## CHAPTER 2

# ENVIRONMENTAL PROTECTION

## VETIVER SYSTEM FOR
## PREVENTION AND TREATMENT OF POLLUTED WATER
## AND CONTAMINATED LAND

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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 attributes highly suitable for treating polluted wastewater from industries as well as domestic discharges and contaminated lands from industries and mining.

- VS can reduce the volume or dispose unwanted wastewater by: seepage control, land irrigation and wetland. Successful applications include treatment of:
    - domestic and municipal sewage effluent and landfill leachate
    - wastewater from intensive animal farms
    - industrial wastewater recycling and disposal
    - industrial and mining seepage.
- VS can improve wastewater quality by: trapping debris, sediment and particles, and absorbing pollutants such as nutrients and heavy metals, detoxification of agrochemical in wetlands. Successful applications include wastewater quality improvement of:
    - water runoff from agricultural land
    - water runoff from urban land
- VS can reduce the impact of pollution caused by contaminated lands from industries and mining by land rehabilitation and phytoremediation.
    - water runoff from industrial and mining land

But the most significant advance recently, is the use of vetiver grass in computer modelling to treat industrial wastewater. For this application, not only all known aspects of vetiver physiological and morphological attributes, but also its potential were carefully studied and analysed in the calibration process.

VS has been used in more than 100 countries with in tropical and subtropical climates for the prevention and treatment of polluted water and contaminated land. This paper presents successful applications in these fields including examples of some computer models and future trend in VS applications in several countries around the world.

**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,* Nash L*,* reclassified as *Chrysopogon zizanioides,* Roberty 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.
    - Rehabilitation and Treatment of Contaminated Land
- Stabilisation of Steep Slopes, both dry land and river banks
- Soil and Water Conservation in Agricultural Land

This paper only deals with the environmental protection topics.

## 2.0 PREVENTION, TREATMENT AND DISPOSAL OF CONTAMINATED WATER (Truong *et al*, 2008).

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. Latest research also shows its exceptional ability to absorb and 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 effluents. Table 1 summarises the unique characteristics of vetiver grass.

### 2.1 Reducing or Disposing Wastewater

For large-scale reduction or total disposal 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 effluents (Fig.1).

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).

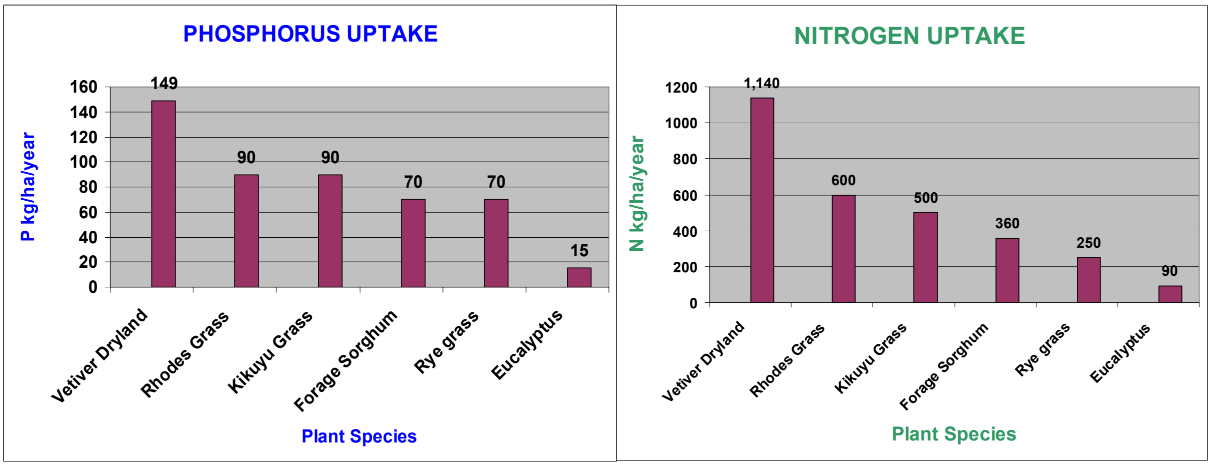
**Table 1: Adaptability range of vetiver grass in Australia and other countries**

| | **Australia** | **Other Countries** |
|---|---|---|
| **Adverse Soil Conditions** | | |
| Acidity | pH 3.3 | pH 4.2 (with high level soluble Al) |
| Al level (Al Sat. %) | Between 68% - 87% | |
| Mn level | > 578 mg/kg | |
| Alkalinity (highly sodic) | pH 9.5 | pH 12.5 |
| Salinity (50% yield reduction) | 17.5 $mScm^{-1}$ | |
| Salinity (survived) | 47.5 $mScm^{-1}$ | |
| Sodicity | 33% (exchange Na) | |
| Magnesicity | 2 400 mg/kg (Mg) | |
| **Heavy Metals** | | |
| Arsenic | 100 - 250 mg/kg | |
| Cadmium | 20 mg/kg | |
| Copper | 35 - 50 mg/kg | |
| Chromium | 200 - 600 mg/kg | |
| Nickel | 50 - 100 mg/kg | |
| Mercury | > 6 mg/kg | |
| Lead | > 1 500 mg/kg | |
| Selenium | > 74 mg/kg | |
| Zinc. | >240 mg/kg | |
| **Location** | $15^0$S - $37^0$S | $41^0$N - $38^0$S |
| **Climate** | | |
| Annual Rainfall (mm) | 450 - 4 000 | 250 - 5 000 |
| Frost (ground temp.) | -$11^0$C | -$14^0$C |
| Heat wave | $45^0$C | $55^0$C |
| Drought (without effective rain) | 15 months | |
| **Fertiliser** | | |
| Vetiver can be established on very infertile soil due to its strong association with mycorrhiza | N and P (300 kg/ha DAP) | N and P, farm manure |
| **Palatability** | Dairy cows, cattle, horse, rabbits, sheep, kangaroo | Cows, cattle, goats, sheep, pigs, carp |
| **Nutritional Value** | N = 1.1 %<br>P = 0.17%<br>K = 2.2% | Crude protein 3.3%<br>Crude fat 0.4%<br>Crude fibre 7.1% |

### *2.1.1 Disposal of domestic 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).

**Fig.1:** Higher capacity of uptake N and P than other plants




### *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).

### *2.1.3 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).

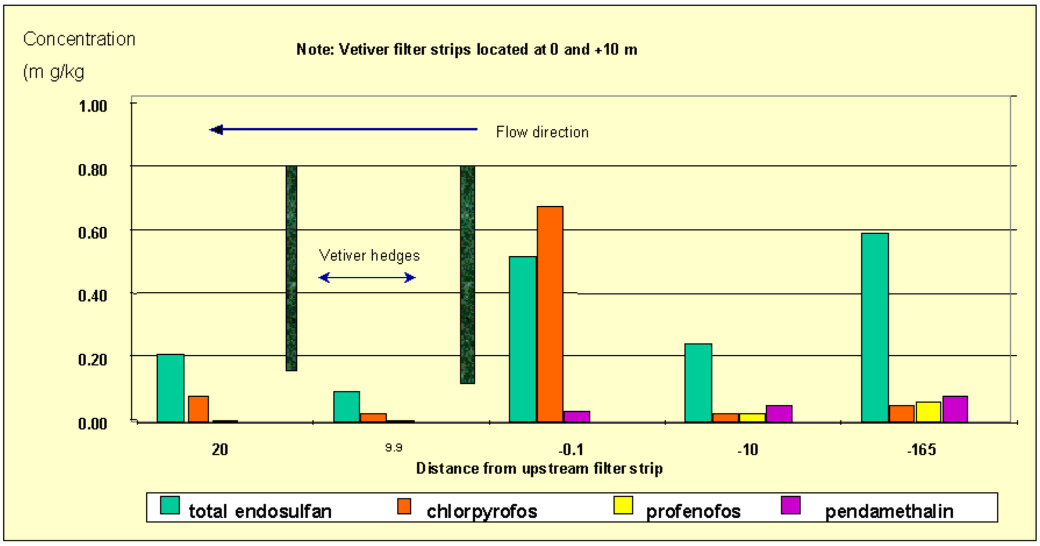
## 2.2 Improving Wastewater Quality

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.

### *2.2.1 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.2).

**Fig 2:** 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).

### *2.2.2 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).

**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: (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. All the wastewater 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 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).

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 $SO_4$ 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).

### *2.2.3 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 its morphological and physiological features (Cull *et al.* 2000):

**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).

**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 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).

**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 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).

### *2.2.4 Computer Modeling*

In recent years**, c**omputer 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).

### *2.2.5 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).

## 3.0 TREATMENT AND REHABILITATION OF CONTAMINATED LANDS

In term of environmental protection, the most significant breakthroughs in the last 20 years are firstly research leading to the establishment of benchmark tolerance levels of vetiver grass to adverse soil conditions and secondly its tolerance to heavy metal toxicities. These have opened up a new field of application for the rehabilitation of toxic and contaminated lands.

### 3.1 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).

### *3.1.1 Australia*

*Coal Tailings:* Five salt tolerant species vetiver grass, marine couch (*Sporobolus virginicus*), common reed grass (*Phragmites australis*), cumbungi (*Typha domingensis*) and *Sarcocornia spp.* were used to rehabilitate a coal tailings pond, which is saline, highly sodic and extremely low in N and P, high levels of soluble S, Mg, Ca, Cu, Zn, and Fe. 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 (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 $Kgha^{-1}$ 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 pyrite content, old gold mine tailings in Australia 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 8-year old tailings sites. One had a pH of 3.6, sulphate at 0.37% and total sulphur at 1.31%. The other 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 first site (pH=3.6) without any liming. But the addition of 5$tha^{-1}$ of agricultural lime significantly improved vetiver growth. On the second site (pH=2.7), although vetiver survived without liming, the addition of lime (20$tha^{-1}$) and fertiliser (500$kgha^{-1}$ 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

### *3.1.2 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, 203 and Xia *et al*, 2003).

### *3.1.3 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.).

### *3.1.4 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.

## 4.0 OVERALL ADVANTAGES OF VETIVER SYSTEM APPLICATION

- **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.
- **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.
- 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.**

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