

VETIVER SYSTEM FOR PREVENTION AND TREATMENT OF CONTAMINATED LAND AND WATER

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ABSTRACT:

The Vetiver System (VS) is now well accepted and used worldwide for numerous applications. Amongst these, environmental protection applications are the most popular due to its effectiveness, simplicity and low cost.

Earlier research conducted to understand the role of the extraordinary physiological and morphological attributes of vetiver grass in soil and water conservation, discovered that vetiver grass also possesses some unique characteristics suitable for environmental protection purposes. Extensive research in Australia, China and Thailand and in other countries has established vetiver tolerance to elevated and sometimes toxic levels of salinity, acidity, alkalinity, sodicity as well as a whole range of heavy metals and agrochemicals. Latest research also shows its exceptional ability to absorb and to tolerate extreme levels of nutrients, to consume large quantities of water in the process of producing a massive growth. These attributes indicated that vetiver is highly suitable for treating polluted wastewater from industries as well as domestic discharges

VS has been used in more than 100 countries with in tropical and subtropical climates for phytoremediation, ranging from wastewater disposal to mine rehabilitation. This paper presents up to date information of the use of VS for the prevention and treatment of contaminated land and water.

KEYWORDS: Pollution, contamination, effluent, wetland, mine tailings, heavy metals

1.0 INTRODUCTION

The Vetiver System (VS), which is based on the application of vetiver grass (*Vetiveria zizanioides*, reclassified as *Chrysopogon zizanioides L*), was first developed by the World Bank for soil and water conservation in India in the 1980s. In addition to its very important application in agricultural lands, scientific research conducted in the last 20 years has clearly demonstrated that VS is also one of the most effective and low cost natural methods of environmental protection. As a result VS is now increasingly being used worldwide for

this purpose. For this reason, vetiver grass is known as a wonder grass, a miracle grass and a magic grass in various parts of the world. The four main applications of VS are:

- Environmental protection by:
 - Prevention, Disposal and Treatment of Wastewater.
 - Prevention and Treatment of Contaminated Land
- Stabilisation of Steep Slopes and Unstable Land
- Soil and Water Conservation in Agricultural Land

This paper only deals with the environmental protection topics.

2.0 SPECIAL FEATURES OF VETIVER GRASS SUITABLE FOR ENVIRONMENTAL PROTECTION PURPOSES

2.1 Extraordinary Morphological Attributes

- Vetiver grass has a strong and massive root system, which is vertical in nature descending 2-3 meters in the first year, ultimately reaching some five meters under tropical conditions.
- The depth of root structure provides the plant with great tolerance to drought, permits excellent infiltration of soil moisture and penetrates through compacted soil layers (hard pans) and reduces/prevents deep drainage, Photo 1.
- The erect and stiff shoots can grow to three meters and when planted close together they form a living porous barrier that retards water flow and acts as a very effective filter, trapping both fine and coarse sediment in runoff water.
- Growth occurs from the crown, which rises relative to soil build-up. It is also highly resistant to pests, diseases, fire, flood and heavy grazing pressure.
- Vetiver is a non aggressive plant; it produces neither stolons nor rhizomes and has to be established vegetatively by root (crown) subdivisions or slips.
- It produces flowers but no seed therefore non invasive and has no weed potential.

Photo 1: Morphological attributes of vetiver grass



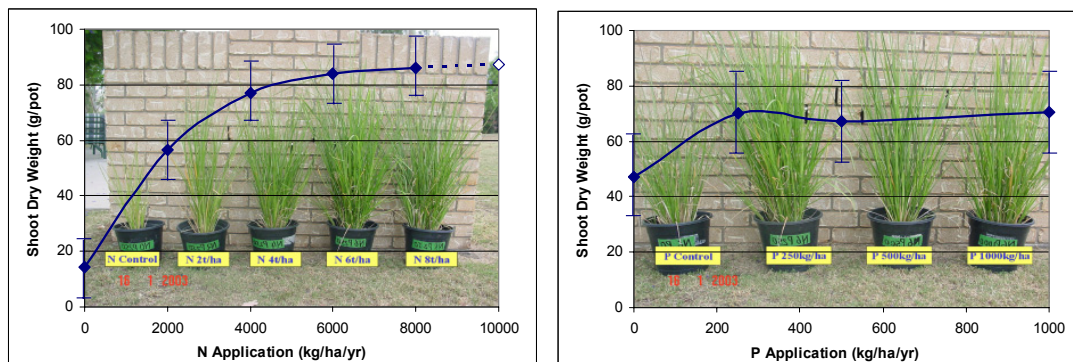
2.2 Extraordinary Physiological Attributes

- Tolerance to extreme climatic variations such as prolonged drought, flood, submergence and temperature levels ranging from -20°C to 55°C.
- Vetiver has been found to thrive under rainfall ranging from 300 mm to 6000 mm per annum.
- Ability to regrow rapidly after being affected by drought, frost, fire, saline and other adverse conditions when the adverse effects are removed.
- Highly tolerant to Al, Mn, As, Cd, Cr, Ni, Pb, Hg, Se and Zn in the soil (Truong and Baker, 1998).
- Highly efficient in absorbing dissolved N and P in polluted water than other plants.
- High level of tolerance to herbicides and pesticides
- Highly tolerant to soil high in acidity, alkalinity, salinity, sodicity and magnesium
- Vetiver grass can be killed easily either by spraying with glyphosate or uprooting and drying out.

3.0 PREVENTION AND TREATMENT OF CONTAMINATED WATER

Extensive research in Australia, China and Thailand and in other countries has established vetiver grass possesses some unique characteristics suitable for environmental protection purposes (Truong, 2004). Such as its tolerance to elevated and sometimes toxic levels of salinity, acidity, alkalinity, sodicity as well as a whole range of heavy metals and agrochemicals mentioned above. Latest research also shows its exceptional ability to absorb and to tolerate extreme levels of nutrients (Wagner *et al.* 2003), (Fig.1), to consume large quantities of water in the process of producing a massive growth, more than 100t/ha of biomass (Truong and Smeal, 2003). These attributes indicated that vetiver is highly suitable for treating polluted wastewater from industries as well as domestic discharges.

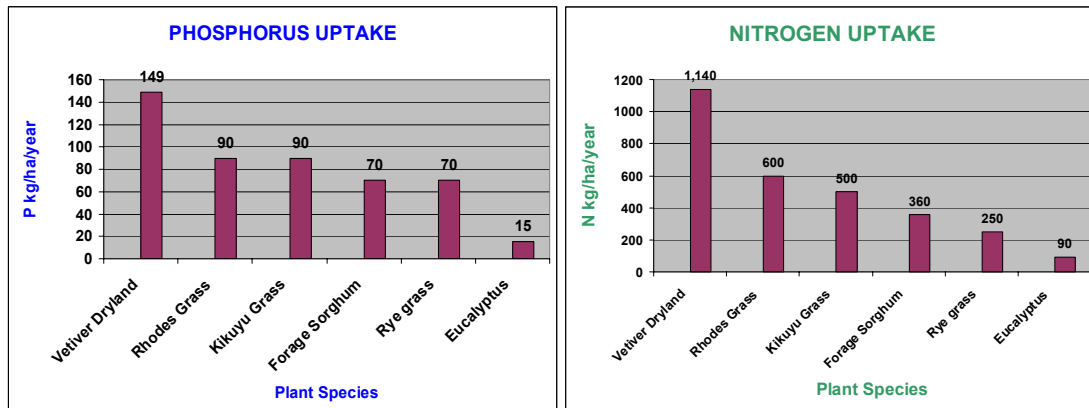
Fig.1: High capacity of absorbing N and P and high level of tolerate to these nutrients.



3.1 Reducing or Eliminating the Volume of Wastewater

For large-scale reduction or total elimination of wastewater, vegetative methods are the only feasible and practicable method available to date. In the past, trees and pasture species have been used for the disposal of wastewater in Australia, but recently vetiver grass has been found to be more effective than trees and pasture species in the disposal and treatment of landfill leachate, domestic and industrial effluent, (Fig.2).

Fig.2: Higher capacity of uptake N and P than other plants



To quantify the water use rate of vetiver, a glasshouse trial showed a good correlation between water use and dry matter yield. From this correlation it was estimated that for **1kg of dry shoot biomass, vetiver would use 6.86L/day**. If the biomass of 12-week-old vetiver, at the peak of its growth cycle, was 40.7t/ha, a hectare of vetiver would potentially use 279KL/ha/day (Truong and Smeal, 2003). Latest data from a landfill leachate site shows vetiver can dispose up to 3.8L/m²/day.

3.1.1 Disposal of septic effluent:

The first application of the VS for effluent disposal was conducted in Australia in 1996, and subsequent trials demonstrated that planting about 100 vetiver plants in an area less than 50m² have completely dried up the effluent discharge from a toilet block in a park, where other plants such as fast growing tropical grasses and trees, and crops such as sugar cane and banana have failed (Truong and Hart, 2001).

3.1.2 Disposal of landfill leachate:

Disposal of landfill leachate is a major concern to all large cities, as the leachate is often highly contaminated with heavy metals, organic and inorganic pollutants. In Australia and China this problem can be solved by irrigating vetiver planted on the top of the landfill mound and retaining dam wall with leachate collected at the bottom of the dumps. Results to date have been excellent, the growth was so vigorous that during the dry period, there was not enough leachate to irrigate the vetiver. A planting of 3.5ha has effectively disposed of 4 ML a month in summer and 2 ML a month in winter (Percy and Truong, 2005).

3.1.3 Disposal of industrial wastewater

In Australia, the disposal of industrial wastewater is subjected to the strict environmental guidelines enforced by the Environmental Protection Authority. The most common method of treating industrial wastewater in Queensland is by land irrigation, which is presently based on tropical and subtropical pasture plants. However with limited land area available for irrigation, these plants are not efficient enough to sustainably dispose of all the effluent produced by the industries. Therefore to comply with the new standards, most industries are now under strong pressure to upgrade their treatment processes by adopting VS as a sustainable means of disposing wastewater (Smeal *et al*, 2003).

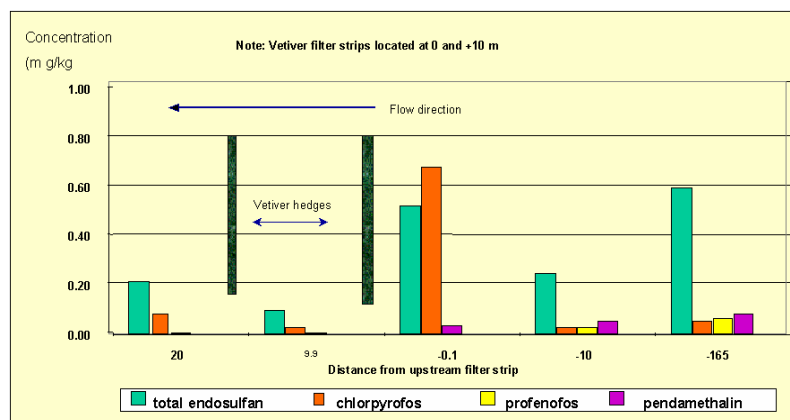
3.2 Improving Wastewater Quality

Off-site pollution is the greatest threat to the world environment, this problem is widespread in industrialised nations but it is particularly serious in developing countries, which often do not have enough resources to deal with the problem. Vegetative method is generally the most efficient and commonly used for water quality improvement.

3.2.1 Trapping debris, sediment and agro-chemicals in agricultural lands

In Australia research studies in sugar cane and cotton farms have shown that vetiver hedges were highly effective in trapping particulate-bound nutrients such as P, Ca and herbicides such as diuron, trifluralin, prometryn and fluometuron and , pesticides such as α , β and sulfate endosulfan and chlorpyrifos, parathion and profenofos. These nutrients and agrochemicals could be retained on site if vetiver hedges were established across drainage lines (Truong *et al*. 2000) (Fig.3).

Fig 3: Herbicide concentration in soil deposited upstream and downstream of vetiver filter strips



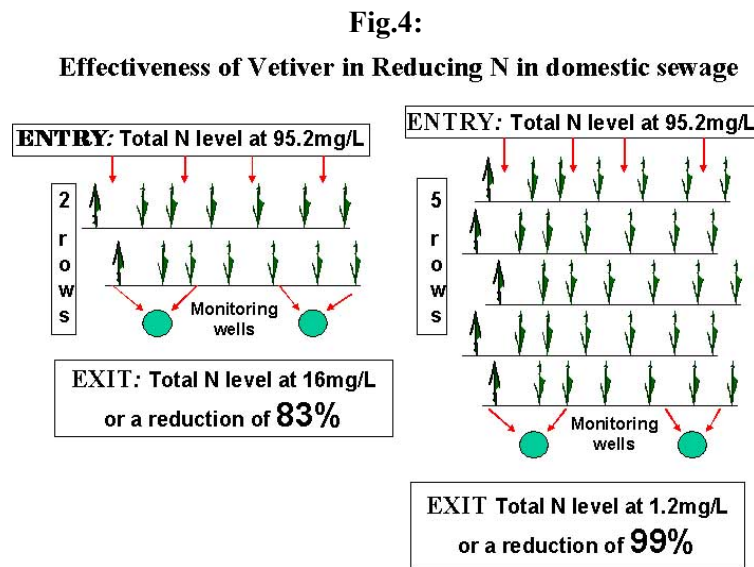
In Thailand, in experiment conducted at the Huai Sai Royal Development Study Centre, Phetchaburi Province has shown that vetiver contour hedgerows planted across the slope form a living dam, while its root system forms an underground barrier that prevents water-borne pesticide residues and other toxic substances from flowing down into the water body

below. The thick culms just above the soil surface also collect debris and soil particles carried along the watercourse (Chomchalow, 2006).

3.2.2 Absorbing and tolerating pollutants and heavy metal

The key feature of VS in treating polluted water lies in its capacity to quickly absorb nutrients and heavy metals, and its tolerance to very elevated levels of these elements. Although the concentrations of these elements in vetiver plants is often not as high as those of hyper-accumulators, however due to its very fast growth and high yield (dry matter production up to 100t/ha/year), vetiver can remove a much higher quantity of nutrients and heavy metals from contaminated lands than most hyper-accumulators.

In Australia, a project was carried out to demonstrate and to obtain quantitative data on the effect of the VS in reducing the volume of effluent and also improving the quality under field conditions. In this trial five rows of vetiver were sub-surface irrigated with effluent discharge from the septic tank. Two sets of monitoring wells were installed, one after two rows and a second one after five rows of vetiver. After five-months of growth, the total N levels in the seepage collected after 2 rows was reduced by 83% and after 5 rows by 99%. Similarly the total P levels were reduced by 82% and 85% respectively (Truong and Hart, 2001) (Fig.4).



In China, nutrients and heavy metals from pig farm are key sources of water pollution. Wastewater from pig farm contains very high N and P and also Cu and Zn, which are used as growth promoters in the feeds. The results showed that vetiver had a very strong purifying ability. Its ratio of uptake and purification of Cu and Zn was >90%; As and N>75%; Pb was between 30% -71% and P was between 15-58%. The purifying effects of vetiver to heavy metals, and N and P from a pig farm were ranked as Zn>Cu>As>N>Pb>Hg>P (Xuhui *et al.*, 2003; Liao *et al.*,2003).

In Thailand, according to Chomchalow, (2006), the most active field of vetiver research in the last few years has been the treatment of wastewater, which indicates that the problem of wastewater is a serious one in Thailand. Different types of wastewater, including leachate and effluent, which have been treated by vetiver were from such sources as: (i) domestic wastewater (ii) food manufacturer, (iii) shrimp pond, (iv) whisky distillery, (v) paper mill, (vi) rice mill, (vii) tapioca flour mill, (viii) dairy plant, (ix) battery manufacturer, (x) lamp-shade manufacturer, (xi) printing ink manufacturer, and (xii) garbage landfill. The nature of wastewater varied with the sources, all of which are of high BOD and COD, some are eutrophicated waters with high amounts of N, P, and K; some are high in heavy metal contamination. Various approaches have been attempted, e.g. through constructed wetland, with combination of other aquatic plants, in combination with chemical treatment (PAC) after sedimentation, etc. Vetiver has been found to be able to solve this problem effectively at a low cost based on simple technology.

In one study, comparative studies of vetiver grown in domestic wastewater from the Royal Irrigation Department community revealed that different ecotypes exhibited different growth and adaptability. 'Surat Thani' ecotype was found to exhibit the highest ability (in percentage) to reduce: nitrate (49.33), bicarbonate (42.66), EC (5.81), and TSS (82.78), while 'Monto' cultivar exhibited the highest ability to reduce: BOD (75.28), total N (92.48), K (14.00), and Na (3.14). The efficiency of wastewater treatment was found to increase with the age of vetiver plant, and the highest was at 3 months of age (Chomchalow, 2006, cit. Techapinyawat 2005).

In Vietnam, a demonstration trial was set up at a sea food processing factory to determine the treatment time required to retain effluent in the vetiver field to reduce nitrate and phosphate concentrations in effluent to acceptable levels. The experiment started when plants were 7 months old. Water samples were taken for analysis at 24 hour interval for 3 days. Analytical results showed that total N content in wastewater was reduced by 88% and 91% after 48 and 72 hours of treatment, respectively. While the total P was reduced by 80% and 82% after 48 and 72 hours of treatment. The amount of total N and P removed in 48 and 72 hour treatments were not significantly different (Luu *et al*, 2006).

The banks of canals and irrigation channels in the acid sulfate soil (ASS) regions of southern Vietnam are highly erodible. Results to date indicate that on moderately acidic soil (pH >3.5) vetiver can be established easily with adequate fertiliser only, but on severe ASS (pH between 2.5 and 3.0), vetiver grass can survive and grow only with lime application, which provides high survival and growth rates. Concentrations of some toxic elements such as Al, Fe, and SO₄ in vetiver grass were very high, much higher than those species considered tolerant to ASS. Moreover these concentrations tend to increase as the plant matures. These high concentrations indicate the level of these elements could be reduced in both surface runoff and deep drainage water, thus reducing the contamination of canal water (Le van Du and Truong, 2003).

3.2.3 Wetlands

Natural and constructed wetlands have been shown effective in reducing the amount of contaminants in runoff from both agricultural and industrial lands. The use of wetlands for the removal of pollutants involves a complex variety of biological processes, such as microbiological transformations and physio-chemical processes, e.g. adsorption, precipitation or sedimentation.

Vetiver is eminently suitable for use as a vegetative buffer or wetland plant species due to the following morphological and physiological features (Cull *et al.* 2000):

- An ability to tolerate flooded soil conditions makes it ideal for use in ephemeral or permanent wetlands.
- The dense stand of stiff, erect stems can reduce flow velocity, increase detention time and enhance deposition of sediment and sediment-bound contaminants (eg. heavy metals and some pesticide residues).
- The dense, finely structured root system can improve bed stability and nutrient uptake, and provide an environment that stimulates microbiological processes in the rhizosphere.
- The high tolerance to elevated effluent loadings such as undiluted landfill leachate and domestic effluent.
- Most importantly its sterility should minimise its potential for becoming an aquatic weed.

In Australia, under wetland conditions, vetiver had the highest water use rate compared with other wetland plants such as *Iris pseudacorus*, *Typha spp*, *Schoenoplectus validus*, *Phragmites australis*. At the average consumption rate of 600mL/day/pot over a period of 60 days, vetiver used 7.5 times more water than *Typha* (Cull *et al.* 2000).

A wetland was constructed to treat sewerage effluent output from a small rural town. The aim of this scheme was to reduce/eliminate the 500ML/day effluent produced by this small town before the effluent is discharged to the waterways. The results so far has been outstanding, vetiver wetland has absorbed all the effluent produced by this small town Table 1. (Ash and Truong, 2003).

In China the disposal of wastewater from intensive animal farms is one of the biggest problems in densely populated areas. China is the largest pig raising country in the world. In 1998 Guangdong Province had more than 1600 pig farms with more than 130 farms producing over 10,000 commercial pigs each year. These large piggeries produce 100-150 ton of wastewater each day, which included pig manure collected from slatted floors, containing high nutrient loads.

Wetlands are considered to be the most efficient means of reducing both the volume and high nutrient loads of the piggery effluent. To determine the most suitable plants for the wetland system, vetiver grass was selected along with another 11 species in this program.

The best species are vetiver, *Cyperus alternifolius*, and *Cyperus exaltatus*. However, further testing showed that *Cyperus exaltatus* wilted and became dormant during autumn and did not rejuvenate until next spring. Full year growth is needed for effective wastewater treatment. Therefore vetiver and *Cyperus alternifolius* were the only two plants suitable for wetland treatment of piggery effluent (Liao, 2 000).

Table 1. Effluent quality levels before and after vetiver treatment

<i>Tests</i>	Fresh Influent	Results 2002/03	Results 2004
PH (6.5 to 8.5)*	7.3 to 8.0	9.0 to 10.0	7.6 to 9.2
Dissolved Oxygen (2.0 minimum)*	0 to 2 mg/l	12.5 to 20 mg/l	8.1 to 9.2 mg/l
5 Day BOD (20 - 40 mg/l max)*	130 to 300 mg/l	29 to 70 mg/l	7 to 11 mg/l
Suspended Solids (30 - 60 mg/l max)*	200 to 500 mg/l	45 to 140 mg/l	11 to 16 mg/l
Total Nitrogen (6.0 mg/l max) *	30 to 80 mg/l	13 to 20 mg/l	4.1 to 5.7 mg/l
Total Phosphorous (3.0 mg/l max) *	10 to 20 mg/l	4.6 to 8.8 mg/l	1.4 to 3.3 mg/l

*Licence requirements.

In Thailand very good research has been conducted in the last few years on the application of VS to treat wastewater at various scales, in constructed wetland. In one study, three ecotypes of vetiver ('Monto', 'Surat Thani' and 'Songkhla 3' were used to treat wastewaters from a tapioca flour mill factory. Two systems of treatment were employed namely: (i) holding wastewater in a vetiver wetland for two weeks and then drained off, and (ii) holding wastewater in a vetiver wetland for one week and drain it off continuously for a total of 3 weeks. It was found that in both systems, 'Monto' ecotype had the highest growth of shoot, root, and biomass, and was able to absorb highest levels of P, K, Mn and Cu in the shoot and root, Mg, Ca and Fe in the root, and Zn and N in the shoot. 'Surat Thani' ecotype could absorb highest levels of Mg in the shoot and Zn in the root, while "Songkhla" ecotype could absorb highest levels of Ca, Fe in the shoot, and N in the root maximally (Chomchalow,2006, cit. Techapinyawat 2005).

3.2.4 Computer Modeling

In recent years, computer models have been increasingly considered as an essential tool for managing environmental systems. The complexity of wastewater management has made computer models instrumental in the planning and implementation of industrial wastewater

disposal schemes. In Queensland, Australia, the Environmental Protection Authority has adopted MEDLI (Model for Effluent Disposal using Land Irrigation) as a basic model for industrial wastewater management. The most significant development in VS use for wastewater disposal in recent years is that Vetiver has been calibrated for use in MEDLI, for nutrient uptake and effluent irrigation (Veiritz, *et al.*, 2003), (Truong, *et al.*, 2003a), (Wagner, *et al.*, 2003), (Smeal, *et al.*, 2003).

3.2.5 Future Trend

As water shortage is looming worldwide, wastewater should be considered as a resource rather than a problem. ***The current trend is to recycle wastewater for domestic and industrial uses***, instead of disposal. Therefore the potential of VS is enormous as a simple, hygienic and low cost means of treating and recycling wastewater resulting from human activities.

The most recent and significant development on the use of vetiver for wastewater treatment is its use in a Soil Based Reed Beds, new application, which the output water quality and quantity can be adjusted to provide a desired standard. This system is now under development and tested at GELITA APA, Australia. The full details of this system are described in Smeal *et al.* (2006).

4.0 TREATMENT OF CONTAMINATED LANDS

In term of environmental protection, the most significant breakthroughs in the last 15 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 rehabilitation of toxic and contaminated lands.

4.1 Tolerance to Adverse Conditions

4.1.1 Tolerance to High Acidity, Aluminium and Manganese Toxicity

Research results showed that with N and P fertilisers, vetiver growth was not affected even under extremely acidic conditions (pH = 3.8) and at a very high level of soil Aluminium Saturation Percentage (68%)., but vetiver did not survive an aluminium saturation level of 90% at soil pH = 2.0. Therefore the threshold level must be between 68% and 90%. Field-testing confirmed later that vetiver grew satisfactorily at soil pH=3.0 and aluminium level between 83-87%, which is extremely high as growth of most plant is affected at level less than 30%. In addition vetiver growth was not affected when the extractable manganese in the soil reached 578 mgKg⁻¹, soil pH as low as 3.3 and plant manganese content was as high as 890 mgKg⁻¹. As a result of its high tolerance level to Al and Mn toxicity, vetiver has been used successfully for erosion control in Acid Sulfate Soils with actual soil pH around 3.5 and oxidised pH is as low as 2.8 (Truong and Baker, 1998).

4.1.2 Tolerance to High Soil Salinity and Sodicity

With the salinity threshold level at $EC_{se} = 8 \text{ dSm}^{-1}$ vetiver grass compares favourably with some of the most salt tolerant crop and pasture species grown in Australia such as Bermuda Grass (*Cynodon dactylon*) with threshold at 6.9 dSm^{-1} ; Rhodes Grass (*Chloris guyana*) at 7.0 dSm^{-1} ; Wheat Grass (*Thynopyron elongatum*) at 7.5 dSm^{-1} and barley (*Hordeum vulgare*) at 7.7 dSm^{-1}

With adequate supply of N and P vetiver grew satisfactorily on Na bentonite tailings with Exchangeable Sodium Percentage of 48% and a coalmine overburden with an exchangeable sodium level of 33%. Moreover the sodicity of this overburden was further exacerbated by the very high level of magnesium (2400 mgKg^{-1}) compared to calcium (1200 mgKg^{-1}).

4.1.3 Tolerance to Heavy Metals

Table 2 shows that vetiver is highly tolerant to As, Cd, Cr, Cu, Hg, Ni, Pb, Se and Zn.

Table 2: Threshold levels of heavy metals to vetiver growth as compared with other species

Heavy Metals	Threshold levels in soil (mgKg^{-1})(Available)		Threshold levels in plant (mgKg^{-1})	
	Vetiver	Other plants	Vetiver	Other plants
Arsenic	100-250	2.0	21-72	1-10
Cadmium	20-60	1.5	45-48	5-20
Copper	50-100	Not available	13-15	15
Chromium	200-600	Not available	5-18	0.02-0.20
Lead	>1 500	Not available	>78	Not available
Mercury	>6	Not available	>0.12	Not available
Nickel	100	7-10	347	10-30
Selenium	>74	2-14	>11	Not available
Zinc	>750	Not available	880	Not available

4.1.4 Distribution of Heavy Metals in Vetiver Plant

The distribution of heavy metals in vetiver plant can be divided into three groups:

- Very little of the As, Cd, Cr and Hg absorbed were translocated to the shoots (1% to 5%)
- A moderate proportion of Cu, Pb, Ni and Se were translocated (16% to 33%) to the top and
- Zn was almost evenly distributed between shoot and root (40%) (Truong, 2004).

4.2 Mine Rehabilitation and Phytoremediation

With the above extraordinary morphological and physiological characteristics, vetiver grass has been used successfully for steep slope stabilisation and phytoremediation of mine tailings in Australia and other countries (Truong, 2004).

4.2.1 Australia

Coal Tailings: A trial was set up to select the most suitable species to rehabilitate a 23 ha, 3.5 million cubic metres coal tailings pond at Saraji coal mine in central Queensland. 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 grass, 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 t ha⁻¹, which was almost 10 times higher than that of marine couch (Truong, 2004).

Fresh Gold tailings: Fresh 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 Kg ha⁻¹ of DAP. Vetiver has been used successfully in a large-scale trial to control dust movement and wind erosion on a 300ha tailings dam. When planted in rows at 10m to 20m spacing, vetiver hedges reduced wind velocity and promoted the establishment of Rhodes grass

Old Gold 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, often very expensive, and the bare soil surface is highly erodible. Field trials were conducted on two old (8 year) tailings sites. One exhibits a soft surface and the other 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 3.75%. Both sites were low in plant nutrients (Table 3).

When adequately supplied with nitrogen and phosphorus fertilisers (300Kg ha⁻¹ of DAP), excellent growth of vetiver was obtained on the soft top site (pH=3.6) without any liming. But the addition of 5t ha⁻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 (20t ha⁻¹) and fertiliser (500kg ha⁻¹ of DAP) improved vetiver growth greatly (Truong, 2004).

4.2.2 China

Mine tailings: It has been demonstrated that *V. zizanioides* is one of the best choices for revegetation of Pb/Zn mine tailings due to its high metal tolerance, furthermore, this grass can be also used for phyto-extraction because of its large biomass. Recent research also suggests that vetiver also has higher tolerance to acid mine drainage (AMD) from a Pb/Zn mine, and wetlands planted with this grass can effectively adjust pH and remove SO₄²⁻, Cu,

Cd, Pb, Zn and Mn from AMD. For example, 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 and Xia, 2003).

Table 3: Heavy metal contents of 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

Industrial wastewater: Wastewater produced from the oil refinery of the Maoming Petro-Chemical Company, Guangzhou, contains high concentrations of organic and inorganic pollutants, therefore it cannot be discharged directly into river or sea unless being treated first. Four plant species, *Vetiveria zizanioides*, *Phragmites australis*, *Typha latifolia*, and *Lepironia articulata* were used in a vertical flow wetlands to test their efficiencies in the purification of oil refined wastewater and their growth in wetlands soaked with oil refined wastewater. The results obtained from a 2-month trial indicated that the purifying rates of constructed wetlands for oil-refined wastewater were all very high at the beginning, but the performance decreased and became basically stable as time passed (Xia *et al.* 2003).

4.2.3 South Africa

Mine tailings: Rehabilitation trials conducted by De Beers in South Africa on slimes dams at several sites, have found that vetiver possessing the necessary attributes for self sustainable growth on the alkaline kimberlite spoils, containing run off, arresting erosion and creating an ideal micro-habitat for the establishment of indigenous grass species. Vetiver has also been used successfully in the rehabilitation of diamond mines at Premier and Koffiefonteine and slimes dams at the Anglo American platinum mine at Rastenburg and the Velkom, President Brand gold mine. (Tantum pers.com.).

4.2.4 Thailand

Chomchalow, 2006, (Cit. Rungtanakiat 2005b) 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.

5.0 OVERALL ADVANTAGES OF VETIVER SYSTEM APPLICATION

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

5.1 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.

5.2 Low cost

Application of the Vetiver System in wastewater 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.

5.3 Minimal maintenance

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

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A Brief Introduction to the First Author

Dr. Paul Truong, a Director and East Asia and South Pacific Representative of The International Vetiver Network, and recently Principal Consultant of Veticon Consulting. In the last 18 years he has conducted extensive R&D and Application of the Vetiver System in erosion and sediment control, and land rehabilitation in tropical and subtropical Australia, Asia and Africa.

His pioneering research on vetiver grass tolerance to adverse conditions, heavy metal tolerance and pollution control has established the benchmark for VS applications in toxic wastes and mine rehabilitation, wastewater treatment, which he has won several World Bank and the King of Thailand Awards.