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Vetiver Grass Technology

For

Mine Rehabilitation

By

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Foreword

One of the immediate activities of the Pacific Rim Vetiver Network (PRVN) is to disseminate information on vetiver technologies, especially those which are adaptive to local conditions of developing countries in the Pacific Rim. In this connection, the Secretariat is publishing a series of technical bulletins which can provide useful information about Vetiver Grass Technology (VGT) to readers who are active members of the PRVN.

In 1998, two bulletins were published, namely “Vetiver Grass System for Environmental Protection” by Paul Truong and Dennis Baker, and “Vetiver Grass for Slope Stabilization and Erosion Control” by Diti Hengchaovanich. Both have received favorable comments from our members as well as other scientists from around the world. As for 1999, another bulletin, “Vetiver Handicrafts in Thailand” by the Department of Industrial Promotion, was published.

The present document is the second paper by Dr. Paul Truong to be published in the series of PRVN Technical Bulletin. It is also the second paper of such a series for 1999. It is mainly dealt with the use of vetiver in rehabilitating mine wastes, particularly contaminated tailings in Australia and South Africa, due to its wide range of tolerance to adverse conditions and heavy metal toxicities.

On behalf of the PRVN, we wish to express sincere thanks to the author, Dr. Paul N.V. Truong, for his generous contribution. We wold also like to express our sincere gratitude to Dr. Narong Chomchalow of Assumption University, and Dr. Suyanee Vessabutr of the Queen Sirikit Botanic Garden, who helped to edit the manuscript on a voluntary basis.

It is hoped that this publication will be of some value to engineers and others in the field of mine rehabilitation, or even those involving in garbage treatment and land fillings, to make use of this amazing plant to its maximum potential.

(Dr. Sumet Tantivejkul)
Executive Secretary, Pacific Rim Vetiver Network
and
Secretary-General, Chaipattana Foundation

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Dr. Paul N.V. Truong has over 20 years of experience in the use of vegetation for erosion and sediment control, land stabilisation and rehabilitation in tropical and subtropical Australia. In the last ten years he has concentrated on the application of the Vetiver Grass Technology (VGT) for the above purposes. His pioneering research and develop-ment on VGT have led to the extension of VGT beyond its original application in soil and water conservation on farmlands into the fields of flood erosion control, environmental and infrastructure protection, and mine rehabilitation. He has won several awards for his role in R & D of VGT from the World Bank and The Vetiver Network.

1. 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 (*Vetiveria 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 (mg/kg)	
	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 paper highlights research results which show the wide ranging tolerance of vetiver to adverse conditions and heavy metal toxicities, and also field applications in Australia and South Africa where vetiver grass is highly effective in the rehabilitation of mining waste, particularly contaminated tailings. All the research and applications reported in this paper 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. TOLERANCE TO ADVERSE SOIL CONDITIONS

2.1 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 mg/kg, soil pH as low as 3.3, and plant manganese was as high as 890 mg/kg. Bermuda grass (*Cynodon dactylon*) which has been recommended as a suitable species for acid mine rehabilitation, has 314 mg/kg of manganese in plant tops when growing in mine spoils containing 106 mg/kg 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.

2.2 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, 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.).

2.3 Tolerance to High Soil Salinity

Results of saline threshold trials show that soil salinity levels higher than EC_{se} = 8 d/sm would adversely affect vetiver growth while soil EC_{se} values of 10 and 20 d/sm 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).

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 60 cm in eight weeks (Truong 1996). These results were supported by observations in Fiji and Australia, where vetiver was found growing in highly saline tidal flats next to mangrove.

Table 2: Salt tolerance level of vetiver grass as compared with some crop and pasture species grown in Australia

Species	Soil EC_{sc} (d/sm)	
	Saline threshold	**50% yield reduction**
Bermuda Grass (*Cynodon dactylon)*	6.9	14.7
Rhodes Grass (CV ‘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

Table 3: Soil salinity levels corresponding to different species establishment

Species	Profile soil EC_{se} (d/sm)	
	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

2.4 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 (Northcote and Skene 1972). Moreover, the sodicity of this overburden is further exacerbated by the very high level of magnesium (2400 mg/kg) compared to calcium (1200 mg/kg) (Table 4).

Results from added soil amendments showed that while gypsum had no effect on the growth of vetiver, nitrogen and phosphorus fertilisers greatly increased its yield. Di ammonium phosphate (DAP) application alone at 100 kg/ha increased vetiver dry matter yield nine times. Higher rates of gypsum and DAP did not 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	(mg/kg)	1200
EC	(d/sm)	0.36	Magnesium	(mg/kg)	2400
Chloride	(mg/kg)	256	Sodium	(mg/kg)	2760
Nitrate	mg/kg)	1.3	Potassium	(mg/kg)	168
Phosphate	mg/kg)	13	ESP*	(%)	33
Sulphate	mg/kg)	6.1			

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

3. TOLERANCE TO HEAVY METALS

3.1 Tolerance Levels and Shoot Contents of Heavy Metals

A series of glasshouse trials was carried out to determine the tolerance of vetiver to high soil levels of heavy metals. Literature search indicated that most vascular plants are highly sensitive to heavy metal toxicity and most plants were also reported to have very low threshold levels for arsenic, cadmium, chromium, copper and nickel in the soil. Results shown in Table 5 demonstrate that vetiver is highly tolerant to these heavy metals. For arsenic, the toxic content for most plants is between 1 and 10 mg/kg, for vetiver the threshold level is between 21 and 72 mg/kg. Similarly for cadmium, the toxic threshold for vetiver is 45 mg/kg and for other plants between 5 and 20 mg/kg. An impressive finding was that while the toxic thresholds of vetiver for chromium is between 5 and 18 mg/kg and that for nickel is 347 mg/kg, growth of most plants is affected at the content between 0.02 and 0.20 mg/kg for chromium and between 10 and 30 mg/kg for nickel. Vetiver had similar tolerance to copper as other plants at 15 mg/kg (Kabat a and Pen dias1984; Lepp 1981).

Table 5: Threshold levels of heavy metals to vetiver growth

Heavy metals	Thresholds to plant growth (mg/kg)		Thresholds to vetiver growth (mg/kg)	
	Hydroponic levels (a)	Soil levels (b)	Soil levels	Shoot levels
Arsenic	0.02-7.5	2.0	100-250	21-72
Cadmium	0.2-9.0	1.5	20-60	45-48
Copper	0.5-8.0	NA	50-100	13-15
Chromium	0.5-10.0	NA	200-600	5-18
Lead	NA	NA	>1 500	>78
Mercury	NA	NA	>6	>0.12
Nickel	0.5-2.0	7-10	100	347
Selenium	NA	2-14	>74	>11

(a) Bowen (1979)
(b) Baker and Eldershaw (1993)
NA Not available

3.2 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 off safely else where, thus gradually reducing the contaminant levels. For example vetiver roots and shoots can accumulate more than five times the chromium and zinc levels in the soil (Table 6).

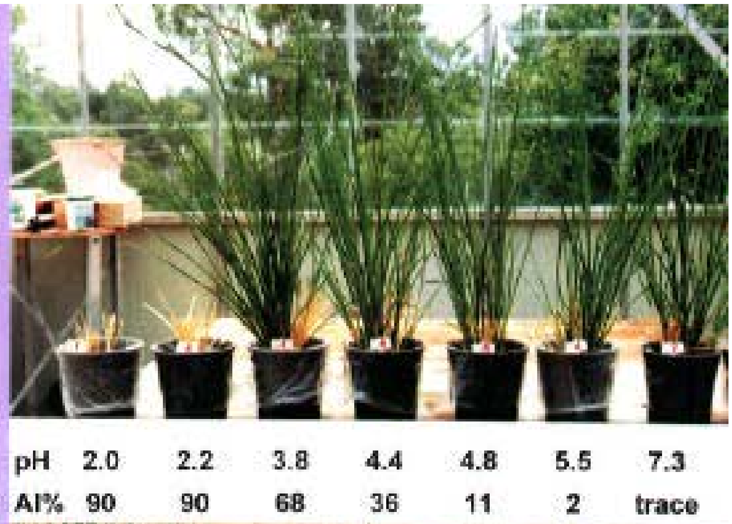
Table 6: Distribution of heavy metals in vetiver shoots and roots

Metals	Soil (mg/kg)	Shoot (mg/kg)	Root (mg/kg)	Shoot/ Root (%)	Shoot / Total (%)
Arsenic	959	9.6	185	5.2	4.9
(As)	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	0.67	0.16	7.77	2.0	2.0
(Cd)	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	50	4	404	1	1
(Cr)	200	5	1170	<1	<1
	600	18	1750	1	1
Average				**<1**	**<1**
Lead	13	0.5	5.1	10	9
(Pb)	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

Metals	Soil (mg/kg)	Shoot (mg/kg)	Root (mg/kg)	Shoot/ Root (%)	Shoot / Total (%)
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
	350	300	610	49	33
	500	540	830	65	39
	750	880	1030	85	46
Average				**69**	**40**

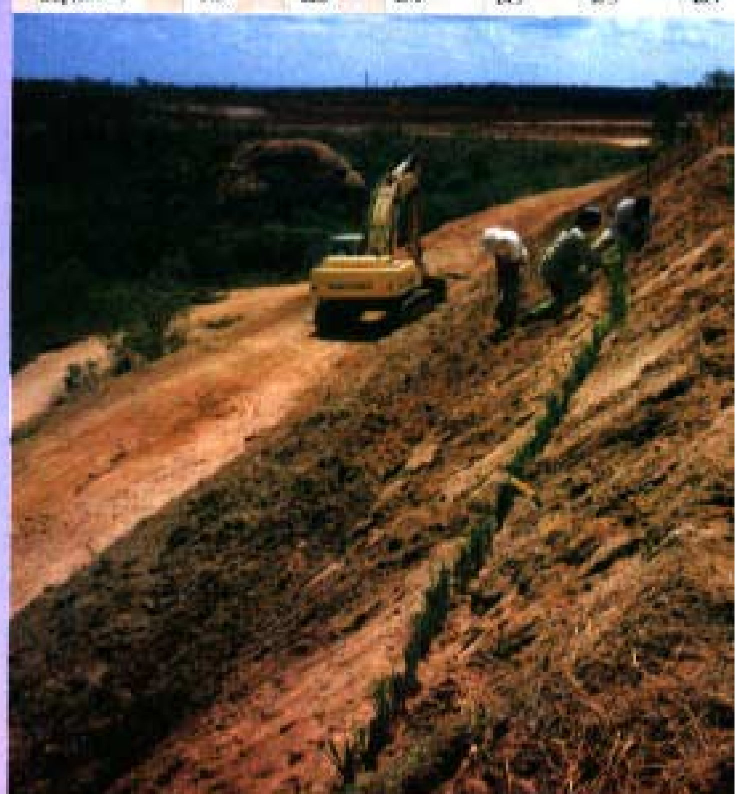
BQ = Below quantification

Vetiver is highly tolerant to Al toxicity: - Aluminium Saturation Percentage of up to 87% had no effect on vetiver growth.



Vetiver is highly tolerant to salinity, with the threshold level at 8 ds/m. Vetiver is among the most salt tolerant crop and pasture species in Australia.

Vetiver is the main erosion control plant used to stabilise the wall of a bauxite residue dam in northern Australia.



4. REHABILITATION OF MINE TAILINGS IN AUSTRALIA

4.1 Coal and Gold Mines Overburden

The overburden of open cut coal mine in central Queensland is generally highly erodible.

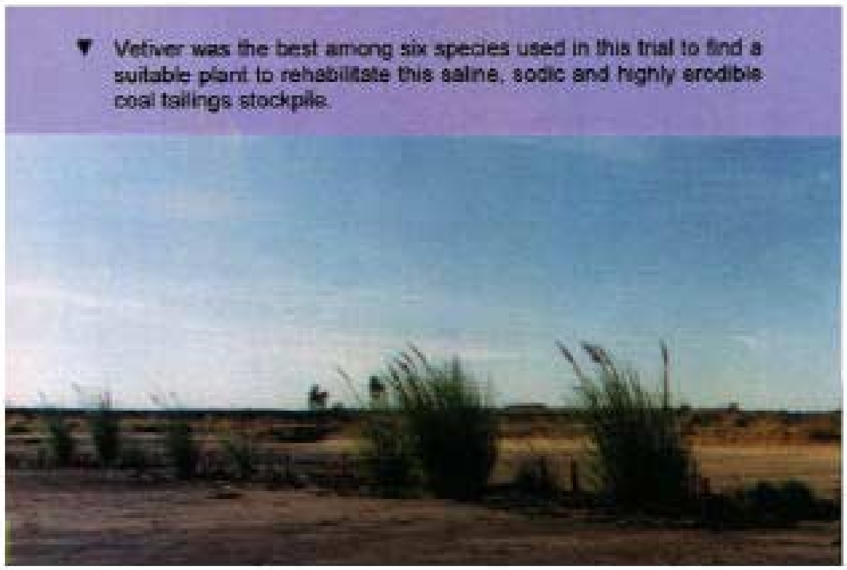
▲ Vetiver was used to stabilise this highly sodic and erodible coal-mine overburden

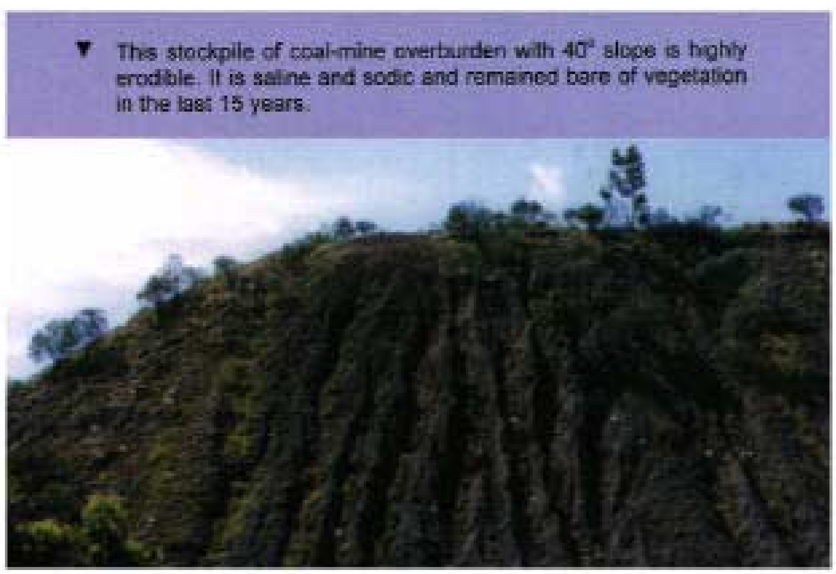
▲ Excellent growth was achieved on this highly sodic coal overburden when adequately supplied with fertiliser and water.

These soils are usually sodic and alkaline (Table 4). Vetiver has established successfully on other sown and native pasture species. Similar successful results were also obtained on a gold mine overburden site.

4.2 Coal Mine Tailings

In an attempt to rehabilitate an old coal mine tailings dam (surface area of 23 ha and capacity of

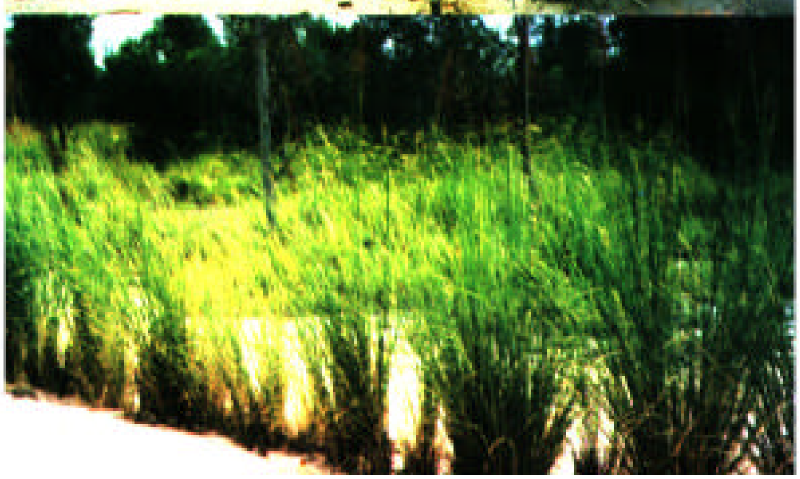




3.5 million cu.m.) a trial was set up to select the most suitable species for the rehabilitation of

Vetiver was planted in the gullies to stop further erosion and to encourage the re-establishment of native species. Excellent growth was obtained six months later.

Satisfactory establishment and growth on this highly acidic (pH 3.8) gold tailing with adequate supply of fertiliser.



Even at pH as low as 2.7, vetiver could be established on this gold tailing with 20t/ha of lime and fertiliser.

The substrate contained high levels of soluble sulphur, 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 increased growth of vetiver by 2 t/ha which was almost ten times higher than that of marine couch (Radloff *et al.* 1995). The results confirm the findings from glass-house trials.

4.3 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 mg/kg), 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 kg/ha of DAP.

Vetiver is now being trialed for a large-scale application to control dust storm and wind erosion on a 300 ha 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 10 to 20 m to reduce wind velocity and at the same time provide a less hostile environment (e.g. shading and moisture conservation) for local native species to be established voluntarily later.

Old tailings: Due to high sulphur 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).

Table 7: Heavy metal contents of a representative gold mine tailings in Australia

Heavy metals	Total contents (mg/kg)	Threshold levels (mg/kg)
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

Field trials conducted on two old (eight years) gold tailing 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 sulphur at 1.31%. The hard top site had a pH of 2.7, sulphate at 0.85% and total sulphur at adequately supplied with nitrogen and phosphorus fertilisers (300 kg/ha of DAP) excellent growth of vetiver was obtained on the soft top site (pH = 3.6) without any liming. But the addition of 5 t/ha of agricultural lime significantly improved vetiver growth. On the hard top site (pH = 2.7) although vetiver survived without liming, the addition of lime (20 t/ha) and fertiliser (500 kg/ha of DAP) improved vetiver growth greatly.

▲ Establishment of vetiver hedges on this highly sodic bentonite residue (Exchangeable Sodium Percentage at 48%), to spread run-off water and trap sediment.

▲ Vetiver planted on a drainage line of a bentonite residue dump.

▼ After 8 months this well-established hedge will act as a very effective water spreader to reduce erosion by concentrated flows and to conserve water for the regeneration of volunteer species.

▼ Good establishment and a satisfactory growth eight months after planting.

4.4 Bentonite Tailings

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 sulph ate and extre mely 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.

4.5 Bauxite Mine

Vetiver is currently being used to stabilise a very large dam wall of a bauxite mine in northern Australia. Trials are being planned to investigate the possibility of establishing vetiver on the highly caustic tailings which has pH level as high as 12. If successful, vetiver will be used to revegetate these tailings *in situ* without capping its surface first with topsoil, which is not generally available and over time the capillary rise of Na and alkalinity will degrade the topsoil cover. This will affect growth of plants which has lower levels of tolerance to sodicity and alkalinity.

5. REHABILITATION OF MINE TAILINGS IN 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 microhabitat for the establishment of indigenous grass species. Rehabilitation using vetiver was particularly successful on kimberlite fines at Cullinan mine where slopes of 35^o 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 (800 mm annual rainfall) and Koffiefonteine (300 mm rainfall) diamond mines where surface temperature of the black kimberlite often exceeds 55^oC, at this temperature most seeds are unable to germinate. Vetiver planted at 2 m VI (vertical interval) provided shades that cool the surface and allowing germination of other grass seeds (Grimshaw pers.com.).

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.)

6. CONCLUSION

From the research results and applications presented above, VGT 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.

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