WORKSHOP 3

VETIVER GRASS TECHNOLOGY FOR REHABILITATION OF MINING WASTES AND TAILINGS

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ABSTRACT

The Vetiver Grass Technology (VGT) was first developed for soil and water conservation in farmlands. While this application still plays a vital role in agricultural lands, vetiver grass unique morphological, physiological and ecological characteristics has a key role in the area of environmental protection.

Unique morphological characteristics include a massive finely structured and deep root system capable of reaching 3-4m in the first year. In addition vetiver is tolerant to extreme climatic variation such as prolonged drought, flood, submergence and extreme temperature. It is also tolerance to wide range of soil pH, from 3.0 to 10.5, highly tolerant to soil salinity, sodicity, acidity, Aluminium and Manganese toxicities, and heavy metals such as Arsenic, Cadmium, Chromium, Nickel, Lead, Zinc, Mercury, Selenium and Copper in the soil.

Case studies where VGT has been successfully used to stabilise and rehabilitate mining overburden and highly contaminated tailings in Asia, Africa. Americas and Oceania will be presented.

1.0 INTRODUCTION

There has been increasing concerns in Australia and worldwide about the contamination of the environment by by-products of rural, industrial and mining industries. The majority of these contaminants are high levels of heavy metals which can affect flora, fauna and humans living in the areas, in the vicinity or downstream of the contaminated sites. Table 1 shows the maximum levels of heavy metals tolerated by environmental and health authorities in Australia and New Zealand.

Concerns about the spreading of these contaminants have resulted in strict guidelines being set to prevent the increasing concentrations of heavy metal pollutants. In some cases industrial and mining projects have been stopped until appropriate methods of decontamination or rehabilitation have been implemented at the source.

Methods used in these situations have been to treat the contaminants chemically, burying or to remove them from the site. These methods are expensive and at times impossible to carry out, as the volume of contaminated material is very large, examples are gold and coal mine tailings.

If these wastes cannot be economically treated or removed, off-site contamination must be prevented. Wind and water erosion and leaching are often the causes of off-site contamination. An effective erosion and sediment control program can be used to rehabilitate such sites. Vegetative methods are the most practical and economical; however, revegetation of these sites is often difficult and slow due to the hostile growing conditions present which include toxic levels of heavy metals.

Vetiver grass (*Chrysopogon zizanioides L.*), due to its unique morphological and physiological characteristics, which has been widely known for its effectiveness in erosion and sediment control (Greenfield,1989), has also been found to be highly tolerant to extreme soil conditions including heavy metal contaminations (Truong and Baker,1998).

Table 1: Investigation Thresholds for Contaminants in Soils (ANZ, 1992)

Heavy Metals	Thresholds ($mgkg^{-1}$) Environmental *	Health *
Antimony (Sb)	20	-
Arsenic (As)	20	100
Cadmium (Cd)	3	20
Chromium (Cr)	50	-
Copper (Cu)	60	-
Lead (Pb)	300	300
Manganese (Mn)	500	-
Mercury (Hg)	1	-
Nickel (Ni)	60	-
Tin (Sn)	50	-
Zinc (Zn)	200	-

*Maximum levels permitted, above which investigations are required.

This presentation highlights research results which show the wide ranging tolerance of vetiver to adverse conditions and heavy metal toxicities, and also its effectiveness in the rehabilitation of mining waste particularly contaminated tailings in Australia and worldwide. All the research and applications reported in this presentation were conducted using the genotype registered in Australia as Monto vetiver, but DNA typing has shown that Monto is genetically identical to the majority of non-fertile genotypes such as *Sunshine* (USA), *Vallonia* (South Africa) and *Guiyang* (China) (Adams and Dafforn, 1997). Therefore the following results can be applied with confidence when these cultivars are used for mine rehabilitation.

2.0 REHABILITATION OF MINING WASTES

2.1 Control measures

Soil disturbance on mine sites inevitably leads to erosion and to the transport of sand, silt and clay particles in stormwater. This sediment load has the potential to cause environmental harm further downstream. Trapping and retaining the sediment on the mining lease is a legal requirement.

The underlying principle behind sediment control is to reduce the velocity of stormwater. This causes suspended soil particles to settle out. The larger course sand particles settle first, followed by fine sand, silt and then clay. Some clay particles may stay in suspension and can only be precipitated using chemicals such as gypsum.

Conventional control measures to reduce the velocity of storm water include engineered structures such as diversion drains and silt traps (sometimes called silt or sediment retention ponds). Hay bales and silt mesh fences are used for short-term silt traps. On some mine sites, 'dirty' stormwater is filtered by channelling it through a wetland. *A series of small sediment traps is more effective than one big one.* The separation of 'clean' and 'dirty' water is an important principle.

Vetiver grass can be used in almost any situation where erosion control or sediment control is required. Several hedges can be planted across a gully at strategic points. Further down the slope, the effectiveness of a conventional silt trap can be increased by planting vetiver hedges across the spillway. A double row of vetiver grass is more effective than a single row.

2.2 Phytoremediation

In term of environmental protection, the most significant breakthroughs in the last 20 years are firstly research leading to the establishment of benchmark tolerance levels of vetiver grass to adverse soil conditions and secondly its tolerance to heavy metal toxicities. These have opened up a new field of application for VS: the prevention, treatment, rehabilitation of mining waste and contaminated lands (Truong, 2004; Shu, 2003).

Recently in a review entitled: ***Vetiver grass, Vetiveria zizanioides: A Choice Plant for Phytoremediation of Heavy Metals and Organic Wastes***, Luu Thai Danh *et al* (2009) explained why vetiver can perform such an outstanding task due to its extraordinary attributes outlined in Chapter 3.

3.0 TOLERANCE TO ADVERSE SOIL CONDITIONS

3.1 Tolerance to high Acidity and Manganese Toxicity.

Experimental results from glasshouse studies show that when adequately supplied with nitrogen and phosphorus fertilisers, vetiver can grow in soils with extremely high acidity and manganese. Vetiver growth was not affected and no obvious symptoms were observed when the extractable manganese in the soil reached 578 $mgKg^{-1}$, soil pH as low as 3.3 and plant manganese was as high as 890 $mgKg^{-1}$. Bermuda grass (*Cynodon dactylon*) which has been recommended as a suitable species for acid mine rehabilitation, has 314 $mgKg^{-1}$ of manganese in plant tops when growing in mine spoils containing 106 $mgKg^{-1}$ of manganese (Taylor *et al*, 1989). Therefore vetiver which tolerates much higher manganese concentrations both in the soil and in the plant, can be used for the rehabilitation of lands highly contaminated with manganese.

3.2 Tolerance to High Acidity and Aluminium Toxicity.

Results of experiments where high soil acidity was induced by sulphuric acid show that when adequately supplied with nitrogen and phosphorus fertilisers, vetiver produced excellent growth even under extremely acidic conditions (pH = 3.8) and at a very high level of soil aluminium saturation percentage (68%). Vetiver did not survive an aluminium saturation level of 90% with soil pH = 2.0; although a critical level of aluminium could not be established in this trial, observation during the trial indicated that the toxic level for vetiver would be between 68% and 90% (Truong, 1996; Truong and Baker,1996). These results are supported by recent works in Vanuatu where vetiver has been observed to thrive on highly acidic soil with aluminium saturation percentage as high as 87% (Miller pers.com.).

3.3 Tolerance to High Soil Salinity

Results of saline threshold trials showed that soil salinity levels higher than EC_{se} = 8 dSm^{-1} would adversely affect vetiver growth while soil EC_{se} values of 10 and 20 dSm^{-1} would reduce yield by 10% and 50% respectively. These results indicate vetiver grass compares favourably with some of the most salt tolerant crop and pasture species grown in Australia (Table 2).

Table 2: Salt Tolerance Level of Vetiver Grass as Compared with Some Crop and Pasture Species Grown in Australia.

Species	Soil EC_{se} (dSm^{-1}) Saline Threshold	50% Yield Reduction
Bermuda Grass (*Cynodon dactylon)*	6.9	14.7
Rhodes Grass (C.V. Pioneer) (*Chloris guyana*)	7.0	22.5
Tall Wheat Grass (*Thynopyron elongatum*)	7.5	19.4
Cotton (*Gossypium hirsutum*)	7.7	17.3
Barley (*Hordeum vulgare*)	8.0	18.0
Vetiver (*Vetiveria zizanioides*)	8.0	20.0

In an attempt to revegetate a highly saline area (caused by shallow saline groundwater) a number of salt tolerant grasses, vetiver, Rhodes (*Chloris guyana)* and saltwater couch (*Paspalum vaginatum*) were planted. Negligible rain fell after planting so plant establishment and growth were extremely poor but following heavy rain during summer (nine months later), vigorous growth of all species was observed in the less saline areas. Among the three species tested, vetiver was able to survive and resume growth under the higher saline conditions (Table 3), reaching a height of 60cm in eight weeks (Truong,1996). These results are supported by observation in Fiji and Australia, where vetiver was found growing in highly saline tidal flats next to mangrove.

Table 3: Soil Salinity Levels Corresponding to Different Species Establishment.

Species	Profile Soil EC_{se} (dSm^{-1}) 0-5cm	10-20cm
Chloris guyana	4.83	9.59
Paspalum vaginatum	9.73	11.51
Vetiveria zizanioides	18.27	18.06
Bare ground	49.98	23.94

3.4 Tolerance to Strongly Alkaline and Strongly Sodic Soil Conditions

A coal mine overburden sample used in this trial was extremely sodic, with ESP (Exchangeable Sodium Percentage) of 33%. Soil with ESP higher than 15 is considered to be strongly sodic (Nothcote and Skene, 1972). Moreover, the sodicity of this overburden is further exacerbated by the very high level of magnesium (2400 $mgKg^{-1}$) compared to calcium (1200 $mgKg^{-1}$) (Table 4).

Results from added soil amendments show that while gypsum had no effect on the growth of vetiver, nitrogen and phosphorus fertilisers greatly increased its yield. DAP (di ammonium phosphate) application alone at 100 kgha^{-1} increased vetiver dry matter yield 9 times. Higher rates of gypsum and DAP did not to improve vetiver growth further. These results were strongly supported by field results.

Table 4: Chemical Analyses of the Coal Mine Overburden.

Soil pH (1:5)		9.6	Calcium	(mgKg^{-1})	1200
EC dSm^{-1}		0.36	Magnesium	(mgKg^{-1})	2400
Chloride	mgkg^{-1}	256	Sodium	(mgKg^{-1})	2760
Nitrate	mgkg^{-1}	1.3	Potassium	(mgKg^{-1})	168
Phosphate	mgkg^{-1}	13	ESP*	(%)	33
Sulphate	mgkg^{-1}	6.1			

* ESP (Exchangeable sodium percentage) = Na % of total cations

4.0 TOLERANCE TO HEAVY METALS

4.1 Tolerance Levels and Shoot Contents of Heavy Metals.

Vetiver grass has been demonstrated to survive and grow on the soils contaminated with high concentrations of a wide range of heavy metals. The heavy metals in mine tailings and heavy metal contaminated soils are often concentrated at high levels. Furthermore, they are not evenly distributed, and vary horizontally with soil depth (Geeson et al., 1998; Schwartz et al., 1999; Whiting et al., 2000; Haines, 2002; Podar et al., 2004). Such heterogeneity form hot-spots across a site where concentrations of heavy metals are very high. High concentration of heavy metals in soils may inhibit plant growth, so may limit application on some sites or some parts of sites. Therefore the survival rate and growth performance of plants are negatively affected at these points leading to low efficiency of the whole process. A series of single heavy metal experiments under glasshouse conditions proved that vetiver has high tolerance to a wide range of heavy metals in soils due to its high threshold levels of these metals in soils (Table 5). Most vascular plants are highly sensitive to heavy metal toxicity with very low threshold levels for metals in the soils. In recent studies, vetiver grass has been reported to survive on the soils containing very high concentration of arsenic, lead, copper, zinc, chromium (Table 5).

Table 5. Threshold levels of heavy metals to vetiver growth based on single element experiment

Heavy metals	**Threshold to growth of most vascular plants (mg kg^{-1})**		**Threshold to vetiver growth (mg kg^{-1})**	**Vetiver survival under the highest levels of contaminants reported in the literature (mg kg^{-1} soil)**
	Hydroponic level [a]	***Soil level*** [b]	***Soil level*** [c]	
Arsenic	0.02-7.5	2.0	100-250	959 [c]
Boron				180 [d]
Cadmium	0.2-9.0	1.5	20-60	60 [e]
Copper	0.5-8.0	NA	50-100	2600 [f]
Chronium	0.5-10.8	NA	200-600	2290 [g]
Lead	NA	NA	>1500	10750 [h]
Mercury	NA	NA	>6	17 [j]

Nickel	0.5-2.0	7-10	100	100 [c]
Selenium	NA	2-14	>74	> 74 [c]
Zinc	NA	NA	>750	6400 [k]

Note: [a] Bowen (1979); [b] Baker and Eldershaw (1993); [c] Truong (1999); [d] Angin et al. (2008); [e] Minh and Khoa (2009); [f] Castillo et al. (2007); [g] Hoang et al. (2007); [h] Rotkittikhun et al. (2007); [j] Lomonte et al. (2011); [k] Danh et al. (2012).

Vetiver grass tolerates not only high concentrations of individual heavy metals in soils but also combinations of several heavy metals. Many metal-contaminated soils are enriched by more than one element (polymetallic) with different dominance of the various metals (Ernst et al., 2000; Ernst and Nelissen, 2000; Walker and Bernal, 2004). Natural hyperaccumulators are very often selective for an individual metal. Consequently, the occurrence of multi-heavy metals would strongly affect their productivity and even other metal tolerant plants. Furthermore, some mine tailings contain very high concentrations of heavy metals that exceed the tolerance ability of even hyperaccumulators, hence their productivity would be seriously affected. In glasshouse studies, vetiver could survive and grow well on multi-heavy metal contaminated soils with total Pb, Zn and Cu in the range of 1155 - 3281.6, 118.3 - 1583 and 68 - 1761.8 mg kg^{-1}, respectively (Chiu et al., 2006; Wilde et al., 2005). Under field conditions, vetiver could grow on mine tailing soils containing total Pb, Zn, Cu and Cd of 2078 - 4164, 2472 - 4377, 35 - 174 and 7 - 32 mg kg^{-1}, respectively (Shu et al., 2002; Yang et al., 2003; Shu et al., 2004; Zhuang et al., 2005).

The survival rates, growth and biomass of vetiver cultivated on heavy metal contaminated soils can be greatly improved by addition of organic matters (domestic refuse and sewage sludge), inorganic fertilizers and especially the combination of organic matters and inorganic fertilizers (Chiu et al., 2006; Wilde et al., 2005; Yang et al., 2003; Shu et al., 2002). The application of organic matter, however, reduced the accumulation of Pb, Zn and Cu in vetiver (Yang et al., 2003; Chiu et al., 2006).

4.2 Distribution of Heavy Metals in Vetiver Plant

Results in Table 6 show that the distribution of heavy metals in vetiver plant can be divided into three groups:

- very little of the arsenic, cadmium, chromium and mercury absorbed were translocated to the shoots (1% to 5%),
- a moderate proportion of copper, lead, nickel and selenium were translocated (16% to 33%) and
- zinc was almost evenly distributed between shoot and root (40%).

The important implications of these findings are that when vetiver is used for the rehabilitation of sites contaminated with high levels of arsenic, cadmium, chromium and mercury, its shoots can be safely grazed by animals or harvested for mulch as very little of these heavy metals are translocated to the shoots. As for copper, lead, nickel, selenium and zinc their uses for the above purposes are limited to the thresholds set by the environmental agencies and the tolerance of the animal concerned.

In addition, although vetiver is not a hyper-accumulator it can be used to remove the some heavy metals from the contaminated sites and disposed of safely elsewhere, thus gradually reducing the contaminant levels. For example vetiver roots and shoots can accumulate more than 5 times the chromium and zinc levels in the soil (Table 6).

Table 6: Distribution of Heavy Metals in Vetiver Shoots and Roots.

Metals	Soil ($mgKg^{-1}$)	Shoot ($mgKg^{-1}$)	Root ($mgKg^{-1}$)	Shoot/ Root %	Shoot / Total %
Arsenic (As)	959	9.6	185	5.2	4.9
	844	10.4	228	4.6	4.4
	620	11.2	268	4.2	4.0
	414	4.5	96	4.7	4.5
	605	6.5	124	5.2	5.0
Average				**4.8**	**4.6**
Cadmium (Cd)	0.67	0.16	7.77	2.0	2.0
	0.58	0.13	13.60	1.0	0.9
	1.19	0.58	8.32	7.0	6.5
	1.66	0.31	14.20	2.2	2.1
Average				**3.1**	**2.9**
Copper (Cu)	50	13	68	**19**	**16**
Chromium (Cr)	50	4	404	1	1
	200	5	1170	<1	<1
	600	18	1750	1	1
Average				**<1**	**<1**
Lead (Pb)	13	0.5	5.1	10	9
	91	6.0	23.2	26	20
	150	13.2	29.3	45	31
	330	41.7	55.4	75	43
	730	78.2	87.8	87	47
	1500	72.3	74.5	97	49
Average				**57**	**33**
Mercury (Hg)	0.02	BQ	0.01	-	-
	0.36	0.02	0.39	5	5
	0.64	0.02	0.53	4	4
	1.22	0.02	0.29	7	6
	3.47	0.05	1.57	3	3
	6.17	0.12	10.80	11	6
Average				**6**	**5**
Nickel (Ni)	300	448	1040	**43**	**30**
Selenium (Se)	0.23	0.18	1.00	53	15
	1.8	0.58	1.60	36	27
	6.0	1.67	3.60	46	32
	13.2	4.53	6.50	70	41
	23.6	8.40	12.70	66	40
	74.3	11.30	24.80	46	44
Average				**53**	**33**
Zinc (Zn)	Control	123	325	38	27
	100	405	570	71	42
	250	520	490	106	51

Metals	Soil ($mgKg^{-1}$)	Shoot ($mgKg^{-1}$)	Root ($mgKg^{-1}$)	Shoot/ Root %	Shoot / Total %
	350	300	610	49	33
	500	540	830	65	39
	750	880	1030	85	46
Average				**69**	**40**

BQ Below Quantification

5.0 CASE STUDIES:

5.1 Australia

Gold Mine Tailings

Fresh tailings: Fresh gold tailings are typically alkaline (pH = 8-9), low in plant nutrients and very high in free sulphate (830 $mgKg^{-1}$), sodium and total sulphur (1-4%). Vetiver established and grew very well on these tailings without fertilisers, but growth was improved by the application of 500 $Kgha^{-1}$ of DAP.

Vetiver was used successfully for a large-scale application to control dust storm and wind erosion on a 300ha tailings dam. When dry the finely ground tailings material can be easily blown away by wind storms if not protected by a surface cover. As gold tailings are often contaminated with heavy metals, wind erosion control is a very important factor in stopping the contamination of the surrounding environment. The usual method of wind erosion control in Australia is by establishing a vegetative cover, but due to the highly hostile nature of the tailings, revegetation is very difficult and often failed when native species are used. The short term solution to the problem is to plant a cover crop such as millet or sorghum, but these species do not last very long. Vetiver can offer a long term solution by planting the rows at spacing of 10m to 20m to reduce wind velocity and at the same time provide a less hostile environment (eg shading and moisture conservation) for local native species to established voluntarily later.

Gold mine tailings vetiver planted to protect cover crop for wind erosion/dust storm control

Old tailings - Due to high sulfur content, old gold mine tailings are often extremely acidic (pH 2.5-3.5), high in heavy metals and low in plant nutrients. Revegetation of these tailings is very difficult and often very expensive and the bare soil surface is highly erodible. These tailings are often the source of contaminants, both above ground and underground to the local environment. Table 7 shows the heavy metal profile of gold mine tailings in Australia. At these levels some of these metals are toxic to plant growth and also exceed the environmental investigation thresholds (ANZ, 1992).

Field trials conducted on two old (8 year) gold tailings sites, one is typified by a soft surface and the other with a hard crusty layer. The soft top site had a pH of 3.6, sulphate at 0.37% and total sulfur at 1.31%. The hard top site had a pH of 2.7, sulphate at 0.85% and total sulfur at 3.75% and both sites were low in plant nutrients. Results from both sites indicated that when adequately supplied with nitrogen and phosphorus fertilisers (300Kgha^{-1}of DAP) excellent growth of vetiver was obtained on the soft top site (pH=3.6) without any liming. But the addition of 5tha^{-1} of agricultural lime significantly improved vetiver growth. On the hard top site (pH=2.7) although vetiver survived without liming, the addition of lime (20tha^{-1}) and fertiliser (500kgha^{-1} of DAP) improved vetiver growth greatly.

Table 7: Heavy Metal Contents of a representative Gold Mine Tailings in Australia.

Heavy Metals	Total Contents (mgKg^{-1})	Threshold levels (mgKg^{-1})
Arsenic	1 120	20
Chromium	55	50
Copper	156	60
Manganese	2 000	500
Lead	353	300
Strontium	335	NA
Zinc	283	200

NA Not available

Coal Mine Tailings

In an attempt to rehabilitate an old coal mine tailings dam, (surface area of 23 ha and capacity of 3.5 million cubic metres) a trial was set up to select the most suitable species for the rehabilitation of this site. The substrate was saline, highly sodic and extremely low in nitrogen and phosphorus. The substrate contained high levels of soluble sulfur, magnesium and calcium. Plant available copper, zinc, magnesium and iron were also high. Five salt tolerant species were used: vetiver, marine couch (*Sporobolus virginicus*), common reed grass (*Phragmites australis*), cumbungi (*Typha domingensis*) and *Sarcocornia spp.* Complete mortality was recorded after 210 days for all species except vetiver and marine couch. Vetiver's survival was significantly increased by mulching but fertiliser application by itself had no effect. Mulching and fertilisers together increased growth of vetiver by 2 tha^{-1} which was almost 10 times higher than that of marine couch (Radloff *et al*). The results confirm the findings from glass house trials.

Coal Mine overburden

The overburden of open cut coalmine is generally highly erodible. These spoils are usually sodic and alkaline. Vetiver has established successfully on these soils and stabilised the spoil dump with slope higher than 45^0 and promoted the establishment of other sown and native pasture species.

This coal mine waste dump was barren for 50 year. Before and after vetiver planting for erosion control

Bentonite Tailings

Sodium Bentonite mine tailings (reject) is extremely erodible as they are highly sodic with Exchangeable Sodium Percentage (ESP) values ranging from 35% to 48%, high in sulphate and extremely low in plant nutrients. Revegetation on the tailings has been very difficult as sown species were often washed away by the first rain and what left could not thrive under these harsh conditions. With adequate supply of nitrogen and phosphorus fertilisers vetiver established readily on this tailings, the hedges provided erosion and sediment control, conserved soil moisture and improved seedbed conditions for the establishment of indigenous species (Bevan *et al* 2000).

Bauxite Redmud

Preliminary results also indicate that vetiver can be established on modified bauxite red mud and residue sand which are highly caustic with pH level between 11and 12.


5.2 Chile

Copper mining is the main economic income of Chile. In 2005 a series of pilot studies using the Vetiver System to remediate the wastes produced by the copper mining industry, which represents an important source of contaminants to the environment - water, soil and air. Demonstration trials were set up on a number of Copper mines in Central region to:

- Determine whether vetiver can grow on highly contaminated copper waste rock and tailings
- Find out whether vetiver can grow on these extreme climatic conditions: high altitude, cold and wet winter, very hot and dry summer
- Ascertain whether vetiver is effective in stabilising the tailings ponds wall (built with copper tailings material only) and waste rock dump against wind and water erosion
- Determine whether vetiver is effective in preventing wind and water erosion in fresh and old tailings ponds (Fonseca,et al, 2006)

In 2010, the following conclusion was presented in the Latin American Vetiver Conference in Santiago, Chile by Arochas *et al* (2010): *Results to date are very encouraging; vetiver could be established on both highly contaminated copper tailings dump and waste rock, where it grew to 1.5m in 6 months. Reasonable growth was also observed at a 3 500m altitude site and although covered by 50cm of snow for one month, it has survived winter at this site. Five years after planting, it can be concluded that Vetiver can be established and grow successfully without topsoil with the addition of nutrients on tailings dams with very high levels of copper (2369mg/kg). Specimens show regular development of the root system. But the roots are weak while the leaves reach a small development in length and diameter under very high Cu levels. But the greatest damage to this species in the tailings dam was caused by dehydration and damage by herbivores. To achieve optimum plant acclimation should have at least:*

- *Optimal quality of the vetiver plant.*
- *Adding fertiliser to provide nutrients to the soil.*
- *Irrigation at least twice a week in summer during the first year.*
- *Protection against herbivores*

5.3 China

In China vetiver produced biomass more than twice that of both local and introduced species used in the rehabilitation of the Lechang Pb and Zn mine, where tailings contain very high levels of heavy metals (Pb at 3 231 $mgKg^{-1}$, Zn at 3 418 $mgKg^{-1}$, Cu at 174 $mgKg^{-1}$ and Cd at 22 $mgKg^{-1}$) (Shu *et al* 2002).

Shu (Shu *et al* 2002) also conducted a series research projects on:

5.3.1 **Vetiver for Phytostabilization-**

Experiment.

Objectives

- To compare the growth of the four grasses on Lechang Pb/Zn mine tailings
    - ❑ *Vetiveria zizanioides*
    - ❑ *Paspalum notatum*
    - ❑ *Cynodon dactylon*
    - ❑ *Imperata cylindraca* (var. *major*)
- To investigate heavy metals accumulation

Results

- Vetiver is the best choices for revegetation of Pb/Zn mine tailings
- Vetiver is an excluder of heavy metals

Experiment 2

Objectives

- **The growth performance of three plants**
- **Effects intercropping of vetiver with *legumes***

Results

- **Vetiver had the highest tolerance and accumulated the lowest concentrations of heavy metals in shoot.**
- **Intercropping of grasses and legumes did not show any competitive and beneficial effects.**
- **Growth of vetiver could aid to stabilize heavy metals in tailing**

Experiment 3

- The land around the smelting factory was severely contaminated by heavy metals
- Many efforts were failed
- Vetiver was well established after 5-months

5.3.2 Vetiver for Phytoextraction

Objectives

Phytoextracting heavy metals from soil using both hyperaccumulators and high-biomass plants including vetiver grass**.**

Results

- **Pb accumulation: Vetiver > P. notatum > I. cylindraca > C.dactylon**
- **Zn accumulation: P. notatum > Vetiver > I. cylindraca > C.dactylon**
- **Cu accumulation: Vetiver > P. notatum > I. cylindraca > C.dactylon**

5.4 Indonesia

Coal mines in South Kalimantan

With great success, VGT was applied for three distinct categories: Rehabilitate mine tailings slopes and embankment; Water Quality Improvements; and Stabilizations banks of channels of waste water disposal ditches,.

Photo 21: Vetiver system application at PT. Adaro, Kalimantan (Photo credit: Presto J. Saputra)

Gold mines in North Sulawesi

In late 2010, a new gold mine development in North Sulawesi decided to adopt the VST to mitigate environmental problems ***prior*** to completing their entire infrastructure. In January 2011, PT Toka Tindung purchased 100,000 vetiver slips that were planted in the most vulnerable locations following recommendations and designs by Indonesia Vetiver Network. PT Toka Tindung also plan to involve the local communities by providing them with vetiver awareness training and to supply vetiver for local nurseries that will sell to the mining company to supply their ongoing needs.

Photo 22: Vetiver application at PT Meares Soputan Mining, Toka Tindung gold mine site

5.5 India

According to Pathak (2011) the followings can be addressed by VST on open cut mines:

- Stabilization of spoil dumps
- Erosion control on broken areas, spoil dumps
- Control siltation of water courses in the catchment areas
- Toxic water in tailing dams
- Rehabilitation of project affected people.

5.6 Africa

Mining and associated rehabilitation projects in Africa and the Indian Ocean Islands have been successfully implemented jointly under the guidance and auspices of “The Vetiver Network International (TVNI) and the International Erosion Control Association (IECA) as a result of the interaction that has developed between the two organisations in Africa and the Indian Ocean Islands.

The cooperation will reflect the major strides that have been achieved on erosion & sediment control, bio-engineering & vegetation restoration and the participation of local communities in general.
It can be recorded that **practically 95% of the 53 countries in the entire African continent** (including Islands) have successfully implemented the Vetiver System for soil & water conservation during the past 200 years. (Noffke, 2013)

The followings are the most recent projects in these countries will illustrate current activities using the Vetiver System, reflecting the major works that have been achieved on erosion & sediment control, bio-engineering & vegetation restoration with community participation in general.

- Democratic Republic of Congo- Selembao
- Ethiopia-SLUF
- Brazzaville Congo - Boukeni Erosion Control Project
- Pointe Noire/Brazzaville Congo - National Highway
- Guinea- Simandou
- Gabon – Gabon Special Economic Zone (OLAM)
- Madagascar- Ilmenite & Ambatovy projects
- South Africa – Department of Agriculture, Limpopo Province.

5.7 South Africa

Rehabilitation trials conducted by De Beers on both tailings dumps and slimes dams at several sites, have found that vetiver possessing the necessary attributes for self sustainable growth on kimberlite spoils. Vetiver grew vigorously on the alkaline kimberlite, containing run off, arresting erosion and creating an ideal micro-habitat for the establishment of indigenous grass species. Rehabilitation using vetiver was particularly successful on kimberlite fines at Cullinan mine where slopes of 35 degrees are being upheld. It is clear that vetiver is likely to play an increasingly important role in rehabilitation and, as a result of this, nurseries are being established at several mines (Knoll, 1997).

At Premier (800mm annual rainfall) and Koffiefonteine (300mm rainfall) diamond mines where surface temperature of the black kimberlite often exceeds 55^{o}C, at this temperature most seeds are unable to germinate. Vetiver planted at 2m VI (Vertical Interval) provided shades that cool the surface and allowing germination of other grass seeds (Knoll, 1997). Vetiver has also been used successfully in the rehabilitation of slimes dams at the Anglo American platinum mine at Rastenburg and the Velkom, President Brand gold mine (Tantum pers.com.)

More recently, mine rehabilitation and associated projects have been conducted in Madagascar (Ambatovy Project) and Xstrata Chromium Mine, Rustenburg, South Africa (Noffke, R. 2013).

Ambatovy Project in Madagascar and Chromium Mine, Rustenburg, South Africa

5.8 Thailand

Roongtanakia *et al*.(2008) reported that vetiver could grow well in lead mine tailings. The application of compost or chemical fertilizer resulted in better growth in height and dry weight than no fertilisers, but did not increase the concentration of lead in the vetiver plant. Higher concentration was found in the root than in the shoot.

5.9 Venezuela

The bauxite mine, CVG BAUXILUM, located in Los Pijiguaos, Bolivar State, incorporated the VST into its general policy to mitigate the impact of mining activities on the local community with the aim of providing social assistance, and economic development to the people of the region. VST has been used in this project, for stabilization of various gradient slopes, on the soil-concrete interface to protect infrastructures on the mine site, stabilization of gullies and border drains, reinforcement of lagoon dikes, bio-filter in gullies and around lagoons. For erosion control a total of 26 300m of vetiver barriers have been planted, from 2003 to June 2006. Now CVG BAUXILUM is planning to plant another 7 400m of Vetiver barriers.

Based on the above results, during the past three years, CVG BAUXILUM has successfully adopted the VST for land rehabilitation and environmental protection to restore this open cut bauxite mining site of Venezuela, to a desirable environmentally friendly level. (Luque et al. 2006; Lisenia et al. 2006)

6.0 OVERALL ADVANTAGES OF VETIVER SYSTEM APPLICATION

Simplicity, low cost and low maintenance are the main advantages of VST over chemical and engineering methods for contaminated land treatments.

6.1 Simplicity

Application of the Vetiver System is rather simple compared with other conventional methods. In addition appropriate initial design, it only requires standard land preparation for planting and weed control in the establishment phase.

6.2 Low cost

Application of the Vetiver System in contaminated land treatment costs a fraction of conventional methods such as chemical or mechanical treatment. Most of the cost lies in the planting material, with small amounts in fertiliser, herbicides and planting labour.

6.3 Minimal maintenance

When properly established, the VST requires practically no maintenance to keep it functioning. Harvesting two or three time a year to export nutrients and to remove top growth for other usuages is all that needed. This is in sharp contrast to other means which need regular costly maintenance and a skilled operator, often an engineer, to operate efficiently.

7.0 CONCLUSION

From the research results and successful applications presented above, VST is highly suitable for the rehabilitation of contaminated mining wastes and tailings. For successful application of vetiver a full understanding of the chemical properties of the materials requiring rehabilitation is needed for best results.

8.0 REFERENCES

Adams, R.P. and Dafforn, M.R.(1997). DNA fingertyping (RAPDS) of the pantropical grass vetiver (*Vetiveria zizanioides L.*) reveals a single clone "sunshine" is widely utilised for erosion control. The Vetiver Network Newsletter, no.18. Leesburg, Virginia USA.

Angin I, Turan M, Ketterings QM, Cakici A. 2008. Humic acid addition enhances B and Pb phytoextraction by Vetiver grass (*Vetiveria zizanioides* (L.). Nash). Water Air and Soil Pollution 188: 335-343

ANZ (1992). Australian and New Zealand Guidelines for the Assessment and Management of Contaminated Sites. Australian and New Zealand Environment and Conservation Council, and National Health and Medical Research Council, January 1992 .

ANZECC & ARMCANZ. 1999. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand, Canberra, Australia.

Arochas, A., Volker, K. and Fonceca (2010): Application of of Vetiver grass for mine sites rehabilitation in Chile. Latin American Vetiver Conference, Santiago, Chile, Oct. 2010.

Baker, D.E. and Eldershaw, V.J. (1993). Interpreting soil analyses for agricultural land use in Queensland. Project Report Series Q093014, QDPI, Brisbane, Australia.

Bevan O, Truong P, Wilson M. 2000. The Use of Vetiver Grass for Erosion and Sediment Control at the Australian Bentonite Mine in Miles, Queensland. Proc. Fourth Innovative Conf., Australian Minerals and Energy Environment Foundation: On the threshold: Research into Practice. August 2000, Brisbane, Australia, pp 124- 128.

Bowen, H.J.M. (1979). Plants and the Chemical Elements. (Ed.). Academic Press, London.

Castillo M, Fonseca R, Candia JR. 2007. Report on the pilot study on the use of Vetiver grass for Cu mine tailings phytostabilisation at Anglo American El Solado mine, Chile. Fundacion Chile (report in Spanish).

Chiu KK, Ye ZH, Wong MH. 2006. Growth of Vetiveria zizanioides and Phragmities australis on Pb/Zn and Cu mine tailings amended with manure compost and sewage sludge: A greenhouse study. Bioresource Technology 97: 158–170

Danh LT, Truong P, Mammucari R, Tran T, Foster N (2009). Vetiver grass, *Vetiveria zizanioides*: A choice plant for phytoremediation of heavy metals and organic wastes. *International Journal of Phytoremediation* 11, 664- 691.

Danh LT, Truong P, Mammucari R, Foster N (2012). Phytoredemdiation of soils contaminated with salinity, heavy metals, metalloids, and radioactive materials. In ‘Phytotechnologies: Remediation of Environmental Contaminants’, edited by Naser A. Anjum, published by CRC Press/Taylor and Francis Group, Boca Raton, Florida, USA, pp 255-282.

Fonseca,R, Diaz, C, Castillo. M., Candia, J and P. Truong, P. (2006). Preliminary results of pilot studies on the use of vetiver grass for mine rehabilitation in Chile. Proc. ICV4, Caracas, Venezuela.

Geeson NA, Abrahams PW, Murphy MP, Thornton I. 1998. Fluorine and metal enrichment of soils and pasture herbage in the old mining areas of Derbyshire, UK. Agriculture, Ecosystems & Environment 68: 217–231.

Greenfield, J.C. (1989). Vetiver Grass:The ideal plant for vegetative soil and moisture conservation. ASTAG - The World Bank, Washington DC, USA.

Greenfield, J.C. 2002. Vetiver Grass: An essential grass for conservation of planet earth. Infinity Publishing Co, Haverford, PA, USA.

Haines BJ. 2002. Zincophilic root foraging in *Thlaspi caerulescens*. New Phytologist 155: 363–372.

Hoang TTT, Tu TCL, Dao PQ. 2007. Progress and results of trials using vetiver for phytoremediation of contaminated canal sludge around Ho Chi Minh City. Proc. Vetiver Workshop. (May 2007 in Vietnamese), Hanoi, Vietnam

Kabata, A. and Pendias, H. (1984). Trace Elements in Soils and Plants. CRC Press, Florida.

Knoll.C.(1997). Rehabilitation with vetiver. African Mining, Vol2 (2)

Lepp, N.W. (1981). Effects of heavy metal pollution on plants. Vol.1: Effects of trace elements on plant functions. (Ed.) Applied Science Publication. London.

Lisena, M., Tovar, C., Ruiz, L,(2006). Estudio Exploratorio de la Siembra del Vetiver en un Área Degradada por el Lodo Rojo”. Proc. ICV4, Caracas, Venezuela.

Lomonte C, Doronila A, Gregory D, Baker AJM, Kolev SD. 2011. Chelate-assisted phytoextraction of mercury in biosolids. Science of the Total Environment 409: 2685–2692.

Luque, R., Lisena, M. and Luque, O. (2006) Vetiver System For Environmental Protection of Open Cut Bauxite Mining At “Los Pijiguaos” –Venezuela.

Noffke, R. (2013). Mine and associated rehabilitation projects in Africa & Indian ocean islands Proc. Second Intern, Vetiver Conference, Medellin,Colombia. October 2013

Northcote, K.H. and Skene, J.K.M. (1972). Australian Soils with Saline and Sodic Properties. CSIRO Div. Soil. Pub. No. 27.

Pathak (2011). CSR-EMP integration through implementation of Vetiver Technology for Environmental Management in mines. 5th Internatioinal Vetiver Conference, Lucknow, India 2011

Podar D, Ramsey MH, Hutchings MJ. 2004). Effect of cadmium, zinc and substrate heterogeneity on yield, shoot metal concentration and metal uptake by *Brassica juncea*: implications for human health risk assessment and phytoremediation. New Phytologist 163: 313–324.

Radloff, B., Walsh, K., Melzer, A. (1995). Direct Revegetation of Coal Tailings at BHP. Saraji Mine. Aust. Mining Council Envir. Workshop, Darwin, Australia.

Roongtanakiat, L., Osotsapar, Y., and Yindiram,C. (2008). Effects of soil amendment on growth and heavy metals content in vetiver grown on iron . Kasetsart J. (Nat. Sci.) 42 : 397 - 406

Rotkittikhun P, Chaiyarat R, Kruatrachue M, Pokethitiyook P, Baker AJM. 2007. Growth and lead accumulation by the grasses *Vetiveria zizanioides* and *Thysanolaena maxima* in lead-contaminated soil amended with pig manure and fertilizer: A glasshouse study. Chemosphere 66: 45–53.

Schwartz C, Morel JL, Saumier S, Whiting SN, Baker AJM. 1999. Root development of the zinc-hyperaccumulator *Thlaspi caerulescens* is affected by metal origin, content and localization in the soil. Plant Soil 208: 03–115.

Shu WS, Xia HP, Zhang ZQ, Lan CY, Wong MH. 2002. Use of vetiver and three other grasses for revegetation of Pb/Zn mine tailings: Field experiment. International Journal of Phytoremediation 4: 47-57.

Shu Wensheng (2003).Exploring the Potential Utilization of Vetiver in Treating Acid Mine Drainage (AMD). Proc. Third International Vetiver Conference, Guangzhou, China, October 2003

Shu, W.S., Zhao, Y.L., Yang, B., Xia, H.P. and Lan, C.Y. 2004. Accumulation of heavy metals in four grasses grown on lead and zinc mine tailings. J. Environ. Sci. 16, 730-434.

Taylor, K.W., Ibabuchi, I.O. and Sulford (1989). Growth and accumulation of forage grasses at various clipping dates on acid mine spoils. J. Environ. Sci. and Health A24: 195-204.

Truong, P.N. (1996). Vetiver grass for land rehabilitation. Proc. First Intern. Vetiver Conf. Thailand (pp 49-56).

Truong, P.N. and Baker, D. (1996). Vetiver grass for the stabilisation and rehabilitation of acid sulfate soils. Proc. Second National Conf. Acid Sulfate Soils, Coffs Harbour, Australia pp. 196-198.

Truong P., Baker D. 1997. The role of vetiver grass in the rehabilitation of toxic and contaminated lands in Australia. Proc. Int. Vetiver Workshop (October 21-26), Fuzhou, China.

Truong, P.N. and Baker, D. (1998). Vetiver Grass System for environmental protection. Technical Bulletin No.1. Pacific Rim Vetiver Network, Bangkok, Thailand.

Truong, P. 1999. Vetiver Grass Technology for Mine Rehabilitation. In: Ground and Water Bioengineering for Erosion Control and Slope Stabilisation, pp 379-389 (Barker, D. H. et al. ed) Sciences Publishers, New Hampshire USA.

Truong, P.N.V. (2004). Vetiver Grass Technology for mine tailings rehabilitation. Ground. and Water Bioengineering for Erosion Control and Slope Stabilisation. Editors: D. Barker, A. Watson, S. Sompatpanit, B. Northcut and A. Maglinao. Published by Science Publishers Inc. NH, USA.

Truong, P., Tran Tan Van and Elise Pinners (2008). Vetiver System Applications: A Technical Reference Manual. The Vetiver Network International, February 2008.

Whiting SN, Leake JR, McGrath SP, Baker AJM. 2000. Positive responses to Zn and Cd by roots of the Zn and Cd hyperaccumulator *Thlaspi caerulescens*. New Phytologist 145: 199–210.

Wilde EW, Brigmon RL, Dunn DL. 2005. Phytoextraction of lead from firing range soil by Vetiver grass. Chemosphere 61: 1451–1457.

Yang, B., Shu, W.S., Ye, Z.H., Lan, C.Y. and Wong, M. H. 2003. Growth and metal accumulation in vetiver and two Sesbania species on lead/zinc mine tailings. Chemosph. 52, 1593–1600.

Zhuang P, Ye ZH, Lan CY, Xie ZW, Shu WS. 2005. Chemically assisted phytoextraction of heavy metal contaminated soils using three plant species. Plant Soil 276: 153–162.