth of plants. As a result, the formed regional vegetation is tropical rain forest.

Maoming Petro-Chemical Company (MPCC for short below), the China Petro-Chemical Corporation is regarded as one of the China's largest nationally graded petro-chemical companies with respect to mining oil shale and refining oil from oil shale. However, the company, in the process of dozens of years of operation, discharged large amounts of wastes, among them oil shale waste residue coming from oil refining has become one of the most conspicuous environmental issues in the company and even in the whole Maoming City. The dumped solid waste not only occupied large areas of land, about 8 km^2, but its drainage resulted in off-site pollution, contaminating farmlands, fishponds and ground waters in the nearby and lower reaches. Due to severe damages to the environment, properties, and health of the local residents, the company has to compensate them over RMB_1 000 000 Yuan (equivalent to about US$120 000) each year. Therefore it is a thorny problem to be settled urgently (Deng *et al.*, 2000).

The huge oil shale dump, used to be natural grassland or farmland, is situated in the north suburb of Maoming City, approximately 10 km from the city center. Since 1971, this tract of land was used to pile oil shale wastes and oil shale contained surface soils, resulted from oil shale excavation, separation, combustion, and refining. It continued until 1992. As a result, solid waste up to 156_10^6 m^3 was disposed during the over two decades, and a huge man-made landform with an area of about 667 ha and a depth of several to over ten meters was developed. Previous investigations by MPCC indicated that the main problems of the dump were very bad soil quality, strong acidity, poor water-holding capacity, and partial contamination by heavy metals (Deng *et al*., 2000). The combination of these adverse physical and chemical features yielded an environment hostile to organisms and, therefore, it was quite difficult to revegetate it. Since 1987, some rehabilitation projects, mainly planting trees around this dump, have been conducted, which produced some ecological and economic benefits. However, the cost for planting trees is quite high and furthermore its speed producing benefits is relatively slow. And even this is the case, there were still over 400 ha area left in the state of desolation, and only part of this area naturally grew some drought-resistant species, such as *Eragrostis* spp., *Chrysopogon aciculatus*, *Paspalum* spp.; no any tree and extremely few shrubs existed naturally (Liu *et al*., 2002).

2.2_Plant Growth Field Experiment

A field plot trial in the oil shale dump was designed to test the growth of vetiver, bahia, St. Augustine, and bana in this kind of substrate amended with inorganic fertilizer and fishpond sludge. Vetiver and bana are highly stalked grasses and have similar morphologies; bahia and St. Augustine are turf-typed and also have similarities each other. They were all transported to the experiment spot simultaneously one year after growing in the nursery of South China Institute of Botany, Guangzhou. Prior to conducting the experiment, a surface soil sample, top 20 cm, was collected at 10 points from the spot with soil core, used for basic characteristic analysis. Water samples leaching out from the four sides and the middle of the residue spot were simultaneously collected (5 duplicates). The whole field experiment was composed of 12 plots, and each plot had an area of 16 m^2 (4 m_4 m) and was equally divided into 4 sub-plots, which were arranged as follows: control (nothing applied), treatment A (5 cm deep fishpond sludge), treatment B (complex inorganic fertilizer), and treatment C (5 cm deep sludge and fertilizer). The fertilizer was come out from Finland, and its N, P, and K contents were all 15%. The application rate of fertilizer was 75 kg N.hm^{-2}, or 200 g fertilizer per sub-plot (4 m^2). Sludge and fertilizer were all applied uniformly prior to cultivating the plants. The four plant species were all planted according to a same format and spacing of 8 clumps _ 8 clumps in each sub-plot. Vetiver was planted 3 tillers per clump, and bana 2 tillers due to its thicker stalk; they two were cut to 30 cm high before planting. St. Augustine and bahia were all planted 2 tillers or stems per clumps and 10–15 cm long for each tiller or stem. The plots and sub-plots were arranged as 3 duplicates in a randomized block design.

The field design and operation was started on May 7^{th} –8^{th}, 2000. The first investigation was carried out on May 27^{th}; the investigation contents contained: 1) the total survived rate of each species, and 2) the plant height and tillers number of vetiver and bana, the two high stalked species. Each sub-plot was marked 8 clumps for investigation, and then marks were made for them after the first investigation. The second investigation and succeeding harvest were carried out on November 16^{th} of the same year. The plant height and tillers number of vetiver and bana were measured the marked 8 clumps of each sub-plot, and the cover and biomass (fresh weight, including roots and shoots) of the four species were investigated. The height and tiller number of bahia and St. Augstine were not determined due to their stoloniferous characteristic. Thereafter, plant samples were carefully reaped, and washed with tap water and rinsed with deionized water successively to remove any attached particles; then they were divided into shoots and roots, and oven-dried at 80_ to a constant weight, and dry weight yields were recorded.

2.3_Sample Analysis

Soil and plant (including roots and shoots) samples were analyzed after they had been ground in a stainless steel mill to pass through a 20-mesh sieve. The soil samples were measured for the following parameters: pH (1:2.5 solid : distilled water, using a pH acidmeter), organic matter (the $K_2Cr_2O_7$ digestion method), total N (the Kjedahl method), total P (the molybdenum blue method after the samples were digested with concentrated H_2SO_4 + $HClO_4$), total K (digested with Na_2CO_3 and then measured with flame photometer), hydrolytic N (the microdiffusion method), available P (molybdenum blue method after samples were extracted with $NaHCO_3$), available K (after samples were extracted with NH_4OAc), and total metal (atomic absorption spectrometry (AAS) after samples were digested with concentrated HNO_3 + $HClO_4$) (Lu, 1999). As to the plant samples, they were digested with concentrated HNO_3 + $HClO_4$ and then contents of Pb and Cd in the digestates were determined by AAS. The pH values of water samples were measured with the same acidmeter used to measure the above soil sample. COD was measured as the consumption of dissolved oxygen after the wastewaters were oxidized with $KMnO_4$; and BOD was also referred to as the consumption of dissolved oxygen after the wastewaters were incubated 5 days at 20_ in an incubator. Total N was oxidized with $K_2S_2O_8$ and analyzed with an ultraviolet spectrophotometer. Ammonia-N and NO_3^--N were determined with direct distillation and colorimetry of phenol disulfonic acid ($C_3(CH)_3(HSO_3)_2OH$), respectively; total P was digested with H_2SO_4-$HClO_4$, then the contents of total P and PO_4^{3-}-P were measured colorimetrically; metal elements were all measured with AAS (He, 2001).

2.4_Statistical Analysis

One-way analysis of variance was carried out to compare the means of different treatments. Means separation tests were performed using LSD at the P=0.05 level after significant F values were obtained.

3 RESULTS AND DISCUSSION

3.1_Basic Chemical Properties of Oil Shale Residue and Its Leachate

The oil shale dump was mainly composed of oil-refined wastes with relatively high contents of organic matter, up to 3.61%, and mixed with infertile soils coming from oil shale excavation (Table 1). Although the soil organic matter content was not low, contents of N, P and K nutrients, especially their available contents, were distinctly scarce. Furthermore the pH of soil and leachate was low, 4.01 and 3.20, respectively, hostile to the growth of plants (Table 1). Heavy metal concentrations in the soil were from the lowest 0.084 mg/kg for Cd to the highest 59.49 mg/kg for Mn. None of the analyzed eight metals exceeded the Second Grade Standard Values of China National Soil and Environment (GB5618–1995), indicating that the kind of substrate generally do not yield heavy metal toxicity to animals through food chains even if it entails reinstating pasture for livestock or wildlife. The leachate quality was also below the China National Second Grade Effluent Standard (GB8978–1996) except for its acidity.

3.2_Survival rates and plant coverage

The survival rates of 4 grasses in different treatments after planting for 20 days and their coverage after planting for 6 months later are listed in Table 2. In any treatment, the survival rates of vetiver were higher as compared to those of the other 3 species. There were, however, no substantial differences among vetiver, bahia, and St. Augustine, and their mean values were, respectively, 98.6%, 96.5%, and 92.0%. For bana, the survival rate was only 61.7%, significantly lower than the former 3 species ($P<0.05$), indicating its poorest adaptation to the oil shale environment. The survival rates within a same species in different treatments were quite similar, indicating that sludge and/or fertilizer application did not influence the survival rate of plants tangibly. Fertilization promoted the growth and sprawl of plants, in particular of bahia and St. Augustine because the covers of plants with fertilization treatment were all higher than those of plants without fertilization (Table 2).

Table 1_General chemical characteristics of the oil shale disposal soil and its leachates

Parameter	Unit	Leachate (mean±sd)	Soil	A*
pH		3.20±1.29	4.01	/
Organic matter	%	/	3.61	/
COD_{Cr}	mg/L	38.0±23.5	/	/
BOD_5	mg/L	1±0	/	/
Total N	g/kg or mg/L	1.90±0.88	0.96	/
Hydrolytic N	mg/kg	/	69.1	/
NH_4^+	mg/L	1.5±0.7	/	/
NO_3^-	mg/L	Not detectable	/	/
Total P	g/kg or mg/L	0.022±0.043	0.40	/
Available P	mg/kg	/	0.60	/
PO_4^{3-}	mg/L	Not detectable	/	/
Total K	g/kg	/	7.90	/
Available K	mg/kg	/	54.80	/
Total Pb	mg/kg or mg/L	0.0017±0.0005	31.82	28.9
Total Cd	mg/kg or mg/L	Not detectable	0.084	0.04
Total Cu	mg/kg or mg/L	0.0061±0.0021	20.35	11.4
Total Zn	mg/kg or mg/L	0.058±0.039	38.63	35.8
Total Mn	mg/kg or mg/L	9.49±1.44	59.49	151
Total Ni	mg/kg	/	14.73	8.8
Total Cr	mg/kg	/	22.59	34.8
Total As	mg/kg	/	8.63	7.1

A is the middle value of natural background values of soil in Guangdong Province, China, cited from Liu *et al.* (2002). "/" means not to be measured or recorded.

Table 2_The survival rate and the coverage of 4 grass species after planting in the oil shale disposal soil for 20 d and 6 months, respectively (mean±sd)

Species	Survival rate (%)				Cover (%)	
	Control	Treatment A	Treatment B	Treatment C	Control	Treatment B
vetiver	99.2±0.8	97.6±1.6	98.4±0.0	99.2±0.8	85	90
bahia	98.4±1.4	95.3±3.6	96.9±1.3	95.3±3.1	50	65
St. Augustine	94.5±2.7	94.5±3.0	83.6±10.7	91.4±3.6	20	30
bana	63.3±3.6	62.5±5.9	57.8±3.4	63.3±2.9	65	70
LSD(0.05)	4.4	7.2	11.1	5.3	/	/

3.3_Tiller Number and Plant Height

Table 3 shows the increments of tillers and height of vetiver and bana 20 days and 6 months after planting. It can be seen from this table that: 1) Vetiver produced new tillers far earlier and faster than bana did. In the first 20 days, increments of new tiller number and net plant height of vetiver dramatically exceeded those of bana; whereas the newly sprouted tiller number of the latter even was lower than its dead number, as a result 3 of 4 treatments became minus values. 2) An early treatment to soil substrate, e.g. fertilization, was probably disadvantageous to the early growth of transplanted plants under the condition of oil shale wastes. This is because the 3 treatments of vetiver were lower than its control regarding increments of tiller number and plant height; bana showed identical trends. 3) Dependency of bana of fertilizer was more visible than vetiver because the former was 4.7 (42.7/9.0) while the latter only 2.1 (49.0/23.0) with respect to the ratio of newly increased tiller number between treatment B and control at the second investigation. Vetiver increased 23 new tillers per 8 clumps in control while bana only increased 9, further indicating that vetiver had strong endurance to infertility (Truong, 1999; Xia *et al.*, 1999). 4) Fertilizer application seemed only to promote new tiller formation, not to the growth of plant height, as the plant heights of the two species in treatment B were not higher than those of control. Our previous observation found that vetiver and bana could increase their tillers by about 10 times and grow up to 1.5–2 m in nursery or even in common soil after planting for 6 months (Xia *et al.*, 1994). Therefore, the above results indicate that the growth and development of the two grasses was severely inhibited in the oil shale mined land with and without fertilization.

Table 3_Increments of plant height and tillers number of vetiver and bana 20 d and 6 months after planting

Observing item	Grass species	First observation				Second observation	
		Control	Treatment A	Treatment B	Treatment C	Control	Treatment B
Increase of tillers (No./8 clumps)	Vetiver	14.3	6.7	7.0	8.3	23.0	49.0
	Bana	-2.0	-1.3	-6.0	1.3	9.0	42.7
Increase of plant height (cm)	Vetiver	30.0	25.8	28.0	22.7	110.3	107.6
	Bana	4.3	2.9	2.8	2.2	97.2	89.2

3.4_Biomass

Biomass growth of the four grasses grown in oil shale waste for 6 months, including control and fertilization treatments, all presented in a distinct sequence of vetiver > bana > bahia > St. Augustine ($P<0.05$) (Table 4). Although the survival rates of bana were far lower than those of bahia and St. Augustine, its biomass was significantly larger than those of the two species. This indicates that bana would grow fully as long as it could survive in oil shale waste. Bana exceeded vetiver and ranked the first place if the biomass was expressed with the amount per clump. For instance, in treatment B, the fresh weights of bana and vetiver were 155 g and 134 g, respectively, per clump averagely. Table 4 shows that vetiver had the smallest, bana and bahia were in the middle, and St. Augustine was the largest ratio of total biomass between the fertilizer treatment and control. This was coincident also in both root and shoot, which further indicated that vetiver had the lowest fertilizer requirement while St. Augustine had the highest. Variance analysis showed that the biomasses of the four species were significantly bigger in Treatment B (fertilizer application) than in the control ($P<0.05$). This indicates that applying fertilizer promoted the growth of the four grasses. This result further verifies that fertilization is effective to vetiver growing on infertile soil (Xia *et al.*, 1994, Panchaban and Ta-oun, 1998). It also indicates that fertilization should be indispensable in order to promote the growth of plants in, and their revegetation to, mined lands, despite a possibly negative influence of fertilizer on survival of grasses (Table 3). In addition, regarding the ratio of biomass of the fertilization treatment to that of the control, except for bahia, the other three species assumed that their values in Treatment B (Fertilization) were smaller than their respective ones in Control (Table 4). That is to say, a relative increment of shoot biomass was more than that of root biomass after applying fertilizer. Plants have been documented to increase root/shoot ratio when stressed by harsh environments (Shu *et al.*, 1997; Xia *et al.*, 1999). In the present study, the root/shoot ratios of three out of four grasses in the fertilization treatment were smaller than in the control. This suggests that fertilizer application ameliorated the habitat of oil shale waste and promoted growth of plants, especially their shoots.

Table 4_Comparison of biomass of 4 herbaceous plants growing in oil shale waste dump[a]

Species	Control				Fertilization (Treatment B)				Fertilization/Control		
	Shoot g dw/m^2	Root g dw/m^2	Total g dw/m^2	Root /shoot	Shoot g dw/m^2	Root g dw/m^2	Total g dw/m^2	Root/ shoot	Shoot	Root	Total
Vetiver	451.3a	55.1a	506.4a	0.122	580.8a	64.6a	645.4a	0.111	1.29	1.17	1.27
Bana	240.5b	26.9b	267.4b	0.109	330.0b	35.3b	365.3b	0.107	1.37	1.31	1.37
Bahia	190.7b	15.4c	206.1b	0.081	245.5c	20.1c	265.6c	0.082	1.29	1.30	1.29
St. Augustine	33.4c	2.15d	35.5c	0.064	57.2d	3.16d	60.4d	0.055	1.71	1.47	1.70

[a] Means followed by the same letter in the same column are not significant different at the 5% probability level by LSD test

3.5_Phytoremediation for Pb and Cd of oil shale waste

Compared to the background values of soils in Guangdong Province, six (Cu, Zn, Ni, Pb, Cd, and As) of the eight heavy metals were on the higher side (Table1), implicating that contents of toxic metals in oil shale of

Maoming are elevated. In view of severer phytotoxicity and higher content of Cd and Pb, especially Cd, than other metals (Table 1), thereby, taking Cd and Pb as example, the uptake features of the four grasses to heavy metals and the effects of fertilizer application on metal uptake were evaluated in here.

3.5.1_Distribution and content of Pb and Cd in plants

Distributions and contents of Pb and Cd in the 4 grass species were all different 6 months after grown in non-fertilization treatment (Control) (Table 5). Concentrations (mg/kg) of Pb in roots ranked as vetiver (2.53) > bahia (1.93) > bana (1.38) > St. Augustine (0.66), while in shoots were in order of vetiver (1.11) > bana (0.98) > bahia (0.94) > St. Augustine (0.51), of which the last species was much lower than the former three. Cd concentration (mg/kg) in roots was as follows: bahia (0.216) > bana (0.175) > St. Augustine (0.112) and vetiver (0.102), but in shoots became bana (0.209) > bahia (0.081), St. Augustine (0.063), and vetiver (0.057). It is obvious that the higher concentration of a metal in a plant indicates the stronger ability of the plant to take up the metal. However, none of the four grasses simultaneously showed the strongest ability to absorb the two metals (Table 5). In the aspect of metal distribution in plants, the four species accumulated far higher concentrations of metals in roots than in their respective shoots except for the distribution of Cd in bana, which transferred most of the absorbed Cd into its shoots. This result reveals that the roots of plants have a retention function to heavy metals (Truong, 1999; Xia *et al.*, 2000; Xia and Shu, 2001). Among them, the strongest retention ability of root to metal occurred in vetiver to Pb and bahia to Cd, and the two concentrations in roots were more twice than in their respective shoots. The above results suggest that: 1) plant species assumes different uptake abilities and allocating situations to different metals; and 2) the uptake and transferring of different plant species to one same metal are also different.

Table 5_The concentrations of Pb, Cd in shoots and roots of the 4 grasses 6 months after establishing in non-fertilization disposal soil

Species	Pb			Cd		
	Shoot (mg/kg)	Root (mg/kg)	Root/ shoot	Shoot (mg/kg)	Root (mg/kg)	Root/ shoot
Vetiver	1.11±0.10a*	2.53±0.33a	2.28	0.057±0.009b	0.102±0.006c	1.79
Bahia	0.94±0.17a	1.93±0.82ab	2.05	0.081±0.054b	0.216±0.033a	2.67
St. Augustine	0.51±0.02b	0.66±0.12c	1.29	0.063±0.008b	0.112±0.032bc	1.78
Bana	0.98±0.15a	1.38±0.11b	1.41	0.209±0.014a	0.175±0.065ab	0.84

*Mean±sd; same letters in the same column indicate no significant difference at P=0.05 level

Table 6_The concentrations of Pb, Cd in shoots and roots of the 4 grasses 6 months after establishing in the disposal soil with fertilizer application

Species	Pb			Cd		
	Shoot (mg/kg)	Root (mg/kg)	Root/ shoot	Shoot (mg/kg)	Root (mg/kg)	Root/ shoot
Betiver	0.98±0.06a*	1.53±0.21a	1.56	0.052±0.002b	0.082±0.014c	1.58
Bahia	0.62±0.03bc	1.26±0.09a	2.03	0.079±0.011a	0.214±0.005a	2.70
St. Augustine	0.41±0.08c	0.44±0.12b	1.07	0.049±0.008b	0.074±0.018c	1.51
Bana	0.81±0.09ab	1.23±0.11a	1.52	0.088±0.016a	0.137±0.078b	1.56

-Mean±sd; same letters in the same column indicate no significant difference at P=0.05 level

Concentrations of Pb and Cd in the four plant species six months after growth in the fertilizer applied waste dump are shown in Table 6. Their concentrations and ranking sequences in the shoots or roots of the four grasses were similar to those in the control (Table 5). In addition, Pb concentration in soil was more 380 times than Cd, which can be calculated from Table 1, but Pb in plants was only 2.9 – 24.8 times higher than Cd (Table 5 and 6). This indicates that the ability of plants to take up Cd is far stronger to take up Pb.

3.5.2_Effects of fertilization on uptake of plants to Pb and Cd

Application of organic manures or P fertilizer can alleviate toxicity of heavy metals to plants due probably to a decrease of the ability of plants to take up heavy metals after fertilization (Xia, 1997; Ye *et al.*, 2000; Xia and Shu, 2001). Compared with the control, concentrations of Pb and Cd in fertilized plants (treatment B) all decreased, from 0.9% to 57.9% (Table 7). The reason that fertilizer application inhibits the uptake of plants to heavy metals is likely because inorganic nutrients compete the absorption sites of root surface with metal elements. However, the decreased scales in different plants were markedly different. Among them, the largest decreased scale was uptake of Cd by bana, the Cd content in its shoots decreased by nearly 60%; whereas the smallest was uptake of Cd by bahia, hardly influenced by fertilizer application. It also can be seen from Table 7 that the decreased scales of Pb and Cd in different plant organs (shoots or roots) were dramatically different, too; the decreased scales were larger in root than in shoot with respect to vetiver and St. Augustine, and larger in shoot than in root with respect to bana, while similar in shoot and root with respect to bahia.

Table 7_Comparison of decrease of contents of Pb, Cd (%) in the 4 grasses after fertilizer application

Species	Pb		Cd	
	Shoots	Roots	Shoots	Roots
Vetiver	11.7	39.5	8.8	19.6
Bana	17.3	10.9	57.9	21.7
Bahia	34.0	34.7	2.4	0.9
St. Augustine	19.6	33.3	22.2	33.9

3.5.3_Accumulation of Pb and Cd by plants

The accumulation amounts of Pb and Cd by the 4 grasses presented a huge disparity (Fig.1) due to different biomass (Table 4) and different concentrations in plants (Table 5 and 6). In the waste soil without fertilization (the control), the amount of Pb accumulation in vetiver was the most (0.64 mg/m^2) whereas that in St. Augustine was the least (0.018 mg/m^2); the former was as much 35.5 times as the latter (Fig. 1). Pb concentrations in the two grasses, however, were apart only 2.2 times (in above-ground part) and 3.8 times (in below-ground part) (Table 5). Likewise, the poorest bioaccumulator to Cd was still St. Augustine in the condition of non-fertilization, and the best was bana; the latter (0.055 mg/m^2) was as much 27.5 times as the former (0.002 mg/m^2) (Fig. 1). Cd concentrations in the two grasses, however, were apart only 3.3 times (in above-ground part) and 1.6 times (in below-ground part) (Table 5). There was a similar phenomenon in the fertilizer applied treatment. It is therefore suggested that the chief reason resulting from a larger accumulation amount of metals in vetiver and bana was mainly due to the larger biomass of the two species apart from the stronger uptake ability. So, when conducting phytoremediation to remove heavy metals from soil, the first considered factor is to select the species with high biomass, and then that with uptake ability. Furthermore, plants having a larger biomass could yield better covering and revegetating benefits (Table 2). As pointed out by some experts that plants hyperaccumulating heavy metals are an attractive phytoremediation option if the low biomass can be improved or plant species can be correctly selected (Brooks, 1998; Chen *et al.*, 2000; Entry *et al.*, 2001). In addition, Fig.1 also shows that fertilizer application did not produce a great influence on the Pb and Cd amounts accumulated in the four grasses, namely the amounts of heavy metal accumulation by plants between treatment B and the control were quite near. Despite a decrease of uptake ability after fertilization (compare Table 6 with Table 5), fertilizer application greatly enhanced biomass (Table 4). As a result, with the exception of Pb accumulation by bahia and of Cd accumulation by bana, the other uptake amounts were enhanced on varying scales by fertilizer application. According to Entry *et al.* (2001), nitrogen fertilization imposes indirect effects on radionuclide accumulation by increasing plant growth. It is also inferred, therefore, that the decrease of concentrations of heavy metals in plants after fertilizer application was not due to the decrease of uptake amounts, but due to the result of dilution by the increase of biomass.

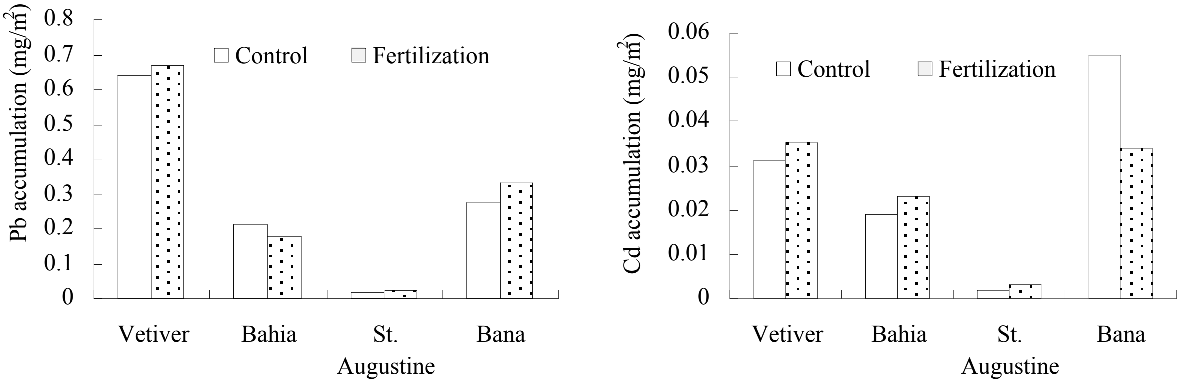

Fig. 1_Comparison of amounts of Pb and Cd accumulated by grasses in per square meter soil

4 CONCLUSION

Based on the results of the work, the following is concluded:

Oil shale waste dump formed a harsh habitat for vegetation development, but herbaceous plants could grow on it, especially after it was amended by fertilizer or fishpond sludge. Therefore it would be possible and promising to rehabilitate the oil shale mined land into grassland for husbandry and wildlife.

Of the 4 species of grasses tested in this study, vetiver presented the best result for ecological rehabilitation of oil shale dump, and it had the highest survival rate, the largest cover and biomass, and the best phytoremediation efficiency.

Fertilizer was a good amendment for oil shale waste, and it could enhance plant cover and biomass, and abate ability of plants to take up heavy metals, thereby reducing the risk of heavy metals' toxicity to animals and man through food chain. However, fertilizer would bring a negative influence on survival rate of plants if it were applied prior to planting plants.

Fertilization did not reduce the amount of heavy metals accumulated in plants; the main reason that concentration of heavy metals in plants was abated by fertilizer application was because an increase of biomass diluted the concentrations of metals in plants.

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References

Bradshaw AD. 1997. Restoration of mined lands—using natural process. Ecological Engineering, 8: 255–269

Bradshaw AD, Huttl RF. 2001. Future minesite restoration involves a broader approach. Ecological Engineering, 17: 87–90

Brooks RR. 1998. Plants that Hyperaccumulate Heavy Metals: Their Role in Phytoremediation, Microbiology, Archaeology, Mineral Exploration and Phytomining. CAB International, Wallingford, UK. p. 380

Carrow RN. 1996. Drought resistance aspects of turfgrasses in the Southeast: Root-shoot responses. Crop Science, 36: 687–694

Chen HM, Zheng CR, Tu C, *et al*. 2000. Chemical methods and phytoremediation of soil contaminated with heavy metals. Chemosphere, 41: 229–234

Deng ZP, Li LH, and Liang C. 2000. Experimental investigation on the reuse of resource in Maoming, Guangdong, oil shale disposal. Ecological Science, 19(4): 57–61

Entry JA, Watrud LS, Reeves M. 2001. Influence of organic amendments on the accumulation of 137Cs and 90Sr from contaminated soil by three grass species. Water Air and Soil Pollution, 126: 385–398

Gilbert M. 2000. Minesite rehabilitation. Tropical Grasslands, 34: 147–154

He SY. 2001. Analysis and Measure for Environmental Pollutants. Chemical Industry Press, Beijing. pp.283

Kalmbacher RS, Martin FG. 1998. Effect of flooding on seed germination and emergence of three pasture grasses. Soil and Crop Science Society of Florida Proceedings, 57: 73–77

Koester HH, Meissner HH, Coertze RJ, *et al.* 1992a. Variation in the production and quality of bana grass over the growing season using hand-clipped samples. Suid Afrikaanse Tydskrif Vir Veekunde, 22: 31–34

Koester HH, Meissner HH, Coertze RJ, *et al*. 1992b. Voluntary intake and quality of diet selected by cattle grazing bana grass, kikuyu and forage sorghum. Suid Afrikaanse Tydskrif Vir Veekunde, 22: 35–41

Liu SZ, Xia HP, Kong GH, *et al.* 2002. The soil and vegetation status of oil shale dump in Maoming City, Guangdong Province and countermeasures for ecological restoration. Ecological Science, 21(1): 25–28

Loch RJ. 2000. Effects of vegetation cover on runoff and erosion under simulated rain and overland flow on a rehabilitated site on the Meandu Minejj, Tarong, Queensland. Australian Journal of Soil Research, 38: 299–312

Lu RK. 1999. Analytical Methods for Soil and Agricultural Chemistry. China Agricultural Science and Technology Press, Beijing

Marcum KB, Murdoch CL. 1994. Salinity tolerance mechanisms of six C-4 turfgrasses. Journal of the American Society for Horticultural Science, 119: 779–784

National Research Council. 1993. Vetiver Grass: A Thin Green Line against Erosion. National Academy Press. Washington DC. pp. 171

Qian YL, Engelke MC. 1999. Performance of five turfgrasses under linear gradient irrigation. Hortiscience, 34: 893–896

Reynolds CM, Wolf DC, Gentry TJ, *et al.* 1999. Plant enhancement of indigenous soil micro-organisms: A low-cost treatment of contaminated soils. Polar Record, 35 (192): 33–40

Shu WS, Zhang ZQ, Lan CY. 2000. Strategies for restoration of mining wastelands in China. Ecological Science, 19(2): 24–29

Sydnor RS, Redente EF. 2000. Long–term plant community development on topsoil treatments overlying a phytotoxic growth medium. Journal of Environmental Quality, 29: 1778–1886

Toomik A, Liblik V. 1998. Oil shale mining and processing impact on landscapes in north-east Estonia. Landscape and Urban Planning, 41: 285–292

Truong PNV. 1999. Vetiver grass technology for mine tailings rehabilitation. In: International Erosion Control Association (Ed.), Proceedings of the First Asia Pacific Conference on Ground and Water Bio-engineering for Erosion Control and Slope Stabilization. Manila, the Philippines. pp. 315–325

Truong PNV, Baker DE. 1998. Vetiver grass for the stabilization and rehabilitation of acid sulfate soils. Proceedings of Second Conference on Acid Sulfate Soils. Coffs Harbour, Australia. pp.196–198

Van De WM, Hanson J, Luethi I. 1999. Morphological and agronomic characterisation of a collection of napier grass (*Pennisetum purpureum*) and *P. purpureum* X *P. glaucum*. Tropical Grasslands, 33: 150–158

Xia HP. 1997. Studies on cadmium in soil-plant system. Chinese Journal of Applied and Environmental Biology, 3: 289–298.

Xia HP. 2001. Development of vetiver system in Guangdong Province, China. Technique Bulletin, No. 2001/3, Pacific Rim Vetiver Network / Office of the Royal Development Projects Board, Bangkok, Thailand. p.20.

Xia HP, Ao HX, He DQ. 1994. Effect of environmental factors on vetiver grass growth. Chinese Journal of Ecology, 13(2): 23–26

Xia HP, Ao HX, Liu SZ. 1998. Vetiver Eco-engineering – a biological technique for realizing sustainable development. Chinese Journal of Ecology, 17: 265–270

Xia HP, Ao HX, Liu SZ, *et al.* 1999. Application of the vetiver Eco-engineering for the prevention of highway slippage in South China. In: International Erosion Control Association (eds.), Proceedings of the First Asia-Pacific Conference on Ground and Water Bioengineering Erosion Control and Slope Stabilization. Manila, The Philippines. pp. 522–527

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

Xia HP, Wang QL, Kong GH. 1999. Phyto-toxicity of garbage leachates and effectiveness of plant purification for them. Acta Phytoecologica Sinica, 23: 289–301

Ye ZH, Wong JWC, Wong MH. 2000. Vegetation response to lime and manure compost amendments on acid lead/zinc mine tailings: a greenhouse study. Restoration Ecology, 8: 289–295

A Brief Introduction to the First Author

Dr. Hanping Xia, a restoration ecologist, is working at the South China Institute of Botany, Chinese Academy of Sciences. Since 1991, he has been engaged in a wide range of R&D on the Vetiver System for the purpose of soil erosion control and polluted environment mitigation, including highway slope stabilization, land reclamation and re-greening, quarry rehabilitation, mine and landfill phytoremediation, wastewater purification, etc. He creatively initiated “the Vetiver Eco-engineering” from his working experience of many years. So far he has one monograph and over 30 academic papers in this aspect published.