VETIVER SYSTEM FOR PREVENTION AND TREATMENT OF CONTAMINATED WATER AND LAND

Paul Truong
Director, The Vetiver Network International
TVNI Asia and Oceania Coordinator
Veticon Consulting, Brisbane, Queensland, Australia
Truong@uqconnect.net

Abstract

The Vetiver System (VS), which is based on the applications of Vetiver Grass *(Chrysopogon zizanioides,* Roberty L.), was researched and developed by *The Vetiver Network International* (TVNI) as an environmental protection tool. Application of VS for environmental protection is a new and innovative phytoremedial technology. VS is being used in more than 100 tropical and subtropical countries in Australia, Asia, Africa and Latin America for treating and disposing polluted wastewater, mining wastes and contaminated lands due to its effectiveness and low cost natural methods of environmental protection.

Extensive R&D in Australia, China and Thailand over the last 20 years have established that vetiver Grass is non invasive it has a high water and nutrient uptake and thrives under most adverse soil and climatic conditions. Vetiver grass is tolerant 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, capable of consuming large quantities of water under wet conditions and to produce a massive growth.

It is a green and environmentally friendly wastewater treatment technology as well as a natural recycling method. Its end-product has several uses including animal fodder, handicraft and material for organic farming.

Due to its extraordinary morphological and physiological characteristics, vetiver grass has also been used successfully for rehabilitation of coal, gold, lead, zinc, copper, bentonite, bauxite mine waste and phytoremediation of highly contaminated land and solid industrial wastes in Australia, Chile, China, South Africa, Thailand and Venezuela

Keywords: Vetiver grass, leachate, effluent, mine tailings, contaminated land, heavy metals,

1.0 INTRODUCTION

The Vetiver System (VS), which is based on the application of vetiver grass (*Chrysopogon zizanioides,* Roberty L), was first developed by the World Bank for soil and water conservation in India in the 1980s. Further research and development by *The Vetiver Network International* (TVNI) in the last 20 years have established VS as an innovative phytoremedial technology for treating and disposing polluted wastewater, mining wastes and contaminated lands due to its effectiveness and low cost natural methods of environmental protection.

VS is being used in more than 100 tropical and subtropical countries in Australia, Asia, Africa and Latin America for treating and disposing polluted wastewater from domestic and industrial discharges due to its effectiveness and low cost natural methods.

Extensive R&D in Australia, China, Thailand and recently Venezuela have established that vetiver Grass is non invasive it has a high water and nutrient uptake and thrives under most adverse soil and climatic conditions. Vetiver grass is tolerant 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, capable of consuming large quantities of water under wet conditions and to produce a massive growth.

It is a green and environmentally friendly wastewater treatment technology as well as a natural recycling method. Its end-product has several uses including animal fodder, handicraft, biofuel and green manure for organic farming.

For these reasons, vetiver grass is known as a wonder grass, a miracle grass and a magic grass in various parts of the world. The two main applications of VS for Environmental Protection are:

- Prevention, Disposal and Treatment of Wastewater.
- Rehabilitation and Treatment of Contaminated Land

2.0 SPECIAL CHARACTERISTICS OF VETIVER GRASS. (Truong et al. 2008)

- ***Tall, erect and stiff shoots*** can grow up to 3m under favorite conditions
- ***Forming a thick living porous barrier***. When planted close together they form a porous barrier that retards and spreads water flow and acts as a very effective filter, trapping both fine and coarse sediment in runoff water
- ***Deep and Massive Root System.*** Vetiver grass has a deep 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.
- ***Tolerance to extreme climatic variations*** such as prolonged drought, flood, submergence and temperature levels ranging from -14ºC to 55ºC and to thrive under rainfall ranging from 300 mm to 6000 mm per annum.
- ***Ability to re-grow rapidly*** after being affected by drought, frost, fire, saline and other adverse conditions when the adverse effects are removed.
- ***Highly resistant*** to pests, diseases and fire
- ***Highly tolerant to traffic*** and high grazing pressure as its new shoots develop from the crown below ground level.
- ***Weed Potential*** Vetiver is a non-aggressive plant; it flowers but set no seeds, it produces neither above nor underground stems and it has to be established vegetatively by root (crown) splitting. It is imperative that any plants used for environmental protection purposes will not become a weed in the local environment.

A sterile plant such as Vetiver is ideal for this application. Vetiver grass can be killed easily either by spraying with Glyphosate or uprooting and drying out

3.0 PREVENTION, DISPOSAL AND TREATMENT OF WASTEWATER.

3.1 Special Characteristics of Vetiver Grass Suitable for Wastewater Treatment

- ***Highly tolerant*** to soil high in acidity, alkalinity, salinity, sodicity and magnesium
- ***Highly tolerant to*** Al, Mn, As, Cd, Cr, Ni, Pb, Hg, Se and Zn in the soil (Truong and Baker, 1998), (Danh et al.2009).
- **Capable of withstanding extremely** high N supply (10 000KgN/ha/year) and P (1000KgN/ha/year) (Wagner et al.,2003).
- ***Capable of responding*** to very high N supply (6 000KgN/ha/year)
- ***Highly efficient in absorbing*** dissolved nutrients particularly N and P in polluted water (Truong and Hart, 2001)
- ***High level of tolerance*** to herbicides and pesticides such as Diuron or Atrazine herbicides at concentrations up to 2000 mg/L levels. (Cull et al. 2000)
- ***Vetiver grass is both a xerophyte*** (drought tolerant due to its deep and extensive root system) and a hydrophyte (wetland plant due to its well developed sclerenchyma [*air cell*] network). Vetiver thrives under hydroponics conditions. (Truong and Hart, 2001)
- ***High water use rate.*** Under wetland conditions or high water supply Vetiver can use more water than other common wetland plants such as *Typha* spp, (approximately 7.5 times more) and *Phragmites australis* and *Schoenoplectus validus*. Under optimal growing conditions, a hectare of vetiver would potentially use 279KL/ha/day. (Cull et al. 2000)

3.2 Effectiveness of Vetiver Grass in Treating Contaminated Water

Latest research also shows its exceptional ability to absorb and to tolerate extreme levels of nutrients (Wagner *et al*. 2003), 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.

3.3 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.

3.3.1 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 $50m^2$ 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). Groundwater monitoring showed that after passing through 5 rows of vetiver the levels of total N reduced by 99% (from 93 to 0.7 mg/L), total P by 85% (from 1.3 to 0.2 mg/L), and faecal Coliforms by 95% (from 500 to 23 organisms/100mL). These levels are well below the following thresholds used by the Australian EPA of total N <10 mg/L; total P <1 mg/L and *E. coli* <100 organisms/100mL

3.3.2 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).

3.3.3 Disposal of industrial wastewater

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).

3.4 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.

3.4.1 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)

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).

3.4.2 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).

In Chile, VS is currently being evaluated for the treatment of wastewater from a very large pig farm near Santiago. This effluent has very high content of N, P and heavy metals (Molina, 2010).

In China the disposal of wastewater from intensive animal farms is one of the biggest problems in densely populated areas as China is the largest pig raising country in the world 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).

In Venezuela, VS is currently being used to dispose wastewater from beer breweries and animal farms, as well as polluted water in lakes and dams (O. Luque pers. com).

In Vietnam, VS was used to treat wastewater from a sea food processing factory in the Mekong Delta a demonstration trial was set up 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 to 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).

3.4.3 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 its unique morphological and physiological features (Cull *et al.* 2000):

Table 1. Effluent quality levels before and after vetiver treatment

Tests	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 Australia, 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 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).

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).

3.5 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 Truong and Smeal (2003).

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 Special Characteristics of Vetiver Grass Suitable for Mine and Contaminated Lands Rehabilitation

In addition to the general important attributes listed under2.2 above, the followings are some unique characteristics of vetiver grass especially suited for mine and contaminated lands rehabilitation:

- Tolerance to highly adverse conditions: acidic and alkaline (soil pH between 3.5-10.5), sodic, magnesic, aluminium and manganese toxicities, and saline soils
- Tolerance to very high levels of heavy metals such as As, Cd, Cr, Cu, Hg, Ni, Pb, Se and Zn in the soil.
- Most of heavy metals absorbed remained in the root; hence it can be used as fodder.
- Ability to re-grow rapidly after being affected by drought, frost, fire, saline and other adverse conditions when the adverse effects are removed.

4.2 Tolerance to Adverse Conditions

4.2.1 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 (68-80%). 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).

4.2.2 Tolerance to High Soil Salinity and Sodicity

With the salinity threshold level at $EC_{se} = 8\ dSm^{-1}$ 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}

4.2.3 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: Thresholds 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

4.2.4 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).

4.3 Mine Waste 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).

4.3.1 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. The substrate contained high levels of soluble sulphur, magnesium and calcium as well as was saline, highly sodic and extremely low in nitrogen and phosphorus. 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 tha^{-1}, which was almost 10 times higher than that of marine couch (Radloff et al, 1995).

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 $Kgha^{-1}$ 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 (300$Kgha^{-1}$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 (Truong, 2004).

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

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 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.

4.3.2 Chile

Copper mines: The main economic income of Chile originates from the mining industry, mainly the mining of copper. For this reason Fundacion Chile is carrying out a series of pilot studies using the Vetiver System to remediate the wastes produced by the 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.

One year after planting, 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 (Fonseca et al, 2006). An update review of this project is presented by Rocio Fonseca at this conference.

4.3.2 China

Mine tailings: It has been demonstrated that *C. 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 SO_4^{2-}, 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, 2003).

4.3.3 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.).

4.3.4 Thailand

Mine tailings: 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.

4.3.5 Venezuela

Bauxite mine: The bauxite mine, CVG BAUXILUM, located in Los Pijiguaos, Bolivar State, incorporated the VS into its general policy to mitigate the impact of mining activities on the local community with the aim of providing social assistance, and economical development to the people of the region. Vetiver system 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 Vetiver System 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)

4.4 Contaminated Lands Rehabilitation and Phytoremediation

Industrial wastes contain very high levels of both organic and inorganic compound have been successfully treated in Australia, China, India, Thailand and Vietnam.

In Australia, Vetiver grass was successfully used to rehabilitate an old waste dump at an explosive factory heavy contaminated with N, as shown below:

- Contaminated soil volume: Approx 6 990m^3
- Total contaminated soil volume: 71 120 m^3
- Soil Ammonia level, ranging from 20-1 220mg/kg, averaging 620mg/kg
- Soil total N level, ranging from 31-5 380mg/kg, averaging 2 700mg/kg
- Water Ammonia level, ranging from 235-1 150mg/L, with one sample at 12 500mg/L

Based on the above average levels of NH_3 and total N, the grand total N content of the top soil (20cm depth) is 0.66kgN/m^2, which is equivalent to 6 600kgN /ha. Vetiver research has shown that Vetiver under optimum moisture supply can be grown on soil applied up to 8 000kgN/ha (Wagner *et al* 2003, attached). Hence it is projected that most of the N in the fill will be removed by vetiver in less than 4 years under favourable weather and at most 6 years under normal weather conditions. In the last few years vigorous growth produced very high biomass with high N content indicating that this projection is on course.

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. (Truong and Cruz, 2010).

5.3 Minimal maintenance

When properly established, the VS requires practicaly no maintence 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.

6.0 REFERENCES

Ash R. and Truong, P. (2003). The use of vetiver grass wetland for sewerage treatment in Australia. Proc. Third International Vetiver Conference, Guangzhou, China, October 2003.

Chomchalow, N, (2006). Review and Update of the Vetiver System R&D in Thailand. Proc. Regional Vetiver Conference, Cantho,Vietnam.

Cull, R.H, Hunter, H, Hunter, M and Truong, P.N. (2 000). Application of Vetiver Grass Technology in off-site pollution control. II. Tolerance of vetiver grass towards high levels of herbicides under wetland conditions. Proc. Second Intern. Vetiver Conf. Thailand, January 2000

Danh, L. T, Truong, P., Mammucari, R., Tran, T. and Foster, N. (2009). Vetiver grass, *Vetiveria zizanioides*: A Choice Plant for Phytoremediation of Heavy Metals and Organic Wastes. International Journal of Phytoremediation, **11**:8,664-691

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.

Liao Xindi, Shiming Luo, Yinbao Wu and Zhisan Wang (2003).Studies on the Abilities of *Vetiveria zizanioides* and *Cyperus alternifolius* for Pig Farm Wastewater Treatment. Proc. Third International Vetiver Conference, Guangzhou, China, October 2003.

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.

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

Luu Thai Danh, Le Thanh Phong, Le Viet Dung and Truong P (2006). Wastewater Treatment At A Seafood Processing Factory In The Mekong Delta, Vietnam. Fourth International Vetiver Conference, Caracas, Venezuela, Oct 2006

Molina, P, (2010). Metodologia de aplicación de la tecnología vetiver (vs) para la absorción de nitrógeno y agua en terrenos regados con efluentes de la industria porcina. This conference

Percy, I. and Truong, P. (2005). Landfill Leachate Disposal with Irrigated Vetiver Grass. Proc, Landfill 2005. National Conf on Landfill, Brisbane, Australia, Sept 2005

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

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

Smeal, C., Hackett, M. and Truong, P. (2003). Vetiver System for Industrial Wastewater Treatment in Queensland, Australia. Proc. Third International Vetiver Conference, Guangzhou, China, October 2003.

Truong, P.N. and Baker, D. (1998). Vetiver grass system for environmental protection. Technical Bulletin N0. 1998/1. Pacific Rim Vetiver Network. Office of the Royal Development Projects Board, Bangkok, Thailand.

Truong, P.N., Mason, F., Waters, D. and Moody, P. (2000). Application of Vetiver Grass Technology in off-site pollution control. I. Trapping agrochemicals and nutrients in agricultural lands. Proc. Second Intern. Vetiver Conf. Thailand, January 2000

Truong, P.N. and Hart, B. (2001). Vetiver system for wastewater treatment. Technical Bulletin No. 2001/2. Pacific Rim Vetiver Network. Office of the Royal Development Projects Board, Bangkok, Thailand.

Truong, P. and Smeal (2003). Research, Development and Implementation of Vetiver System for Wastewater Treatment: GELITA Australia. Technical Bulletin No. 2003/3. Pacific Rim Vetiver Network. Office of the Royal Development Projects Board, Bangkok, Thailand.

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.

Truong, P and Cruz, Y. (2010). Vetiver System: A Low Cost and Natural Solution for the Prevention and Treatment of Contaminated Water. Proc. X Congress Water Resources and Environmental Health**,** Barcelo, Costa Rica.

Wagner, S., Truong, P, Vieritz, A. and Smeal, C (2003). Response of vetiver grass to extreme nitrogen and phosphorus supply. Proc. Third International Vetiver Conference, Guangzhou, China, October 2003.

Xuhui Kong, Weiwen Lin, Biqing Wang and Fuhe Luo (2003). Study on vetiver's purification for wastewater from pig farm. Proc. Third International Vetiver Conference, Guangzhou, China, October 2003.