Vetiver System for Water Quality Improvement

Reviewer

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Clean Water Shortage, an Imminent Global Crisis
How Vetiver System can Reduce Its Impact

Abstract: Fresh water scarcity is predicted to become the greatest single threat to international stability, human health, global food supply and even the spectre of war over water. According to the World Resources Institute, within 25 years, more than half of the world population will be suffering severe fresh water shortages.

Earlier research has demonstrated vetiver grass's extraordinary ability to withstand highly adverse climatic and edaphic conditions including elevated levels of salt, acidity, alkalinity, sodicity as well as a whole range of heavy metals. Latest research also shows its extraordinary ability to absorb and tolerate extreme levels of nutrients and consume a large quantity of water in the process of producing a massive growth. These attributes indicate that vetiver is ideally suitable for treating contaminated and polluted wastewater from industries as well as domestic discharge.

This review covers past and current research and applications of Vetiver System in treating wastewater, including:

Wastewater volume or quantity by: seepage control, land irrigation and wetland.

Wastewater quality by: trapping sediment and particles, tolerating and absorbing pollutants, and heavy metals and detoxification of industrial, mining and agrochemical wastes.

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. The results again establish and confirm our admiration for this unique plant.

Key words: vetiver, pollution, wastewater, effluent, landfill leachate, MEDLI

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1 INTRODUCTION

水 到处是水 却没有一滴能喝

" Water, water everywhere, nor any drop to drink"

Samuel Coleridge

These words from the famous English nineteen-century poet have a fresh resonance in the 21st century, when fresh water scarcity is predicted to become the greatest single threat to international stability, human health, global food supply, poverty, gender inequality and even the spectre of war. According to the World Resources Institute, within 25 years, more than half of the world population will be suffering severe fresh water shortages. This looming crisis is reflected by a host of international conferences in the last few years.

The "International Conference on Water" held in Singapore in 2001 concluded that billions of people throughout the world are facing the problem of fresh water shortage. This includes water for agricultural uses, for everyday household uses, and even for consumption and drinking.

The theme of FAO's '2002 World Food Day' is, "Water: Source of Food Security", which states a well-known fact that water is the most important factor in food production. The limited availability of water for agricultural production is increasingly affecting the ability of the farms in every continent of the globe to produce enough food for the ever-increasing population (Chomchalow, 2003).

The goal of the International Fresh Water Conference held in Bonn, Germany in December 2001, was to develop solutions to global water problems. One fifth of the world's population do not have access to sufficient clean drinking water. Wastewater from around 2.5 billion people cannot be disposed of hygienically. Polluted drinking water is the number one cause of disease around the world. At the same time, poor water supply reinforces poverty and gender inequality.

In Thailand, the recently announced "National Policy on Water", utilizing 200,000 million Baht to develop 25 river basins to solve the water deficient problem of the farmers should be congratulated (Chomchalow, 2003).

In Australia, the World Water Development Report, "Water for People, Water for Life" claimed political 'inertia' has worsened water resource problems, triggered by population growth, pollution and expected climate change. In an UNESCO report, when based on a range of factors such as quality of freshwater, wastewater treatment facilities and pollution regulations, Australia with an Index Value of 0.73, ranks 20th, behind the top three, Finland (1.85), Canada (1.45) and New Zealand (1.35).

The UN, which nominated 2003 as the "International Year of Fresh Water", also sponsored the "Third World Water Forum" in Japan in March 2003. This forum reported that despite 25 years of conferences, targets and international agreements, the world water crisis will reach unprecedented level by 2050, when up to 7 billion people in 60 countries could face water shortage. More than a billion people do not have access to safe drinking water; more than two million people die each year from diseases in using contaminated water. According to UNESCO the average supply of water available per person will drop by one third within 20 years. Climatic change will account for 20% of the decline in water supply through erratic rainfall and a rise in sea level. While pollution continues unabated, with 2 million tonnes of waste dumped daily into world waters.

The forum also discussed the spectre of war over water. In Asia, conflict could erupt over the Mekong, a river originating in China but essential to the economic life of its traditional enemies to the south. Water is already a source of conflict in the Middle East, where Israel derives half of its water from the occupied West Bank. Turkey is planning to dam the headwaters of the Tigris and Euphrates, which flow through Iraq and to pipe water to Saudi Arabia. Little wonder that William Cosgrove, Vice President of the World Water Council, an aquatic think tank, told the forum: "Our discussions will have far more effect on humankind for the 21st century than the current crisis in the Middle East".

Between 1970 and 1990 per capita water supplies decreased worldwide by a third. As developing countries on average use 30% to 50% less water than developed countries, this looming crisis will affect developing countries most, where more water is needed for both agricultural and industrial development as well as for health improvement.

So what is the solution? Desalinisation of seawater and chemically treated polluted and contaminated water are energy-hungry and very costly that all developing countries cannot afford. But most importantly, the by products of these treatment processes, such as salt and concentrated toxic materials are often themselves, bigger problems.

Application of the Vetiver System for wastewater treatment is a new and innovative phytoremedial technology, which has the potential to meet all the right criteria. It is a natural, green, simple, practicable and cost effective solution and most importantly, its by-product offers a range of uses from handicrafts, animal feeds, thatches, mulch and fuel just to name a few.

2 HOW VETIVER SYSTEM CAN REDUCE THIS IMPACT?

The Vetiver System can reduce the impact of this imminent global crisis in two ways by:

- Reducing or eliminating the unwanted volume of wastewater or contaminated water
- Improving the quality of wastewater and polluted water

Treating effluent with vetiver is actually a '***recycling process'***, not a treatment process *per se*, as in the process of 'treatment', the vetiver plant absorbs essential plant nutrients such as N, P and cations, and stores them for other uses. In Australia with large scale planting, this ***recycling plant*** is anticipated to provide high nutrient materials for animal feed, mulch for gardens, manure for organic farming and an organic source for composting just to name a few (Smeal *et al*., 2003).

3 HOW VETIVER SYSTEM WORKS?

Earlier research conducted to understand the role of the extraordinary physiological and morphological attributes of vetiver grass in soil and water conservation, discovered that vetiver grass also possesses some unique characteristics suitable for environmental protection purposes (Truong, 2000b). Extensive research in Australia, China and Thailand has established vetiver tolerance to elevated and sometimes toxic levels of salinity, acidity, alkalinity, sodicity as well as a whole range of heavy metals and agrochemicals.

Latest research also shows its unheard–of ability to absorb and to tolerate extreme levels of nutrients (Wagner *et al*., 2003), to consume a large quantities of water in the process of producing a massive growth (Truong and Smeal, 2003). These attributes indicated that vetiver is highly suitable for treating contaminated and polluted wastewater from industries as well as domestic discharge.

3.1 Special Morphological Features of Vetiver Grass Suitable for Effluent Disposal

- Stiff and erect stems which can stand up to high velocity flows
- 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.

3.2 Special Physiological Features of Vetiver Grass Suitable for Effluent Disposal

- Highly tolerant to adverse climatic conditions such as frost, heat wave, drought, flood and inundation

- Highly tolerant to adverse edaphic conditions such as high soil acidity and alkalinity, saline, sodic, magnesic, Aluminum and Manganese toxicities (Truong *et al*., 2002)
- Highly tolerant to elevated levels of heavy metals such as Arsenic, Cadmium, Copper, Chromium, Lead, Mercury, Nickel, Selenium and Zinc (Truong and Baker, 1998; Truong, 2001)
- Capable of responding to very high N supply (6000 KgN/ha/year)
- Capable of withstanding extremely high N supply (10,000 KgN/ha/year) and P (1000 KgN/ha/year) (Wagner *et al*., 2003)
- Highly tolerant to and capable of breaking down some agrochemicals (Cull *et al*., 2000; Winters, 1999).

3.3 High Water Use Rate

- Vetiver uses more water than other common wetland plants such as *Typha* spp., *Phragmites australis* and *Schoenoplectus validus* (Cull *et al*., 2000)
- Vetiver uses approximately 7.5 times more water than Typha
- Water use by vetiver grass was not affected by exposure to either Diuron or Atrazine herbicides at concentrations up to 2000 mg/L levels (Cull *et al*., 2000).

4 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 Australia, tree and pasture species have in the past been used for the disposal of leachate, domestic and industrial effluent.

To quantify the water use rate of vetiver, a glasshouse trial showed a good correlation between water use (soil moisture at field capacity) and dry matter yield. From this correlation it was estimated that for ***1 kg of dry shoot biomass, vetiver would use 6.86 L/day***. If the dry matter yield (DM) of 12-week-old vetiver, at the peak of its growth cycle, was 40.7 t/ha, a hectare of vetiver would potentially use 279 KL/ha/day (Truong and Smeal, 2003).

The three common methods of controlling the volume of wastewater are:

- Seepage control
- Land irrigation
- Wetland

4.1 Seepage Control

Research conducted in Australia, China and Thailand has clearly demonstrated that VS, when appropriately applied, is very effective in seepage control.

The first application of VS for seepage control was conducted in Brisbane, Australia in 1995. Vetiver grass was shown to be very effective not only in control erosion on the slope of a landfill site but also in eliminating seepage from a 25-year-old landfill. The seepage was heavily contaminated with heavy metals, particularly Chromium and Cadmium and other toxic chemicals. (Truong and Stone, 1996).

Since then VS has been used successfully to dispose of leachate from plant nurseries (Truong and Hart, 2001) and most recently at the Datianshan Landfill near Guangzhou City where Vetiver was planted to control erosion and seepage on the wall of the landfill dam. Vetiver did not only stabilise the landfill dam effectively, but it also played an important role in controlling seeping leachate on the dam wall. The concentrations of NH_4-N, NO_3-N, and total N in leachate collected from the landfill dam vegetated with vetiver were about 50% less than those of leachate collected from non-vegetated area (Liu *et al*., 2003).

4.2 Land Irrigation

Under the land irrigation system, vetiver plants are grown as a pasture to dispose both the large effluent volume and to remove soluble elements (particularly N and P) or filter sediment-bound chemicals on sloping lands.

4.2.1 Disposal of septic effluent

The first application of the VS for effluent disposal was also conducted in Australia in 1996, where secondary treated effluent was used to irrigate lawns and garden beds of a holiday camp. The vetiver absorbed all the effluent runoff, which previously ran down the slope. The absorption was so complete that while the first three rows had luxuriant growth, reaching almost 2 m in eight months, the next five rows down the slope were less than 1m tall showing nutrient deficiency symptoms (Truong and Hart, 2001). Recently it has been 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 Australia, 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). More details are presented in 5.2.1 of this paper.

4.2.2 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. Tweed Shire Council, NSW, Australia solved this problem by irrigating 6ha of vetiver planted on the top of the landfill mound. Results to date has been excellent, as soon as an area was planted it was irrigated with leachate by overhead spray irrigation and almost 100% establishment was achieved (Percy and Truong, 2003).

4.2.3 Disposal of industrial wastewater

The most common method of treating industrial wastewater in Australia is by land irrigation, which is 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. R & D conducted at a gelatine factory and at an abattoir in Queensland has shown the Vetiver System as having the potential to meet all the relevant criteria (Smeal *et al*., 2003).

The most significant development in VS use for wastewater disposal, presented at this conference is the application of vetiver for computer modelling for nutrient uptake and effluent irrigation (Veiritz *et al*., 2003; Truong *et al*., 2003a; Wagner *et al*., 2003; Smeal *et al*., 2003).

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. MEDLI is a Windows based computer model for designing and analysing effluent disposal systems, which use land irrigation, for a wide range of industries such as piggeries, feedlots, abattoirs, sewage treatment plants, and food processing factories (Truong *et al*., 2003a).

To date the application of MEDLI in tropical and subtropical Australia has been restricted to a number of tropical and subtropical crops and pasture grasses, which have been specially calibrated for MEDLI use. Due to its extraordinary capacity for nutrient uptake, particularly N and P and its enormous potential for effluent irrigation schemes, vetiver grass has recently been calibrated for MEDLI application. Vetiver demonstrates the high growth rates of a C4 grass (Radiation Use Efficiency (RUE) of 21 kg/ha per MJ/m^2). This value is far superior to other C4 grasses such as sugarcane at 18 kg/ha per MJ/m^2 and maize at 16 kg/ha per MJ/m^2. By contrast, the RUE of C3 grasses such as Bermuda couch grass is only 5.3 kg/ha per MJ/m^2. The deeply penetrating roots of vetiver also have the potential to reclaim land previously irrigated with effluent that may have excess levels of nutrients at depth. Total N and P removal at 1200 kgN/ha/year and 100 kgP/ha/year could be achieved. The moderate shoot concentrations indicate that these rates of nutrient removal were primarily due to the high growth rate of vetiver, rather than a capacity to store high concentrations of nutrients in their tissues (Vieritz *et al*., 2003; Wagner, *et al*.,2003).

4.3 Wetlands

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).

4.3.1 Disposal of sewerage effluent

The Esk Shire Council in Queensland, Australia, has recently installed a VS wetland to treat sewerage effluent output from a small rural community. The aim of this scheme was to reduce the volume and to improve water quality before the effluent discharges to the natural wetlands. The effluent is being treated first in the effluent storage pond by floating pontoons and then passing through a Vetiver grass contoured wetland constructed on 3 hectares of land. This project will provide a large-scale prototype of possible sewerage treatment schemes in developing countries or in locations where there is plenty of land and where the local authority doesn't want to pay for installing and operating high cost solutions (Ash and Truong, 2003).

Very good research has been conducted in Thailand in the last few years on the application of VS to treat wastewater at various scales.

Chantkaeo *et al.* (2002) carried out a 'constructed wetland' experiment to purify domestic wastewater. Two systems were used: one with wastewater drained into the wetland for five days then allow the wetland to dry for two days; the other was to supply wastewater continuously to the wetland and allow it to overflow through the wetland with one day standing. It was found that in the first system with five-day standing and two-day dry period, a total volume of wastewater passed through the system per seven day cycle was 232.5 m^3 (33.1 m^3/day) with the waste, 4.13 mg/L BOD (0.59/day). The second system with overflow wastewater with one-day standing water in the wetland, the total treated amount of wastewater was 59.99 m^3/day with waste, 0.93 mg/L BOD/day.

Ta-oun *et al*. (2003) studied the effect of wetland depth (5, 10, and 15 cm) and flow length (3, 6, and 9 m) on the growth of two vetiver varieties and their effectiveness in treating wastewater. Their results show that BOD values at water levels of 5 and 10 cm. were lower than those of 15 cm for all varieties and DO varied from 3-7 mg/L depending on the length of time. The results also show that lowland type vetiver grass consumed more water than upland types by about 30-70%. When comparing different distances of flow, the results show that the BOD decreased when the distance increased. DO increased when the time increased but at a smaller value when measured with deeper water levels from 5, 10 and 15 cm.

In China a test was conducted to evaluate the role of vetiver grass and different substrates (including coal refuse, fly ash, cinder, soil and gravel) in purifying landfill leachate collected at Likeng of Guangzhou City, which contained high levels of COD (10,963 mg/L) and NH_4-N (1909 mg/L). The experiment lasted for 75 days and the results showed that vetiver grass was very effective in purification of landfill leachate in wetlands. The removal efficiency of wetland microcosms planted with vetiver grass was better than those without vetiver grass: COD by 9.09%; N-NH_4 by 12.93%; TKN by 15.72%; N-NO_3 by 104.8%; TP by 17.44%; TSP by 57.02% and TSS by 1.61% (Lin *et al*., 2003).

4.3.2 Disposal of wastewater from intensive animal farms

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. Therefore the disposal of highly polluted wastewater can be a major problem. 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, 2000). On further tests Liao e*t al*. (2003) found that when vetiver and *Cyperus alternifolius* were grown in pig farm wastewater with COD_{Cr} at 825 mg/L, BOD_5 at 500 mg/L, NH_3-N at 130 mg/L and TP 23 at mg/L, these plants could reduce these levels to 64%, 68%, 20% and 18% respectively with a hydraulic retention time (HRT) of 4 days.

5 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.

Chemical and vegetative methods are generally the two remedial means most commonly used for water quality improvement. But the former is energy-hungry and very costly so most developing countries cannot afford and most importantly, the by-products, such as salt and concentrated toxic materials are often bigger problems themselves. On the other hand, vegetative treatment or phytoremediation is a natural, simple, practicable and cost effective solution and most importantly, its by-products can offer a range of other uses.

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 low nutrient levels

Capable of producing fast growth and high dry matter yield.

Vetiver is one of a very few plants, if not a unique plant that has the potential to meet all the criteria, as listed under 3.1, 3.2 and 3.3 (Wagner *et al*., 2003; Truong, 2001).

As a result, most of the work under the "Vetiver and Water" theme presented at this conference have concentrated in improving wastewater quality; hence major achievements have been made in this field. Basically one or a combination of the following can improve the quality of wastewater:

Trapping debris, sediment and particles

Absorbing and tolerating pollutants and heavy metals,

Detoxification of industrial and agrochemicals in wetlands.

5.1 Trapping Debris, Sediment and Particles

5.1.1 Agricultural lands

Herbicides and pesticides applied to farmlands are important for controlling weed and insect pests in crops but this practice, if not properly managed, can lead to serious off-site contamination of the surrounding environment. In particular, residues of these chemicals can adversely affect flora and fauna in downstream aquatic ecosystems. 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, and parathion and profenofos. These nutrients and agrochemicals could be retained on site if vetiver hedges were established across drainage lines (Truong, 2000a; Truong *et al*., 2000).

Vetiver hedges have demonstrated the effectiveness of in water quality improvement by stabilising highly acidic drains banks and trapping nutrients, sediment, agrochemicals and cane trash. Intensive monitoring and sampling of the section of drain planted with vetiver has demonstrated the economic and environmentally effectiveness of vetiver grass in improving water quality in term of pH, trash input, sediment and dissolved oxygen (Truong *et al*., 2003b).

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, 2003).

5.1.2 Highways

Runoff water from highways contain high levels of both organic and inorganic compounds that are toxic to plant growth. The Gold Coast City, Australia has successfully established a highly effective bio-filter system on a drain to trap debris blown and washed down a nearby highway. While the high levels of toxic pollutant did not affect vetiver growth, its stiff and erect stems trap the coarse debris in high flow in the drain following heavy rains.

5.2 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 100 t/ha/year), vetiver can remove a much higher quantity of nutrients and heavy metals from contaminated lands than most hyperaccumulators.

5.2.1 Absorbing pollutants and heavy metals

Hart *et al*. (2003) conducted a series of trials to evaluate the efficacy of hydroponic Vetiver in treating effluent after it has been primary treated in septic tanks. Results indicate that under a hydroponic flow through system, the best method is for effluent to flow at 20 L/min through Vetiver roots. One square metre of hydroponic Vetiver can treat 30,000 mg of N and 3575 mg of P in eight days. Nutrient reduction was 13,688 kg/ha/yr for N and 1026 kg/ha/yr for P, this level is much higher than those from other crop and pasture plants such as: Rhodes grass (600 kg/ha/yr of N and 90 kg/ha/yr of P); Kikuyu grass (500 kg/ha/yr of N and 90 kg/ha/yr of P); Green Panic (430 kg/ha/yr of N and 70 kg/ha/yr of P); Forage Sorghum (360 kg/ha/yr of N and 70 kg/ha/yr of P); Rye grass (500 kg/ha/yr of N and 90 kg/ha/yr of P) and Eucalypts trees (90 kg/ha/yr of N and 15 kg/ha/yr of P).

This phenomenal capacity of N absorption is illustrated in the following two examples:

1_A project was carried out in Australia 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 2 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).

2_To determine the efficiency of vetiver grass in improving the quality of domestic effluent, a hydroponic trial was conducted using a mixture of black and grey waters. Results showed that total N level was reduced by 94%, total P by 90%, faecal coliform by 44%, EC by 50%, E. coli by 91% and dissolved oxygen >800 mg/L (Truong and Hart, 2001).

These results reconfirmed earlier Chinese research showing vetiver could remove most soluble N and P in effluent over a very short period of time and thus eliminating blue-green algae in the polluted water (Anon, 1997; Zheng *et al*., 1997).

Recently Thai researchers have conducted several studies on vetiver's ability to tolerate and absorb heavy metals and other pollutants from landfill leachate and mine wastes. The heavy metals include Zn, Cu, Pb, Cr, and Ni (Chayotha *et al.*, 2002); Mn, Zn, Cu, Cd, and Pb (Roongtanakiat and Chairoj, 2002); N, K, Ca, Mg, Pb and Cd (Sripen *et al.*, 2000); Pb and Zn (Bannasak, 2001). Agrochemicals include endosulfan (Mahisarakul *et al*., 2003).

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 feedstuffs. 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 (Kong *et al*., 2003).

The banks of drainage and irrigation channels in the acid sulfate soil (ASS) regions of southern Vietnam are highly erodible. Results to date indicate that 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).

5.2.2 Tolerating pollutants and heavy metals

In an experiment to determine the upper tolerance limit of vetiver to N and P applications, Wagner *et al.* (2003) showed that vetiver growth increased with the level of N supply up to 6000 kg/ha/year. However very little growth response occurred at rates higher than 6000 kg/ha/year although rates up to 10,000 kg/ha of N did not adversely affect vetiver growth. Similarly no growth response occurred at P rates higher than 250 kg/ha/year. However its growth was not adversely affected at P application rates up to 1000 kg/ha/year.

Leachate from the Likeng Landfill site in Guangzhou contained high concentrations of pollutants, well above the effluent limits, which could be harmful to flora and fauna in the surrounding environment. Among the four plant species tested for their tolerance and efficiency in treating leachate, vetiver grass was the least affected by both low and high concentration leachate. The tolerance of the four species to garbage leachate was ranked as vetiver > alligator weed > Bahia grass > water hyacinth (Xia *et al*., 2002).

5.3 Detoxification of Industrial and Agrochemical Wastes: Wetlands

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

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

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

5.3.1 Agricultural wastewater

Constructed wetland research in Australia has shown that vetiver is extremely tolerant to two commonly used herbicides, Atrazine and Diuron. Vetiver growth was not adversely affected by application of these two chemicals at rates up to 2000 $\mu g\ L^{-1}$. By contrast, growth in *Phragmites australis* was significantly reduced at the highest rate of application of both herbicides (Cull *et al.*, 2000). In addition it was also found that pots vegetated with yellow iris *(Iris pseudacorus)* and vetiver grass significantly reduced total Atrazine levels in the pot environment. The mechanisms responsible for the enhanced degradation have not been clearly identified. But soils micro-organisms must play an important role in reducing soil Atrazine levels. This may explain the enhanced degradation in iris and vetiver, particularly vetiver, as it was not seen to sequest a significant amount of Atrazine into its tissues. An investigation of the organic compounds and exudates released by the roots of these plants may provide insight into the desirable conditions for microbial growth and enhancement of microbial degrader populations (Winters, 1999).

5.3.2 Industrial wastewater

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

An investigation was conducted to determine the efficiency in chromium removal of two species of vetiver grasses: *Vetiveria zizanioides* (Linn.) and *Vetiveria nemoralis* in a tannery wastewater constructed wetlands with Free Water Surface (FWS). FWS with Surat Thani ecotype at water level. 0.10 m had the best performance in chromium removal, with an efficiency of 89.29 %. While the efficiency of Prajoub Kirikhan ecotype at water level 0.15 m was 86.30 % It can be concluded that optimum FWS for tannery wastewater treatment was with Vetiver grass; Surat Thani ecotype at 0.10 m wastewater depth. In growth studies, it was found that growth of both species was not affected by wastewater depth (Srisatit and Sengsai, 2003).

A wetland microcosm experiment demonstrated that vetiver grass has great potential in treating high-concentrated landfill leachate. But concentrated landfill leachate should be pre-treated to reduce its NH_4^+-N concentration to 383 mg/L or even lower. Vetiver grass growing on different substrates performed differently, the order of growth performance (biomass) is as follows: soil > cinder > gravel > coal refuse > fly ash (Lin *et al*., 2003).

5.3.3 Mining wastewater

Acid mine drainage (AMD) released from mining industries usually has a low pH and contains high heavy metals levels, which significantly impacts on water quality and ecosystems in southern China. A microcosm test was conducted to assess the tolerance of different wetland species to AMD and the purification capacity of a wetland. The tested plant species included: *V. zizanioides* (VZ), *Phragmites australis* (PA), *Cyperus alternifolius* (CA), *Panicum repens* (PR), *Gynura crepidiodes* (GC), *Alocasia macrorrhiza* (AM) and *Chrysopogon aciculatus* (CHR). Chemical analysis indicated that AMD collected from Lechang lead/zinc mine tailings contained high concentrations of Zn, Mn, Pb, Cd, Cu and SO_4^{2-}, and was also extremely acid. The 75-day experiment indicated *Cyperus alternifolius* had the highest while *Gynura crepidiodes* had the lowest tolerance index to AMD among the six plants tested. *V. zizanioides* also had high tolerance to the AMD. The capacity of wetlands in adjusting pH and removing SO_4^{2-}, Cu, Cd, Pb, Zn and Mn only lasted for 35 days, which may be due to the high acidity of AMD (Shu, 2003).

6 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.

6.1 Simplicity

Application of the Vetiver System is rather simple compared with other conventional methods. In addition appropriate initial design, only requires standard land preparation for planting and weed control in the establishment phase.

6.2 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.

6.3 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.

7 CONCLUSION AND FUTURE TRENDS

The information presented above clearly demonstrates that the Vetiver System is a very efficient and low cost method for treating effluent and leachate from both domestic and industrial sources. When properly designed and applied, the VS will certainly play a key role in minimising the impact of the imminent global clean water shortage.

In domestic situations worldwide, the potential of vetiver grass systems is enormous as a simple, hygienic and low cost means of treating human sewage, whether it is from a single home on non-sewered small and large ‘out of town’ properties, small communities or as an adjunct to current sewage treatment plants.

But the most promising of all is the incorporation of vetiver into a computer model for industrial wastewater management plans for municipal sewage treatment, food processing factories, large-scale livestock yards and abattoirs etc, is a quantum leap from its humble beginning of a grass for soil and water conservation in farmlands.

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A Brief Introduction to the Author

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