

PLENARY 2

GLOBAL APPLICATIONS OF THE VETIVER SYSTEM

Paul Truong

TVNI Technical Director

Director for Asia and Oceania,

Brisbane, Australia

<paultruong@vetiver.org>

ABSTRACT

The Vetiver System (VS), which is based on the application of vetiver grass (*Vetiveria 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. Historically, the order of development of the five main applications of VS is:

1. **Soil and Water Conservation in Agricultural Land**
In agricultural land, vetiver hedges provided a very effective and low cost method of soil and water conservation on sloping land, resulted in significant crop yield improvement.
2. **Stabilisation of Infrastructures**
Its extensive and deep root system provides an ideal tool for erosion control of unconsolidated soil and the stabilisation of steep slopes such as road and railway batters, dam wall, river and canal banks and landslips.
3. **Environmental Protection**
 - **Phytoremediation of wastewater:** The Vetiver System can dispose and/or treat wastewater by reducing the volume or improving the quality of polluted water
 - **Phytoremediation contaminated lands:** Vetiver grass has been used successfully for rehabilitation of mine overburden and phytoremediation of mine tailings.
4. **Socio-economic impact on rural community**
 - **Poverty alleviation:** Providing income through supply planting materials and handicraft production
 - **Rural employment** to rural community particularly women and children

5. Mitigation of Climate Change impact

Natural disaster mitigation, biofuel and Carbon sequestration

6 Other major uses of vetiver plant

Other important uses of vetiver include animal fodder, handicrafts and ornamental

1.0 INTRODUCTION

The Vetiver System (VS), which is based on the application of vetiver grass, *Chrosopogon zizanioides* L.Roberty, (ex *Vetiveria 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 main applications of VS are:

1. Soil and water conservation in agricultural land
2. Stabilisation of infrastructures
3. Environmental protection by phytoremediation of wastewater and contaminated lands
4. Socio-economic improvement on rural community
5. Mitigation of Climate Change impact
6. Other major uses of vetiver plant

2.0 SOIL AND WATER CONSERVATION IN AGRICULTURAL LAND

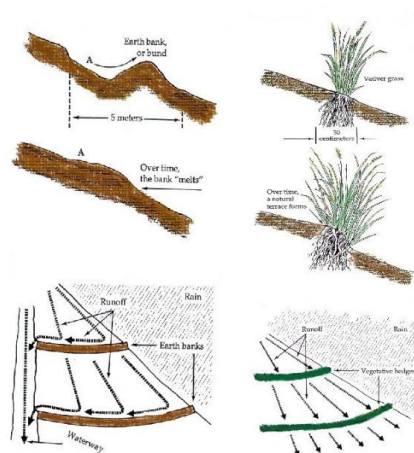
2.1 Vegetative Flow-Through versus Conventional Engineering Soil Conservation Systems

A review conducted for the World Bank comparing the effectiveness and practicality of different soil and water conservation systems found that constructed measures must be site specific and require detailed and accurate engineering and design. Furthermore, all structured systems require regular maintenance. Most of the evidence also suggests that constructed works reduce soil losses, but do not reduce runoff significantly and in some cases have a negative impact on soil moisture. The vegetative conservation system, on the other hand, when planted on the contour, forms a protective barrier across the slope, which slows the runoff water causing sediment to be deposited. Since the barriers only filter the runoff and do not convey it, water seeps through the hedge, reaching the bottom of the slope at lower velocity without causing any erosion and without being concentrated in any particular area. This is known as the flow-through system according to John Greenfield. This is in sharp contrast with the contour terrace/waterway system in which runoff water is collected by the terraces and diverted as quickly as possible from the field to reduce its erosive potential. All runoff water is therefore collected and concentrated in the waterways where most erosion occurs in agricultural lands, particularly on sloping lands, and this water is lost from the field. With the flow-through system, not only is this water conserved but also no land is wasted on the waterways (Fig.1). Ideally, species to be used as barriers for effective erosion and sediment control should have the following features.

- Form an erect, stiff and uniformly dense hedge so as to offer high resistance to overland water flow and have extensive and deep roots, which bind soil to prevent riling and scouring near the barrier.
- Ability to survive moisture and nutrient stress and to re-establish top growth quickly after rain.
- Minimum loss of crop yield implying that the barrier should not proliferate as a weed, not compete for moisture, nutrients and light and not be a host for pests and diseases.
- Preferably require only a narrow width to be effective and supply products of economic value to farmers.

Vetiver grass exhibits all these characteristics and it is unique in that it can thrive in arid and humid conditions, growing under some extreme soil conditions and survives wide temperature ranges

Figure 1: Comparison between conventional terrace/contour system and VS in soil and water conservation



2.2 Effectiveness of Vetiver Hedges in Soil and Water Conservation and Crop Yield

In India on cropping land with 1.7% slope, Vetiver contour hedges reduced runoff (as percentage of rainfall) from 23.3% (control) to 15.5%, soil loss from 14.4 t/ha to 3.9 t/ha and sorghum yield increased from 2.52 t/ha to 2.88 t/ha over a four year period. The yield increase was attributed to mainly *in situ* soil and water conservation over the entire toposequence under the Vetiver hedge system. Under small plot conditions at the International Crops Research Institute for the Semi-Arid Tropics vetiver hedges gave more effective runoff and soil loss control than lemon grass or stone bunds. Runoff from the Vetiver plots was only 44% of that of the control plots on 2.8% slope and 16% on 0.6% slope. Relative to control plots, average reductions of 69% in runoff and 76% in soil loss were recorded from Vetiver plots.

In Nigeria, vetiver strips were established on 6% slopes for three growing seasons to assess effects of vetiver grass on soil and water loss, soil moisture retention and crop yields. Results showed that soil physical and chemical conditions were ameliorated behind the vetiver strip for a distance of 20m. Crop yields were increased by a range 11 – 26% for cowpea and by about 50% for maize under vetiver management. Soil loss and runoff water at the end of 20m runoff plots were 70% and 130% higher respectively in non-vetiver plots than vetiver plots. Vetiver strips increased soil moisture storage by a range of 1.9% to 50.1% at various soil depths. Eroded soils on non-vetiver plots were consistently richer in nutrient contents than on vetiver plots. N use efficiency was enhanced by about 40%.

Similar results were also reported on a range of soil types, land slopes and crops in Venezuela and Indonesia In Natal, South Africa, vetiver hedges have increasingly replaced contour banks and waterways on steep sugarcane lands, where farmers have found that the Vetiver system is the most effective and low cost form of soil and water conservation in the long term (Table 1).

Results of a cost benefit analysis conducted on the Maheswaran watershed in India where both engineering structures and vegetative barriers with Vetiver grass were used, showed that Vetiver systems are more profitable even during the initial stages due to their efficiency and low cost.

Table 1. Effects of the Vetiver System on soil loss and runoff in agricultural lands (Rodriguez 1993.)

Countries	Soil loss (t/ha)			Runoff (% of rainfall)		
	Control	Conventiona l	VS	Control	Conventiona l	VS
Thailand	3.9	7.3	2.5	1.2	1.4	0.8
Venezuela	95.0	88.7	20.2	64.1	50.0	21.9
Venezuela (15%)*	16.8	12.0	1.1	88	76	72
Venezuela (26%)*	35.5	16.1	4.9			
Vietnam	27.1	5.7	0.8			
Bangladesh		42	6-11			
India		25	2			
		14.4	3.9		23.3	15.5

* Land slope

3.0 STABILISATION OF INFRASTRUCTURES

The use of vegetation as a bio-engineering tool for land stabilisation and erosion control has been implemented for centuries and its popularity has increased remarkably in the last decades. This is partly due to the fact that more knowledge and information on vegetation are now available for application in engineering designs, but also partly due to the cost-effectiveness and environment-friendliness of this “soft”, bio-engineering approach.

3.1 Special Characteristics of Vetiver Grass Suitable for Land Stabilisation

- Extremely deep and massive finely structured root system, capable of reaching down to 2 to 3m in the first year. This extensive and thick root system binds the soil and at the same time makes it very difficult to be dislodged and extremely tolerant to drought.
- The tensile strength of vetiver roots varies between 40-180 Mpa. The mean design tensile strength is about 75 Mpa - **equivalent to approximately one sixth of mild steel.** This

indicates that vetiver roots are as strong as, or even stronger than that of many hardwood species, which have been proven positive for root reinforcement in steep slopes.

- New roots are developed from nodes when buried by trapped sediment. Vetiver will continue to grow with the new ground level eventually forming terraces, if trapped sediment is not removed
- Stiff and erect stems which can stand up to relatively deep water flow (0.6-0.8m).
- Dense hedges when planted close together, reducing flow velocity, diverting runoff water and forming a very effective filter.
- Tolerance to extreme climatic variation such as prolonged drought, flood, submergence and extreme temperature from -14°C to 55°C.
- Ability to re-grow very quickly after being affected by drought, frost, salt and other adverse soil conditions when the adverse effects are removed.
- High level of tolerance to soil acidity, salinity, sodicity and acid sulfate conditions.

3.2 Tensile and Shear Strength of Vetiver Roots

Thai research showed that the tensile strength of vetiver roots increases with the reduction in root diameter, implying that stronger fine roots provide higher resistance than larger roots. The tensile strength of vetiver roots varies between 40-180 Mpa for the range of root diameter between 0.2-2.2 mm. The mean design tensile strength is about 75 Mpa (equivalent to approximately one sixth of mild steel) at 0.7-0.8 mm root diameter which is the most common size for vetiver roots. This indicates that vetiver roots are as strong as, or even stronger than those of many hardwood species which have been proven positive for slopes reinforcement (Table 2).

Table 2: Tensile Strength of Roots of Some Plants

Botanical name	Common name	Tensile strength (MPa)
<i>Salix spp</i>	Willow	9-36*
<i>Populus spp</i>	Poplars	5-38*
<i>Alnus spp</i>	Alders	4-74*
<i>Pseudotsuga spp</i>	Douglas fir	19-61*
<i>Acer sacharinum</i>	Silver maple	15-30*
<i>Tsuga heterophyllia</i>	Western hemlock	27*
<i>Vaccinum spp</i>	Huckleberry	16*
<i>Hordeum vulgare</i>	Barley	15-31*
	Grass, forbs	2-20*
	Moss	2-7kPa*
<i>Chrosopogon zizanioides</i>	Vetiver grass	40-120 (Average 75**)

Chinese research conducted further tests on other grasses as shown in Table 3. Although Vetiver has the second finest roots, its tensile strength is almost 3 times higher than on the plant tested.

In a soil block shear test, Thai research also found that root penetration of a two year old Vetiver hedge with 15cm plant spacing can increase the shear strength of soil in adjacent 50 cm wide strip by 90% at 0.25 m depth. The increase was 39% at 0.50 m depth and gradually reduced to 12.5% at 1.0 m depth. Moreover, because of its dense and massive root system it offers better shear strength increase per unit fiber concentration (6-10 kPa/kg of root per cubic meter of soil) compared to 3.2-3.7 kPa/kg for tree roots.

Other less well known characteristics of Vetiver grass is its power of penetration. Its 'innate' strength and vigour enable it to penetrate through difficult soil, hard pan or rocky layers with weak spots. Vetiver roots basically behave like living soil nails or dowels of two to three meter depth. Together with its fast growing ability in difficult soil conditions, these characteristics make the grass a much better candidate for slope stabilization than other plants.

3.3 Hydraulic Characteristics

Recent research in Holland has shown that Vetiver grass is able to establish a full-stop of bank erosion caused by rapid drawdown. Therefore it is highly suitable as an anti-erosion measure. A combination of cohesive soil and Vetiver grass provides the best protection against erosion, which implies that it is highly suitable for banks in delta areas, which consist pre-dominantly of cohesive soil. A single hedge of Vetiver grass planted on the outer slope of a dike can reduce the wave run-up volume by 55%, in contrary with sod-forming grasses that give no reduction. Planting multiple hedges along the contour of the outer slope might result in even more reduction. The application of Vetiver grass on existing dikes may provide a substantial reinforcement of these dikes.

Table 3: Diameter and tensile strength of root of various herbs

Grass	Mean diam. of roots (mm)	Mean tensile strength (MPa)
Late Juncellus	0.38 ± 0.43	24.50 ± 4.2
Dallis grass	0.92 ± 0.28	19.74 ± 3.00
White Clover	0.91 ± 0.11	24.64 ± 3.36
Vetiver	0.66 ± 0.32	85.10 ± 31.2
Common Centipede grass	0.66 ± 0.05	27.30 ± 1.74
Bahia grass	0.73 ± 0.07	19.23 ± 3.59
Manila grass	0.77 ± 0.67	17.55 ± 2.85
Bermuda grass	0.99 ± 0.17	13.45 ± 2.18

3.4 Main Applications in Land Stabilisation

With its deep, extensive and penetrating root system vetiver grass provides an ideal tool for the stabilisation of steep and unstable slopes. More recently software developed by Claudio Amati, PE with the University of Milan to determine the additional shear strength provided to soil by Vetiver roots in various soils under vetiver hedges treatments. This software is particularly suitable to assess the contribution of vetiver roots needed for the application of VS on steep batter stabilisation particularly earthen levees, where vetiver hedgerows will protect and consolidate the slopes and therefore the levees themselves.

3.4.1 *Stabilisation of road, highway and railways batters*

The main reasons for slope instability are surface erosion and structural weakness of the slope. While surface erosion often leads to rill and gully erosion, structural weakness will cause mass movement or land slip. Normally a good vegetative cover is very effective against surface erosion and deep rooted plants such as trees and shrubs can provide the structural re-enforcement for the ground. However on newly constructed slopes, the surface layer is often not well consolidated, so rill and gully erosion often occurs on even well covered slopes. For these, structural re-enforcement is also needed very soon after construction, but trees are slow and often difficult to establish on such hostile environment. Vetiver grass is fast growing and with its very extensive and deep root system can provide the structural strength needed in a relatively short period of time. As mentioned above vetiver roots have been found to have average design tensile strength equivalent to one-sixth of mild steel.

3.4.2 *Reducing landslip and landslide incidence*

The incidence of landslip on steep slopes due to heavy rainfall as the case of hurricane or in earth quake prone regions of Central America and Chile can be significantly reduced by vetiver grass planting. Its deep and strong root system would provide an effective anchor against mass movement.

3.4.3 *River and stream bank stabilisation*

The combination of the deep root system and thick growth of the vetiver hedges will protect the banks of river and stream under flood conditions. Its deep roots prevent it from being washed away while its thick top growth reduces flow velocity and its erosive power. In addition properly laid out hedges can be designed to direct water flow to appropriate areas. In Australia, field trials using hydraulic characteristics determined by the above-mentioned tests showed that vetiver hedges were successful in reducing flood velocity and limiting soil movement, resulting in very little erosion in fallow strips and a young sorghum crop was completely protected from flood damage. VS has been used very effectively to stabilise River and stream bank against flash flood in Vietnam, China and Indonesia.

3.4.4 *Runoff, Erosion Control, Water Diversion and Sediment Trapping*

When planted in row, vetiver plants will form thick hedges and with their stiff stems these hedges can stand up to at least 0.6 m, forming a living porous barrier which slows and spreads runoff water. Appropriately laid out these hedges can act as very effective diversion structures spreading and diverting runoff water to stable areas or proper drains for safe disposal. As water flow slows down,

its erosive power is reduced and any eroded material is trapped by the hedges. Therefore vetiver would be very effective in stabilizing table drains, gullies, creek banks and other drainage structures.

3.4.5 Protection of Concrete and Gabion Structures

The deep root system of the vetiver hedges will protect the ground surface next to the concrete structures such as culvert inlets and outlets, gabion structures or other solid barriers from scouring and erosion by high velocity flows. When planted upstream from the inlets, vetiver hedges will not only protect the inlets but they also trap the sediment outside the culverts where it can be easily cleaned if required.

3.5.6 Advantages and Disadvantages of VS in Land Stabilisation

The major advantage of VS over conventional engineering measures is its low cost. For slope stabilization in China for example, the saving is in the order of 85-90%. In Australia the cost advantage of VS versus conventional engineering methods ranges from 64% to 72%, depending on the method used. Secondly, as with other bio-engineering technologies, VS provides a natural and environment friendly method of erosion control and land stabilization which 'softens' the harsh look often associated with conventional engineering measures such as concrete and rock structures. This is particularly important in urban and semi-rural areas where the visual degradation of the environment caused by infrastructure development is often a major concern of local population. Thirdly, VS maintenance costs are low in the long term. In contrast with conventional engineering structures, the efficiency of bio-engineering technology improves with time as the vegetative cover matures.

The only disadvantage of VS is that it requires a good watering and sometimes weed control the first 1 to 2 years, but once established it is virtually maintenance free in the long term.

4.0 DISPOSAL AND TREATMENT OF WASTEWATER

4.1 Special Features of Vetiver Grass Suitable for Wastewater Disposal and Treatment

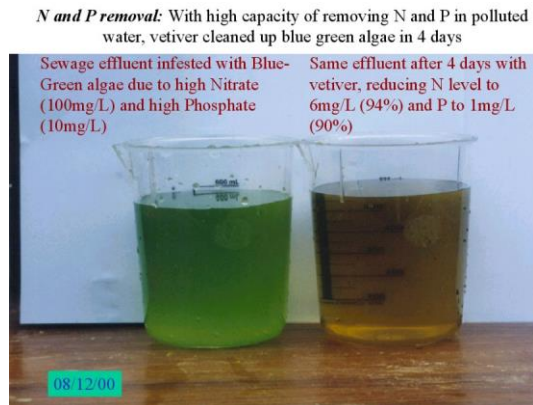
- Thick growth, forming a living porous barrier which acts as a very effective filter, trapping both fine and coarse sediment
- Deep, extensive and penetrating root system which can reduce/prevent deep drainage, (Photo 1).
- Highly resistance to pests, diseases and fire Tolerance to extreme climatic variation such extreme temperature from -15° C to 55° C.
- Tolerance to prolonged drought, submergence and flood
- 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
- High level of tolerance to herbicides and pesticides
- Highly efficient in absorbing dissolved N, P, Hg, Cd and Pb in polluted water, (Photo 2).
- Vetiver uses more water than other common wetland plants such as *Typha* spp, *Phragmites australis* and *Schoenoplectus validus*.
- Ability to regrow very quickly after being affected by the above adverse conditions after growing conditions improved or soil ameliorants added

- Vetiver has no above or underground stems, it flowers but produce no seeds and is sterile, so no weed potential.

Photo 1: Extensive and deep root.



Photo 2:



4.2 Mechanism of Disposal and Treatment of Wastewater.

The Vetiver System can dispose and/or treat wastewater in two ways by:

- Reducing the volume or eliminating the contaminated wastewater by:
 - Land irrigation
 - Wetland
- Improving the quality of polluted water by
 - Trapping debris, sediment and particles
 - Absorbing pollutants and heavy metals,
 - Detoxification of industrial and agrochemicals in wetlands

4.2.1 Reducing the volume or eliminating the contaminated wastewater

For large-scale reduction or total elimination of wastewater, vegetative methods are the only feasible and practicable method available to date. In Australia, tree and pasture species have in the past been used for the disposal of leachate, domestic and industrial effluent.

Land irrigation: Under glasshouse conditions, a good correlation was established between water use and biomass. 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.

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 wetlands have been successfully used in Australia for sewage disposal, in China for reducing both the volume and high nutrient loads of the piggery effluent, in Thailand and Vietnam for industrial wastewater and for sewage effluent.

4.2.2 Improving the quality of polluted water

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. However to fulfill this task effectively, the plant species needs to be:

- Tolerant to extremely adverse growing conditions
- Tolerant to high levels of agrochemicals, heavy metals, toxic organic and inorganic compounds
- Tolerant to elevated nutrient levels
- Capable of producing fast growth and high biomass.

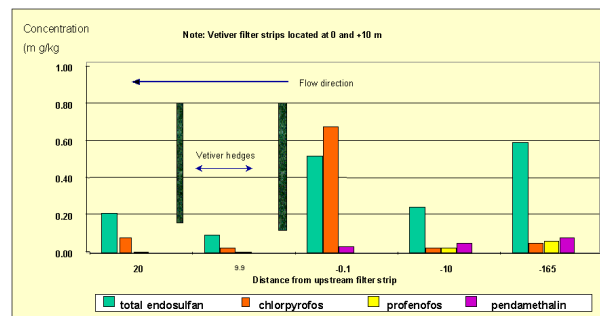
Vetiver is one of a very few plants, if not a unique plant, that has the potential to meet all the criteria.

Trapping debris, sediment and particles in agricultural lands

In Australia research studies in sugarcane 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, (Fig 1).

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.

Fig 1: Herbicide concentration in soil deposited upstream and downstream of vetiver filter strips

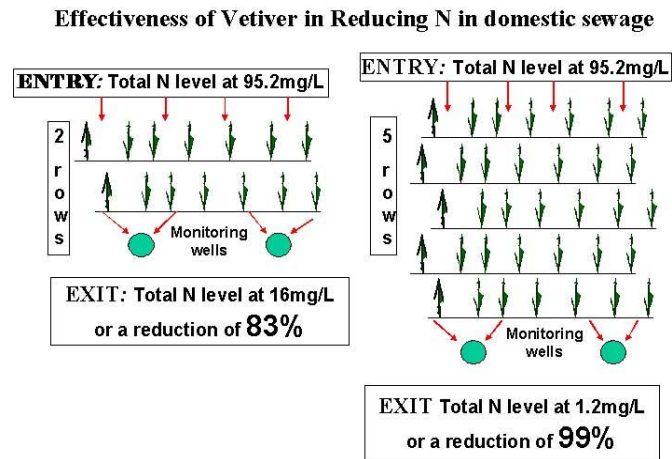


Absorbing and tolerating pollutants and heavy metals: The key feature of VS in treating polluted water lies in its capacity to quickly absorb nutrients and heavy metals, and its tolerance to very elevated levels of these elements. Although the concentrations of these elements in vetiver plants is often not as high as those of hyperaccumulators, however due to its very fast 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 hyperaccumulators.

In Australia, in a project to demonstrate the effect of the VS in reducing the volume and improving the quality of effluent showed that 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 (Fig.2).

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.

Fig.2:



In Vietnam, wastewater from pig farm contains very high N and P and also heavy metals has been successfully treated with vetiver floating pontoons, (Photo 2).

Photo 2: Vetiver floating pontoons on a pig farm in Vietnam



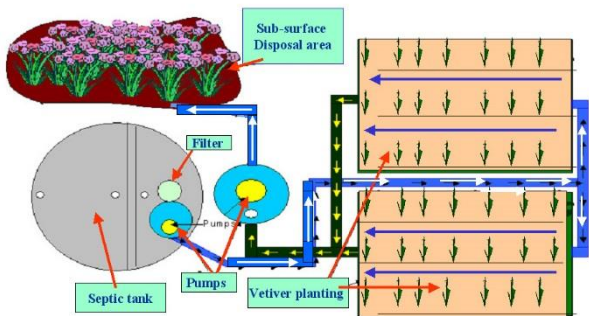
Future Trend: As water shortage is looming worldwide, wastewater should be considered as a resource rather than problem. **The current trend is to recycle wastewater for domestic and industrial uses**, instead of disposal. Therefore the potential of VS is enormous as a simple, hygienic and low cost means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

Domestic wastewater recycling/treatment:

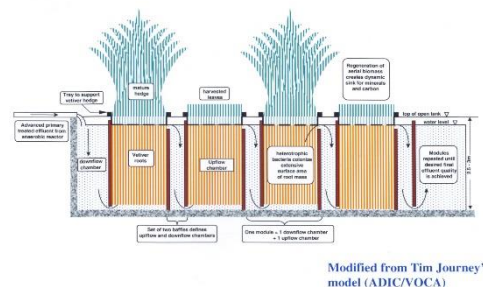
After treating in the vetiver bed, domestic sewage is used to water the garden (Fig.3).

Fig.3: Some recycling scheme for domestic effluent

Diagrammatic layout of a domestic disposal system



Schematic drawing of proposed vetiver hydroponics module to polish household effluent



Industrial wastewater recycling/treatment with Soil Based Reed Beds (SBRB):

SBRB has been used widely throughout the world to effectively treat domestic wastewater, as well as a diverse range of highly contaminated industrial, chemical and agricultural effluents. The SBRB system has three simple components, which interact in a complex manner to provide an ideal medium for wastewater treatment: (i) A shallow bed of soil in which reeds is planted, (ii) A suitable plant which ideally should thrive under water logged conditions, tolerate high level of pollutants, high capacity of absorbing these pollutant and has high biomass production under these extremely adverse conditions, (iii) Micro-organisms (fungi and bacteria) in the soil. Full details of SBRB and how it works are presented in a paper at this conference (Smeal and Truong).

Computer Modelling: 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 grass has been calibrated for use in MEDLI, for nutrient uptake and effluent irrigation.

5.0 PHYTOREMEDIATION AND REHABILITATION OF CONTAMINATED LANDS

5.1 Vetiver Grass Special Characteristics Suitable for Mining Waste Rehabilitation

Vetiver grass is both a xerophyte and a hydrophyte and, once established, is not affected by droughts or floods. The unique characteristics of vetiver suitable for phytoremediation and rehabilitation of contaminated lands can be summarized as (Table 4):

- **Tolerance to High Acidity, Aluminium and Manganese Toxicities:** Vetiver growth was not affected under extremely acidic conditions (pH = 3.0) and at a very high level of soil Aluminium Saturation Percentage between 83-87%. In addition vetiver can tolerate extractable manganese in the soil higher than 578 mgKg⁻¹, and plant manganese content was as high as 890 mgKg⁻¹.
- **Tolerance to High Soil Salinity:** 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
- **Tolerance to High Soil Sodicity** 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).

- *Tolerance to Heavy Metals:* Table 1 shows that vetiver is highly tolerant to As, Cd, Cr, Cu, Hg, Ni, Pb, Se and Zn.
- *Distribution of Heavy Metals:*
 - 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%).

Table 4: Threshold levels of heavy metals to vetiver growth as compared with other species

Heavy Metals	Threshold levels in soil (mgKg ⁻¹)(a)		Threshold levels in plant (mgKg ⁻¹)	
	Vetiver	Other plants (b)	Vetiver	Other plants (c)
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

5.2 Application of VS in Mine Rehabilitation and Phytoremediation of mine tailings

With the above extraordinary characteristics, vetiver grass has been used successfully for mine waste rehabilitation and phytoremediation of mine tailings in Australia, Chile, China, South Africa, Thailand and Venezuela.

5.2.1 Coal mines

In Australia, the substrate of a 23 ha, 3.5 Mm³ coal tailings pond 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 tha⁻¹, which was almost 10 times higher than that of marine couch. Vetiver has also been used to stabilise and rehabilitate waste rock of open cut coal mines in Queensland, Australia (**Photo 3**).

Photo 3: Gold mine tailing (left) and coal mine tailing rehabilitation in Australia



5.2.2 Gold mines

In Australia, 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 (Photo 3).

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 5).

Table 5: 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

3.2.3 Lead and Zinc mines

In China and Thailand, 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 phytoextraction because of its large biomass. Recent research also suggests that *V. zizanioides* also has higher tolerance to acid mine drainage (AMD) from a Pb/Zn mine, and wetland microcosms 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 and Xia, 2003).

5.2.4 Other mines

Vetiver has been used successfully for erosion and sediment control at the Bentonite mine in Australia, copper mine in Chile, bauxite mine in Australia and Venezuela, diamond mines, gold mine and platinum mine in South Africa (Photos 4 &5).

Photo 4: Bauxite mine rehabilitation in Venezuela



Photo 5: Copper mine rehabilitation in Chile



6.0 SOME OTHER MAIN USES OF VETIVER GRASS

6.1 Animal feed

In many countries in Asia, Africa and Latin Americas, vetiver shoots have been widely used for animal feed, particularly in semi-arid zone or regions often affected by drought. In Australia where VS was used for industrial effluent disposal, vetiver was readily grazed by cattle and sheep because of its high nutritive values (Table 6 and Photo 6)

Table 6: Nutritional values of Vetiver, Rhodes and Kikuyu grasses grown in Australia

Analytes	Units	Vetiver grass			Rhodes	Kikuyu
		<i>Young</i>	<i>Mature</i>	<i>Old</i>	<i>Mature</i>	<i>Mature</i>
Energy (Ruminant)	kCal/kg	522	706	969	563	391
Digestibility	%	51	50	-	44	47
Protein	%	13.1	7.93	6.66	9.89	17.9
Fat	%	3.05	1.30	1.40	1.11	2.56
Calcium	%	0.33	0.24	0.31	0.35	0.33
Magnesium	%	0.19	0.13	0.16	0.13	0.19
Sodium	%	0.12	0.16	0.14	0.16	0.11
Potassium	%	1.51	1.36	1.48	1.61	2.84
Phosphorus	%	0.12	0.06	0.10	0.11	0.43
Iron	mg/kg	186	99	81.40	110	109
Copper	mg/kg	16.5	4.0	10.90	7.23	4.51

Manganese	mg/kg	637	532	348	326	52.4
Zinc	mg/kg	26.5	17.5	27.80	40.3	34.1

Photo 6: Animal grazing in Australia and Vietnam



6.2 Handicrafts

Both roots and shoots of the vetiver plant have been used for handicrafts in India, Thailand, Indonesia and Vietnam. In the last few years “Fundacion Empresas Polar” Vetiver Project (VFEPP) has launched and achieved unprecedented results in using vetiver for handicraft production in many regions of Venezuela(Photo 7).

Photo 7: Handicrafts produced in rural Venezuela



6.3 Ornamental

In addition to its extraordinary attributes Vetiver grass is also a very attractive plant. It has been used as an ornamental plant around the world (Photo 8).

Photo 8: Ornamentals in China and Vietnam



6.4 Mulch

Vetiver shoots have also been used as mulch to control weeds and conserve soil moisture in many countries around the world.

6.5 Biomass Fuel

Dry vetiver biomass has a thermal value of 7,000btu/lb and can be produced at a cost of less than US\$10/ton and if sold at US\$35/ton for boiler fuel, dry vetiver biomass is worth US\$2.50/MMbtu. Therefore at today's energy prices, vetiver biomass fuel is cheaper than coal. In addition dry vetiver shoots and roots together constitute a "carbon sink" of more than 100 tons/hectare (Photo 9)

Photo 9: Biofuel in Dominican Republic



6.6 Carbon sequestration and Storage

Research at CIAT, Colombia showed that *Andropogon guyanus* (Vetiver close relative) stores 53t /ha/year of CO₂. But Vetiver has a huge root mass attaining 2-4 m depth after two years, much more massive than *Andropogon guyanus*. In addition, vetiver has a huge biomass above ground, between 100-130t/ha/year, so potentially vetiver can capture at least the same level of CO₂.

7.0 OVERALL ADVANTAGES OF VETIVER SYSTEM APPLICATION

Simplicity, low cost and low maintenance are the main advantages of VS over chemical and engineering methods for wastewater treatment.

- Application of the Vetiver System is rather simple compared with other conventional methods. In addition to appropriate initial design, it only requires standard land preparation for planting and weed control in the establishment phase.
- Application of the Vetiver System in wastewater treatment costs a fraction of conventional methods such as engineering, chemical or mechanical treatments. Most of the cost lies in the planting material, planting labour with small amounts of fertiliser.
- ***When properly established, the VS requires practically no maintenance to keep it functioning. Harvesting two or three time a year to export nutrients and to remove top growth for other usages 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.***