

# Ecological rehabilitation and phytoremediation with four grasses in oil shale mined land

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## Abstract

Vetiver grass (*Vetiveria zizanioides*), bahia grass (*Paspalum notatum*), St. Augustine grass (*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 99%, followed by bahia and St. Augustine, 96% and 91%, respectively, whereas bana had the lowest survival rate of 62%. The coverage and biomass of vetiver were also the highest after 6-month planting. Fertilizer application significantly increased biomass and tiller number of the four grasses, of which St. Augustine was promoted most, up to 70% for biomass, while vetiver was promoted least, only 27% for biomass. 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 27.5–35.5 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.

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**Keywords:** Oil shale mined land; Phytoremediation to heavy metal; *Vetiveria zizanioides*; *Paspalum notatum*; *Stenotaphrum secundatum*; *Pennisetum glaucum* × *P. purpureum*

## 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 harsh surroundings form a lot of land dereliction without vegetation cover. Alone in China, for example, a total of  $2.88 \times 10^6$  ha of destroyed land have been produced in

mined areas and furthermore a mean of 46 700 ha of destroyed land is increased annually. 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, the successful restoration is greatly dependent on the choice of plant species and their methods of establishment (Bradshaw, 1997; Bradshaw and Huttli, 2001).

Compared to trees and shrubs, herbaceous plants, especially grasses have characteristics of rapid growth, large biomass, strong resistance, and effective

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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., 1999a; Gilbert, 2000; Loch, 2000; Ye et al., 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 (Truong, 1999; Xia and Shu, 2001). In Australia, vetiver has been used successfully to stabilize 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; Xia and Shu, 2001). Bahia grass (*Paspalum notatum* Flugge) is also an excellent species with respect to 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 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′. 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 °C, and the mean monthly maximum and minimum temperatures are 28.4 °C (July) and 15.5 °C (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 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<sup>2</sup>, 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.

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 has been used to pile oil shale wastes and oil shale contained surface soils, resulting from oil shale excavation, separation, combustion, and refining. It continued until 1992. As a result, solid waste up to 156 × 10<sup>6</sup> m<sup>3</sup> 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 indicated that the main problems of the dump were bad soil quality, strong acidity, poor water-holding capacity, and partial contamination by heavy metals. 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 trees and extremely few shrubs existed naturally (Liu et al., 2002).

## 2.2. Plant growth field experiment

A field plot trial was designed in the oil shale dump 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 (five duplicates). The whole field experiment was composed of 12 plots, and each plot had an area of 16 m<sup>2</sup> (4 m × 4 m) and was equally divided into four 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 from Finland, and its N, P, and K contents were 15% each. The application rate of fertilizer was 75 kg N ha<sup>-1</sup>, or 200 g fertilizer per sub-plot (4 m<sup>2</sup>). 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 clump and 10–15 cm long for each tiller or stem. The plots and sub-plots were arranged as three duplicates in a randomized block design.

The field design and operation was started on May 7–8th, 2000. The first investigation was carried out on May 27th; 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 established 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 6th of the same year. The marked 8 clumps of each sub-plot were used to measure the plant height and tillers number; and then 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. Augustine 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 °C

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 (0.84 mm) sieve. The soil samples were measured for the following parameters: pH (1:2.5 solid:distilled water, using a Beckman pH meter), organic matter (the K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub> digestion method), total N (the Kjeldahl method), total P (the molybdenum blue method after the samples were digested with concentrated H<sub>2</sub>SO<sub>4</sub> + HClO<sub>4</sub>), total K (digested with Na<sub>2</sub>CO<sub>3</sub> and then measured with flame photometer), hydrolytic N (the microdiffusion method), available P (molybdenum blue method after samples were extracted with NaHCO<sub>3</sub>), available K (after samples were extracted with NH<sub>4</sub>OAc), and total metal (atomic absorption spectrometry (AAS) after samples were digested with concentrated HNO<sub>3</sub> + HClO<sub>4</sub>). As to the plant samples, they were digested with concentrated HNO<sub>3</sub> + HClO<sub>4</sub> 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 meter used to measure the above soil sample. Chemical oxygen demand (COD) was measured with KMnO<sub>4</sub>; and biochemical oxygen demand (BOD) was also referred to as the consumption of dissolved oxygen after the leachates were incubated 5 days at 20 °C in an incubator. Total N was oxidized with K<sub>2</sub>S<sub>2</sub>O<sub>8</sub> and analyzed with an ultraviolet spectrophotometer. NH<sub>4</sub>-N and NO<sub>3</sub>-N were determined with direct distillation and colorimetry of phenol disulfonic acid (C<sub>3</sub>(CH<sub>3</sub>)(HSO<sub>3</sub>)<sub>2</sub>OH), respectively; total P was digested with H<sub>2</sub>SO<sub>4</sub>-HClO<sub>4</sub>, then the contents of total P and PO<sub>4</sub><sup>3-</sup>-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 the least significant difference test (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

Table 1  
General chemical characteristics of the oil shale disposal soil and its leaching wastewater

Parameter	Unit	Leachate (mean $\pm$ sd)	Soil
pH	–	3.20 $\pm$ 1.29	4.01
Organic matter	g kg <sup>-1</sup>	–	36.1
COD <sub>Cr</sub>	mg l <sup>-1</sup>	38.0 $\pm$ 23.5	–
BOD <sub>5</sub>	mg l <sup>-1</sup>	1.0 $\pm$ 0.0	–
Total N	mg l <sup>-1</sup> or g kg <sup>-1</sup>	1.9 $\pm$ 0.9	1.0
Hydrolytic N	mg kg <sup>-1</sup>	–	69.1
NH <sub>4</sub> -N	mg l <sup>-1</sup>	1.5 $\pm$ 0.7	–
NO <sub>3</sub> -N	mg l <sup>-1</sup>	Not detectable	–
Total P	mg l <sup>-1</sup> or g kg <sup>-1</sup>	0.02 $\pm$ 0.04	0.4
Available P	mg kg <sup>-1</sup>	–	0.6
PO <sub>4</sub> <sup>3-</sup> -P	mg l <sup>-1</sup>	Not detectable	–
Total K	g kg <sup>-1</sup>	–	7.9
Available K	mg kg <sup>-1</sup>	–	54.8
Total Pb	μg l <sup>-1</sup> or mg kg <sup>-1</sup>	1.7 $\pm$ 0.5	31.8
Total Cd	μg l <sup>-1</sup> or mg kg <sup>-1</sup>	Not detectable	0.1
Total Cu	μg l <sup>-1</sup> or mg kg <sup>-1</sup>	6.1 $\pm$ 2.1	20.4
Total Zn	μg l <sup>-1</sup> or mg kg <sup>-1</sup>	58.0 $\pm$ 39.0	38.6
Total Mn	mg l <sup>-1</sup> or mg kg <sup>-1</sup>	9.5 $\pm$ 1.4	59.5
Total Ni	mg kg <sup>-1</sup>	–	14.7
Total Cr	mg kg <sup>-1</sup>	–	22.6
Total As	mg kg <sup>-1</sup>	–	8.6

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 0.1 mg kg<sup>-1</sup> for Cd to the highest 59.5 mg kg<sup>-1</sup> 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 severe heavy metal toxicity to animals through food chains even if it entails re-instituting pasture for livestock or wildlife. The leachate quality was also better than the China National Second Grade Effluent Standard (GB8978-1996) except for its acidity.

### 3.2. Survival rates and plant coverage

The survival rates of four grasses in different treatments after planting for 20 days and their coverage after planting for 6 months later are listed in Table 2. The survival rates of vetiver, bahia, St. Augustine, and bana were 99%, 96%, 91%, and 62%, respectively. Among them, bana assumed the lowest survival rate, significantly lower than the other three species ( $P < 0.05$ ), indicating its poorest adaptation to the oil shale environment. The survival rates within the 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 2  
The survival rate and the coverage of four grass species after planting in the oil shale disposal soil for 20 days and 6 months, respectively

Species	Survival rate (%) (mean $\pm$ sd)				Cover (%)	
	Control	Treatment A	Treatment B	Treatment C	Control	Treatment B
Vetiver	99 $\pm$ 1	98 $\pm$ 2	98 $\pm$ 0	99 $\pm$ 1	85	90
Bahia	98 $\pm$ 1	95 $\pm$ 4	97 $\pm$ 1	95 $\pm$ 3	50	65
St. Augustine	95 $\pm$ 3	95 $\pm$ 3	84 $\pm$ 11	91 $\pm$ 4	20	30
Bana	63 $\pm$ 4	63 $\pm$ 6	58 $\pm$ 3	63 $\pm$ 3	65	70
LSD (0.05)	4	7	11	5	–	–

Table 3  
Increments of plant height and tiller number of vetiver and bana 20 days and 6 months after planting

Observing item	Grass species	First observation (day 20)				Second observation (day 180)	
		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

### 3.3. 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 three of four 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 three 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., 1999b). (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.

### 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 and 134 g, respectively, per clump averagely. Table 4 shows that vetiver was the smallest, bana and bahia were in the middle, and St. Augustine was the largest with special reference to the ratio of total biomass between the fertilizer treatment and control. Concretely speaking, St. Augustine was promoted most by fertilization, up to 70%, followed by bana and bahia, 37% and 29%, respectively, whereas vetiver was promoted least, only 27%. 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

Table 4  
Comparison of biomass of four herbaceous plants growing in oil shale waste dump

Species	Control				Fertilization (treatment B)				Fertilization/control		
	Shoot (g m <sup>-2</sup> )	Root (g m <sup>-2</sup> )	Total (g m <sup>-2</sup> )	Root/shoot	Shoot (g m <sup>-2</sup> )	Root (g m <sup>-2</sup> )	Total (g m <sup>-2</sup> )	Root/shoot	Shoot	Root	Total
Vetiver	451.3a <sup>a</sup>	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	2.1d	35.5c	0.064	57.2d	3.2d	60.4d	0.055	1.71	1.47	1.70

<sup>a</sup> Data followed by the same letters in the same column are not significant different at  $P = 0.05$  level by LSD test.

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 To-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 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 (Xia et al., 1999b). In the present study, the root/shoot ratios of three out of four grasses in the fertilization treatment were smaller than those in the control. This suggests that fertilizer application ameliorated the habitat of oil shale waste and promoted growth of plants, especially their shoots.

### 3.5. Phytoremediation for Pb and Cd of oil shale waste

Compared to the background values of soils in Guangdong Province (Liu et al., 2002), six (Cu, Zn, Ni, Pb, Cd, and As) of the eight heavy metals were on the higher side (Table 1), implicating that contents of toxic metals in oil shale of Maoming are elevated. In view of severer phytotoxicity of Cd and Pb, especially Cd, than other metals, and their higher contents than the background values of soils in Guangdong Province, 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.

#### 3.5.1. Distribution and content of Pb and Cd in plants

Distributions and contents of Pb and Cd in the four grass species were all different 6 months after growing in non-fertilization treatment (control) (Table 5). Concentrations of Pb in roots ranked as vetiver > bahia > bana > St. Augustine, while in shoots were in the order

of vetiver > bana > bahia > St. Augustine, of which the last species was much lower than the former three. Cd concentration in roots was as follows: bahia > bana > St. Augustine and vetiver, and in shoots bana > bahia, St. Augustine, and vetiver. 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 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 the same metal are also different.

Concentrations of Pb and Cd in the four plant species 6 months after growing 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 (Tables 5 and 6). This indicates that the ability of plants to take up Cd is far stronger to take up Pb, or the availability of Cd in soil to plants was far higher than that of 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 (Ye et al., 2000; Xia and Shu, 2001). Compared with the control, concentrations of Pb and Cd in fertilized plants (treatment B) all decreased,

Table 5

The concentrations of Pb, Cd in shoots and roots of the four grasses 6 months after establishing in non-fertilization disposal soil

Species	Pb			Cd		
	Shoot ( $\text{mg kg}^{-1}$ )	Root ( $\text{mg kg}^{-1}$ )	Root/shoot	Shoot ( $\text{mg kg}^{-1}$ )	Root ( $\text{mg kg}^{-1}$ )	Root/shoot
Vetiver	$1.11 \pm 0.10^{\text{a}}$	$2.53 \pm 0.33^{\text{a}}$	2.28	$0.057 \pm 0.009^{\text{b}}$	$0.102 \pm 0.006^{\text{c}}$	1.79
Bahia	$0.94 \pm 0.17^{\text{a}}$	$1.93 \pm 0.82^{\text{ab}}$	2.05	$0.081 \pm 0.054^{\text{b}}$	$0.216 \pm 0.033^{\text{a}}$	2.67
St. Augustine	$0.51 \pm 0.02^{\text{b}}$	$0.66 \pm 0.12^{\text{c}}$	1.29	$0.063 \pm 0.008^{\text{b}}$	$0.112 \pm 0.032^{\text{bc}}$	1.78
Bana	$0.98 \pm 0.15^{\text{a}}$	$1.38 \pm 0.11^{\text{b}}$	1.41	$0.209 \pm 0.014^{\text{a}}$	$0.175 \pm 0.065^{\text{ab}}$	0.84

<sup>a</sup> Mean  $\pm$  sd; same letters in the same column indicate no significant difference at  $P = 0.05$  level by LSD test.

Table 6

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

Species	Pb			Cd		
	Shoot ( $\text{mg kg}^{-1}$ )	Root ( $\text{mg kg}^{-1}$ )	Root/shoot	Shoot ( $\text{mg kg}^{-1}$ )	Root ( $\text{mg kg}^{-1}$ )	Root/shoot
Vetiver	$0.98 \pm 0.06\text{a}^{\text{a}}$	$1.53 \pm 0.21\text{a}$	1.56	$0.052 \pm 0.002\text{b}$	$0.082 \pm 0.014\text{c}$	1.58
Bahia	$0.62 \pm 0.03\text{bc}$	$1.26 \pm 0.09\text{a}$	2.03	$0.079 \pm 0.011\text{a}$	$0.214 \pm 0.005\text{a}$	2.70
St. Augustine	$0.41 \pm 0.08\text{c}$	$0.44 \pm 0.12\text{b}$	1.07	$0.049 \pm 0.008\text{b}$	$0.074 \pm 0.018\text{c}$	1.51
Bana	$0.81 \pm 0.09\text{ab}$	$1.23 \pm 0.11\text{a}$	1.52	$0.088 \pm 0.016\text{a}$	$0.137 \pm 0.078\text{b}$	1.56

<sup>a</sup> Mean  $\pm$  sd; same letters in the same column indicate no significant difference at  $P = 0.05$  level by LSD test.

Table 7

Comparison of decrease of contents of Pb, Cd (%) in the four grasses after fertilizer application

Species	Pb		Cd	
	Shoots	Roots	Shoots	Roots
Vetiver	12	40	9	20
Bana	17	11	58	22
Bahia	34	35	2	1
St. Augustine	20	33	22	34

from 1% to 58% (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.

### 3.5.3. Accumulation of Pb and Cd by plants

The accumulation amounts of Pb and Cd by the four grasses presented a huge disparity (Fig. 1) due to different biomass (Table 4) and different concentrations in plants (Tables 5 and 6). In the waste soil without fertilization (the control), the amount of Pb accumulation in vetiver was the most ( $0.64 \text{ mg m}^{-2}$ ) whereas that in St. Augustine was the least ( $0.018 \text{ mg m}^{-2}$ ); 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 St. Augustine in the condition of non-fertilization, and the best was bana; the latter ( $0.055 \text{ mg m}^{-2}$ ) was as much 27.5 times as the former

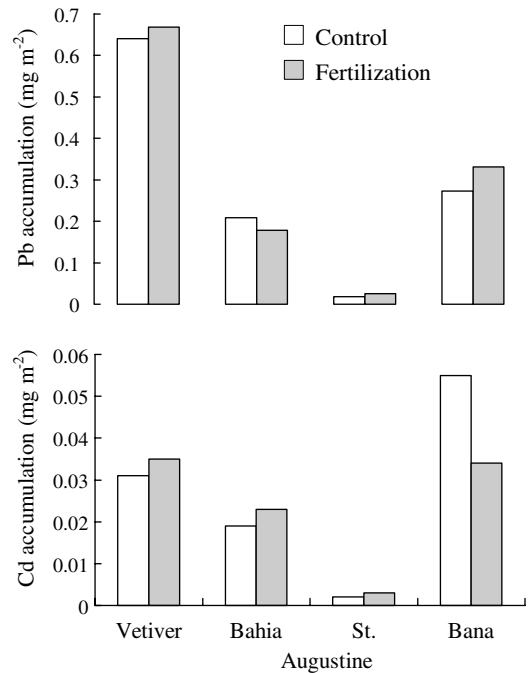


Fig. 1. Comparison of amounts of Pb and Cd accumulated by grasses in per square meter soil after 6 months transplanting.

( $0.002 \text{ mg m}^{-2}$ ) (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.

#### 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 four 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 chains. 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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