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Phytoremediation: Role of Plants in Contaminated Site Management

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1. Introduction

Bioengineering is a new branch of civil engineering which integrates live materials, mainly plants and microorganisms, to address the problems of environmental management and sustainable development. The technology originated in Germany in the 1930s, but gained importance in the 1980s, when researches in environmental biotechnology discovered the environmental virtues of some specially adapted plants and microbes. Bioengineering is the 'green' or 'soft' cheaper alternative to the 'hard' and costly civil engineering works for environmental reconstruction.

Phytoremediation (Greek: *phyton* = plant; Latin: *remediare* = remedy) is emerging 'green bioengineering technology' that uses plants to remediate environmental problems. A number of green plants- trees, herbs, grasses and shrubs, both aquatic and terrestrial, have been discovered to have been endowed with the wonderful properties of environmental restoration, such as decontamination of polluted soil and water, stabilization of engineered slopes and embankments on highways, railways, bridges and dams, and prevention of soil erosion. They are aesthetically pleasing, passive, solar-energy driven and pollution abating nature's (green) technology meeting the same objectives of fossil-fuel driven and polluting conventional technology. They thrive in very harsh environmental conditions of soil and water; absorb, tolerate, transfer, assimilate, degrade and stabilise highly toxic materials (heavy metals and organics such as solvents, crude oil, pesticides, explosives and polyaromatic hydrocarbons) from the polluted soil and water; and firmly holds the soil in place by their extensive root network to prevent any erosion. The plants act both as 'accumulators', and 'excluders'. Accumulators survive despite concentrating contaminants in their aerial tissues. They biodegrade or biotransform the contaminants into inert forms in their tissues. The excluders restrict contaminant uptake into their biomass. The plant biomass eventually becomes valuable biological source for the community or for the plant-based industries.

2. Plant Species Involved in Phytoremediation

Several plants are being identified and trialed to be used in phytoremediation task. The most versatile plant species, both terrestrial and aquatic that have been identified after rigorous laboratory and field experiments are as listed below:

1. Vetiver grass (*Vetiveria zizanioides*);
2. Barmuda grass (*Cynodon dactylon*);
3. Bahia grass (*Paspalaum notatum*);
4. Sunflower oil plant (*Helianthus annus*);
5. Poplar tree (*Populus spp.*);
6. Mustard oil plant (*Brassica juncea*);
7. Periwinkle (*Catheranthus roseus*);
8. Cumbungi (*Typha angustifolia*);
9. Water hyacinth (*Eichhornia cressipes*);
10. Duck Weed (*Lemna minor*);
11. Red Mulberry (*Morus rubra*);
12. Kochia (*Kochia scoparia*);
13. Foxtail barley (*Hordeum jubatum*);
14. Switch grass (*Panicum variegatum*);
15. Musk thistle (*Carduus nutans*);
16. White raddish (*Raphanus sativus*);
17. Catnip (*Nepeta cataria*);
18. Big bluestem (*Andropogan gerardii*);
19. Indian grass (*Sorghastrum nutans*);
20. Canada wild rye (*Elymus candensis*);
21. Nightshade (*Solanum nigrum*);
22. Wheat grass (*Agropyron cristatum*);
23. Alfa-alfa (*Medicago sativa*);
24. Tall Fescue (*Festuca anundinacea*);
25. Lambsquarters (*Chenopodium berlandieri*);
26. Reed grass (*Phragmites australis*);
27. Tall wheat grass (*Thynopyron elongatum*);
28. Rhodes grass (*Chloris guyana*);
29. Flatpea (*Lathyrus sylvestris*);
30. Carrot (*Daucus carota*);

Other species are *Elodea canadensis, Ceratophyllum demersum, Potamogeton spp., Myriophyllum spp, Spartina alterniflora, Pinus sylvestris, Poa alpine, Bouteloua gracilis* (Rice et al. 1995; Watanabe 1997). A number of them are still wild, while others have been domesticated for their food value. They are highly salt and toxicity tolerant, have extensive root binding system and were tried in the rehabilitation works. A number of them readily absorb, volatilise and / or metabolise compounds such as tetrachloroethane, trichloroethylene, metachlor, atrazine, nitrotoluenes, anilines, dioxins and various petroleum hydrocarbons. Ideal species for the job are members of the grass family Gramineae and Cyperaceae and the members of families

Brassicaceae (in particular the genera Brassica, Alyssum and Thalapsi), and Salicaceae (in particular willow and poplar trees). Grasses such as the vetiver, clover and rye grass, Bermuda grass, tall fescue etc. have been particularly effective in the remediation of soils contaminated by heavy metals and crude oil (Kim 1996).

Large scale plantation of sunflower plants (*Helianthus annus*) have been made around Chernobyl (erstwhile USSR), where nuclear disaster in 1985 spewed vast amount of radioactive materials into the environment. The land and soil in the area was badly contaminated. Sunflower is reported to absorb radionuclides from soil and decontaminate it. This phytoremediation technology costs $ 2 per hectare for decontamination of soil which might have costed million of dollars by other means.

Duckweeds can 'absorb' and 'adsorb' all the dissolved gases and substances, including the heavy metals, from the wastewater. Within 2 to 3 weeks, the quality of wastewater improves significantly in terms of BOD and DO values, heavy metals and suspended solids and becomes useful for irrigation, industrial uses and aquaculture. It purifies the wastewater rich in phosphorus, nitrate and potassium until the water is crystal clear with phosphorus and nitrogen contents coming down to 0.5 mg/litre within 20 days. Water hyacinths harbor a large number of microorganisms in symbiotic relationships on their roots which feed off upon minerals and organic chemicals (contaminants) from the effluents. Water hyacinth can remove heavy metals by 20-100%. In just 24 hours, the weed can extract more than 75% of lead from contaminated water. It also absorbs cadmium, nickel, chromium, zinc, copper, iron and pesticides and several toxic chemicals from the sewage. In just 7 days of exposure, it can lower BOD by 97% and remove over 90% of nitrates and phosphates. It can also remove radioactive substances.

The current paper focuses mainly about the phytoremediation techniques of the vetiver grass (*Vetiveria zizanioides*).

3. Phytoremediation: The Biophysical and Biochemical Mechanisms

Remediation of organic and inorganic contaminants involves either physical removal of compounds or their bioconversion (biodegradation or biotransformation) into biologically inert forms. The conversion of metals into inert forms can be enhanced by raising the pH (e.g. through liming), or by addition of organic matter (e.g. sewage sludge, compost etc.), inorganic anions (e.g. phosphates) and metallic oxides and hydroxides (e.g. iron oxides). The plants themselves can play a role here by altering soil redox conditions and releasing anions and /or lignins. Phytoremediation technology works mainly through:

3.1 Phytoextraction and Phytoaccumulation

Plant roots uptake (extract) metal contaminants from the soil, polluted and the wastewater, and accumulate them in their roots. Plant roots absorb both organics and inorganics. The bioavailability of a given compound depends upon the lipophilicity and the soil or water conditions e.g. pH and clay content. Considerable amount of the contaminants may be translocated above through the xylem and accumulated in the shoots and leaves. The roots, shoots and leaves are collected (harvested) and incinerated to decompose the contaminants.

3.2 Phytostabilisation

Certain plant species immobilise contaminants in the soil and groundwater through absorption by and adsorption on to roots or precipitation within the root zone (rhizosphere).

3.3 Phytodegradation

Some plant species breakdown the contaminants after absorbing them. This they do through enzyme-catalyzed metabolic process within their root or shoot cells. Others breakdown the contaminants in the substrate itself by secreting enzymes and chemical compounds. The enzymes secreted are usually dehydrogenases, oxygenases and reductases. The biodegraded constituents are converted into insoluble and inert materials that are stored in the lignin or released as exudates (Watanabe 1997). Some plants biodegrade contaminants with the aid of microbes which live in symbiotic association on their roots.

3.4 Phytotransformation

Several inorganic and organic contaminants once absorbed inside the root, may become biochemically bound to cellular tissues (biotransformed), in the forms that are biologically inert or less active (Watanabe 1997).

3.5 Phytovolatilisation

Plants absorb and transpire the impurities from soil and water through their aerial organs. Some contaminants like selenium (Se), mercury (Hg) and volatile organic compounds (VOCs), can be released through the leaves into the atmosphere (Cunningham and Ow 1996).

3.6 Rhizofiltration

It is based on a combination of principle of phytoextraction and phytostabilization specially suited to remove metals and radionuclides from polluted water. Contaminants are absorbed and concentrated by plant roots, then precipitated as their carbonates and phosphates (Salt et al. 1995). Hydroponically grown terrestrial plants like vetiver (*Vetiveria zizanioides*) and sunflower (*Helianthus annuus*) which have large root systems and greater biomass, are specially suitable. Species that do not readily transfer contaminants from the roots to stem are preferred, since the accumulated metals and radionuclides can be removed by simply harvesting the roots. Rhizofiltration works in the effecient removal of organics such as tetrachloroethane, trichloroethylene, metachlor, atrazine, nitrotoluenesanilines, dioxins and various petroleum hydrocarbons (Rice et al. 1997).

3.7 Plant - Assisted Microbial Degradation

Certain plant roots release substances that are nutrients for microorganisms like bacteria and fungi. This results in increased biological activity of the microbes in the area immediately surrounding the root zone (rhizosphere). By encouraging a microbiologically active rhizosphere, the plants facilitate accelerated digestion (biodegradation) of wide variety of organic contaminants in the upper soil layers and / or wastewater / polluted water (Anderson et al. 1993). Many organic compounds are degraded by microorganisms located in the rhizospheres (on the roots) of plants. The enhanced rhizosphere biodegradation results from the ability of certain plants to provide favourable habitats for soil microbes to act (Cunningham and Ow 1996). Mackova et al. (1997) reported effective degradation of PCBs (Polychlorinated Biphenyls) by cells of *Solanum nigrum* that were infected with bacterial strains of *Agrobacterium tumefaciens* and *A. rhizogenes*. The water hyacinths (*Eichhornia cressipes*) works on the same biological principle. It harbours several microbes in its root zone which perform the task of biodegradation of heavy metals in polluted water and also helps in absorption and adsorption of chemical impurities.

Certain metals, such as mercury (Hg) and selenium (Se), can be phytovolatalised usually through plant-microbe interactions (Cunningham and Ow 1996). Genes for synthesizing the enzyme ‘bacterial mercuric ion reductase’ has been engineered into *Arabidopsis thaliana* and the resulting transformant transgenic plant is capable of tolerating and volatalising mercuric ions. The toxic cation is absorbed by the root and reduced to volatile Hg (O) by the introduced mercuric ion reductase (Rugh et al. 1996).

4. The Vetiver Grass Technology (VGT)

Worldwide use of vetiver grass, for soil and water conservation and to protect the farmlands from soil erosion, started in the 1980s following its promotion by the $US 100 million World Bank Watershed Management Project in India (Sinha 1996).

Major research works are being done in India, China, Thailand and Australia on this grass for its uses in environmental management. A global network with 4000 members over 100 countries, and a regional network have been established in Latin America, Europe, China, the Pacific Rim and the Oceania. U.S., France, Italy, Spain, Soviet Russia, China, India, Sri Lanka, Malaysia, Fiji and Thailand are using the grass extensively for protection of their lands and water bodies (Greenfield 1989).

Australia has also taken great initiative towards the use of this wonder grass for various environmental purposes including decontamination and rehabilitation of contaminated lands (sites) and water bodies, stabilization of mining overburdens, sediment control and soil conservation (Sinha et al. 2003). It was introduced into Australia by the Indian settlers in Fiji early in the 1900s. All the researches and its environmental applications conducted in Australia are based on the genotype 'Monto' (Truong and Loch 2000).

4.1 Biological Diversity in the Wonder Grass Vetiver

The 'wonder grass' vetiver, also sometimes referred as the 'miracle grass' is native of India, and has been used for land protection as well as, soil and moisture conservation for centuries. Two genotypes of *V. zizanioides* viz. the wild and fertile north Indian and the sterile south Indian genotype exist and are being mostly used in Asia. The sterile one is preferred globally, because it does not pose the threat of becoming a weed. Two other species used for soil conservation are *V. nigratana* (native of Thailand) and *V. nemoralis* (native of southern Africa).

Australia selected the genotype 'Monto' after its rigorous test for sterility. This is genetically similar to the majority of sterile south Indian genotype of *V. zizanioides* used in other countries. The 'Monto' genotype is highly palatable and readily grazed by cattle, dairy cows, sheep and horses as well as some native animals in Australia (Truong and Baker 1998a).

4.2 Morphological Character and Ecological Adaptations of Vetiver

i. Vetiver grows very rapidly and becomes effective for environmental restoration works in only 4-5 months as compared to 2-3 years taken by trees and shrubs for the same job.

ii. It has stiff and erect stem and finely structured network of 'deep and spongy root system' often reaching 3- 4 meters in the very first year of growth. When buried under sediment, vetiver root will establish from the nodes thus continuing to grow with the new soil level. New shoots emerge from the base helping it to withstand heavy traffic and heavy grazing pressure.
iii. It is also non-invasive, has no runners or rhizomes, and only spread by tillering.
iv. It is highly resistant to pest, diseases and fire and tolerant to prolonged drought, flood, frost and submergence. It is difficult to burn vetiver even in dry and frosted conditions. Vetiver not only survived but continued to grow through the worst drought in Australia early in the 1990s. It can re-grow very quickly after being affected by adverse environmental conditions.
v. Vetiver's survival and growth is significantly increased (2 ton / ha) by mulching and application of fertilizer di-amonium phosphate (DAP).
vi. It can withstand extreme temperatures from –15°C to 48°C in Australia and even higher in India and South Africa (over 55°C).
vii. It can grow in regions where annual rainfall vary from 200 mm to 3000 mm. In Sri Lanka, it has been shown to survive where rainfall is as much as 5000 mm per annum.
viii. It can tolerate very high acidity and alkalinity conditions (pH from 3.0 to 10.5); high soil salinity (EC = 8 dScm), sodicity (ESP = 33%) and magnesium;
ix. It can tolerate very high levels of heavy metals Al, Mn, Mg, As, Cd, Cr, Ni, Cu, Pb, Hg, Se, Zn and the herbicides and pesticides in soils (Table 1).

Table 1. Tolerance and toxicity levels of Vetiver and other plants to heavy metals in soil

Heavy metals	Other plants (mg/kg)	Vetiver (mg/kg)
Arsenic (As)	20	100-250
Cadmium (Cd)	1.5	20- 60
Nickel (Ni)	<60	100-200
Selenium (Se)	2-14	>74
Zinc (Zn)	200	> 750
Manganese (Mn)	500	578
Copper (Cu)	35-60	50-100
Chromium (Cr)	50	200-600
Lead (Pb)	300	> 1500
Mercury (Hg)	1	>6

Source: Truong & Baker (1998a): *Vetiver Grass System for Environmental Protection*

x. Vetiver is highly sensitive to shading and can even disappear. This property of Vetiver is of great advantage in rehabilitation of a disturbed waste land.

> Vetiver would first stabilise the eroded ground, improve the micro-environment of the habitat for the local and native species (trees and shrubs) to grow and eventually give up after shading. Experience has shown that within two years, native species can reduce vetiver growth and dominate the area. Vetiver is thus, a very suitable species for land rehabilitation which eventually makes way for the native species to flourish.

4.3 Propagation and Planting of Vetiver

Although vetiver can be planted as bare root slips by splitting up older plants, a better establishment rate is obtained by raising young plants first. Young vetiver plant is broken into planting slips of two to three tillers with intact root and stem. The top of slips is cut to 200 mm and the roots to 50 mm. Each slip is planted in a pot with sandy loam soil fertilized by 5 gm of di-amonium phosphate (DAP). Pots are watered everyday and kept in full sun. Vetiver becomes ready for planting on site when at least two new shoots appear.

The rooted vetiver slips can be directly planted on ground (site) at 150 mm apart to ensure a close hedge. Roots are covered with 20-30 mm of soil and firmly compacted. DAP is added @ of 50 g/meter length. Water is given every second day and twice a week after it is established. Trimming the young plants stimulates early tillering and the hedge closes up faster. Mature hedge requires no further fertilizer or water.

4.4 The Bioengineering of Vetiver Action

Vetiver works as a ‘biological sieve’ in preventing the movement of soil (and the attached pollutants), by conserving and ‘cleaning’ water, and by strengthening, through its root system, the soil profiles, thus preventing water induced slippage and collapse and subsequent damage to life and property. It can stabilize engineering structures such as river banks, small dams, and levees which require hard engineering solutions (of stones, gabions, mattresses) to strengthen all these structures and thus help prevent catastrophic events due to structural failures.

VGT is a ‘biological’ or ‘soft engineering’ method that is responsive to serious environmental mitigation needs over a broad range of ecological conditions for wide applications that normally require ‘hard engineering’ solutions. In Malaysia, shear tests done on vetiver roots showed that the tensile strength of the roots was at 75 Mpa (one third of the strength of mild steel reinforcement) is as strong as, or even stronger than that of many hardwood species which have been proven positive for ‘root reinforcement’ in steep slopes. The US Corps of Engineers Construction Engineering Research Laboratory have been using vetiver grass for bioengineering solutions in borrow pits, abandoned strip mines, stream banks and embankments and gully heads. It has been found to reduce soil loss by 90% and rainfall run-off by 70%, thus improving groundwater recharge; remove excess agrochemicals from the farm soil and increase crop yield by as much as 40%; improve tree seedling growth (15%) and survival rate (95%); rehabilitate wastelands (gullies, mined areas, degraded lands) and improve polluted sites (landfills). It can even prevent or at least significantly reduce natural disasters caused by hurricanes, landslides and massive floods (Grimshaw 2000).

5. Role of VGT in Environmental Management

5.1 Erosion Control and Sediment Trapping by VGT

Vetiver is a ‘living wall’. The massive root systems of vetiver bind the soil firmly and make it very difficult to be dislodged and eroded under high velocity of wind or water flows. Stems also stand up to relatively deep water flow and when planted close together, form dense hedges which reduce water flow velocity and work as an effective ‘sediment filter’ (for both coarse and fine sediment) trapping the silt from the run-off water behind the hedge. Chemical pollutants in run-off water are often adsorbed by these sediments. Vetiver filter strips are extensively used in Queensland Australia, to trap sediments in both agricultural and industrial lands. At working quarries, vetiver hedges are planted across waterways and drainage lines. This significantly reduced erosion and trapped the silts thus lessening the sediments in the dam water.

In Louisiana, US, the vetiver grass was very successfully used for ‘gully erosion’ control. Three scenic streams were getting filled with silt. Check dam was built to control the problem but it failed. Vetiver was planted near the check dams, on the sides and slopes. Within 8 weeks, the hedges grew to 2m and trapped the silt and mud that was going into the stream (Truong and Baker 1998b).

5.2 Decontamination of Polluted Soils by VGT

Vetiver roots can absorb and accumulate several times of some of the heavy metals present in the soil and water (Truong and Baker 1998a). Studies further indicated that very little (1 to 5%) of the arsenic (As), cadmium (Cd), chromium (Cr) and mercury (Hg) and very moderate amount (16 to 33%) of copper (Cu), lead (Pb), nickel (Ni) and selenium (Se) absorbed were translocated to the shoots (Table 2). Hence, its green shoots can be harvested for mulch. Vetiver can be disposed off safely elsewhere, thus gradually reducing the contamination levels.

Table 2. Absorption and distribution of heavy metals in Vetiver shoot and root

Metals	Soil (mg/kg)	Shoot (mg/kg)	Root (mg/kg)
Arsenic (As)	959.00	9.6	185.00
Cadmium (Cd)	1.60	0.31	14.20
Chromium (Cr)	600.00	18.00	1750.00
Copper (Cu)	50.00	13.00	68.00
Lead (Pb)	1500.00	72.30	74.50
Mercury (Hg)	6.17	0.12	10.80
Nickel (Ni)	300.00	448.00	1040.00
Selenium (Se)	23.60	8.40	12.70
Zinc (Zn)	750.00	880.00	1030.00

Source: Truong, Paul (1999): *Vetiver Grass Technology for Mine Rehabilitation*

In a study made at Griffith University, we found that vetiver removed nearly 30% of cadmium (Cd) from the contaminated soil in just 5 weeks.

5.3 Farm Soil Decontamination

With the heavy use of agro-chemicals in the wake of green-revolution, most farmlands in world today are badly polluted. Vetiver has high capacity to absorb and remove agro-chemicals like carbofuran, monocrotophos and anachlor from soil thus preventing them from contaminating and accumulating in the crop plants. At the Scott Lumber Company site in Missouri, U.S., 16,000 tonnes of soils, contaminated with polyaromatic hydrocarbons (PAHs), were biologically treated with VGT. The PAH concentration was effectively reduced by 70% (Pinthong et al. 1998).

6. Stabilization and Rehabilitation of Mining Overburdens

6.1 Some Case Studies from Australia

Vetiver Grass Technology (VGT) is now being successfully used in Australia to stabilize mining overburdens. It is currently being used to stabilize a very large dam wall of a bauxite mine in Northern Territory and a bentonite mine, coal and gold mines in Queensland. It is also being used for a large-scale application to control dust storm and wind erosion on a 300 ha tailings dam.

6.1.1 Bentonite Mine Tailings

Commercial Minerals Limited, operates a large bentonite mine and processing plant in Queensland Australia. The mine spoils were extremely erodible, as they had high sodium content, high sulphate, very little moisture and extremely low in nutritional value. The major ecological concern of the mining operation was the run-off of sediment laden stormwater from the disturbed areas to the surrounding catchment areas. Vetiver grass was grown as hedges on the highly sodic bentonite spoils to arrest the run-off and also for erosion and sediment control. Mulching and fertilization was done and within 10 months of planting, excellent results were seen. Shoot growth was on an average 3 cm per week over the first three weeks and root growth was also extensive. The hedges supported 100% soil moisture within a 3.4m arc along the rows. When the hedges were complete (with no gaps), it trapped up to 200 mm deep sediment. This sediment now hosts several annual and perennial native species. Samples of runoff water was collected upstream and downstream of the vetiver hedges which indicated that vetiver was able to remove most of the solids and pollutants from the clay contaminated stormwater. Heavy rains inundated the vetiver rows and some plants remained submerged for over 2 weeks and yet in healthy conditions.

6.1.2 Coal Mine Tailings

The overburden of open cut coal mine in central Queensland, Australia is generally highly erodible. These soils are usually highly sodic (ESP 33%), saline, acidic (pH 3.5) and alkaline (pH 9.5), and extremely low in nitrogen (1.3 mg/kg) and phosphorus (13 mg/kg) and high in soluble sulphur (6.1 mg/kg), magnesium (2400 mg/kg), calcium (1200 mg/kg) and sodium (2760 mg/kg). Plant available copper, zinc, magnesium, and iron are also high. Soil with exchangeable sodium percentage (ESP) higher than 15 is considered to be strongly sodic. Moreover, the sodicity of coal tailings is further exacerbated by the very high levels of magnesium compared to calcium.

To rehabilitate an old coal mine tailings dam with a surface area of 23 ha and capacity of 3.5 million cubic meter, vetiver grass was grown on these mining spoils with 20% slopes. Mulching and fertilization was done with DAP application. Within 2-3 months vetiver established firmly and stabilized the slope of spoil dump. The microenvironment also became receptive for the growth of native species (Radloff et al, 1995; Truong and Baker 1996; Truong 1999).

6.1.3 Gold Mine Tailings

Fresh gold mine tailings in Australia are typically alkaline (pH 8-9), low in plant nutrients, and very high in free sulphate (830 mg/kg), sodium and total sulphur (1-4%) and high in arsenic. Vetiver established on such spoils even without fertilizers, but growth was improved with application of 500 kg/ha of DAP.

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. Arsenic is

1120 mg/kg, chromium 55 mg/kg, copper 156 mg/kg, manganese 2000 mg/kg, lead 353 mg/kg, strontium 335 mg/kg, and zinc 283 mg/kg. These tailings are source of contaminants, both above ground and underground to the local environment. Field trials were conducted on two 8 years old gold mine, one with soft surface (pH 3.6; sulphate 0.37%) and the other with hard crust (pH 2.7; sulphate 0.85). Excellent growth of vetiver was observed when supplied with DAP at 300 kg/ha (Truong 1999).

6.1.4 Bauxite Mines Tailings

Bauxite mine tailings are highly caustic (alkaline) with pH as high as 12. Vetiver is successfully growing on these aluminum tailings in Northern Territory of Australia and has stabilised a very large dam wall of bauxite spoils (Truong 1999).

6.2 Case Study from China

Environmental rehabilitation works were carried out with *Vetiveria zizanioides*, *Cynodon dactylon*, *Paspalaum notatum* and *Imperata cylndraca* var. *major* at the Lechang lead (Pb) and zinc (Zn) mines in Guangdong Province which covered an area of 1.5 square kilometer producing approximately 30,000 tons of tailings annually, with a dumping area of 60,000 square meter. The tailings contained very high content of heavy metals lead (Pb), cadmium (Cd), zinc (Zn) and copper (Cu). It had very low levels of nutrients nitrogen (N), potassium (K) and phosphorus (P) and organic matter. The tailings were amended with 10 cm of domestic refuse + complex fertilizer (NKP). *V. zizanioides* was the best species to revegetate the mine tailings.

6.3 Case Study from South Africa

In South Africa vetiver has been very successfully used to stabilise / rehabilitate ‘slime dams’ (tailings) at de Beers Diamond Mines where surface temperature was 55°C (Knoll 1997).

7. Rehabilitation of Waste Landfills: Leachate Retention and Purification

Municipal and industrial waste landfills and industrial waste sites are usually contaminated with heavy metals such as arsenic (As), cadmium (Cd), chromium (Cr), nickel (Ni), copper (Cu), lead (Pb) and mercury (Hg) which are highly toxic to both plants and humans. Works done in Queensland have shown that vetiver can stabilise the highly erodible slopes and drainage lines and also suck up the leachate substantially from the contaminated landfill sites. Leachate from a landfill near Judy Holt Park, at Wellington point in Australia, was polluting a nearby watercourse. A biological barrier of vetiver was laid and today the area is ecologically restored with no sign of toxic leachate and the native species have come up in the area. Vetiver is successfully being used for checking landfill seepage problems by the Redland Shire Council in Brisbane. It is proving its worth in Brisbane valley, preventing run-off into local waterways from the effluent of landfills and acid sulphate soils that might otherwise leach into the Lake Somerset. The massive root system is removing extensive nitrogen and phosphorus build up from the effluent at Church Youth Camp, just 200 meters from the lake (Truong and Baker, 1998b).

At a major landfill in Bangkok, where 5000 tons of garbage was dumped everyday, a section was marked for vetiver plantation in July 1999. After four months, it was found that vetiver was able to survive fairly well despite the presence of leachate and toxicity normally present at all waste dump sites. Work done in China showed that vetiver could also purify and cleanse the urban garbage leachate. Small-scale planting of vetiver was carried out on a garbage dump in Guangzhou city and it was found that the grass could not only survive well, but also eliminate some of the foul odor from the dump site. Of all, the ammoniac nitrogen was the best cleansed, and its purification rate was between 83 – 92% indicating that vetiver can strongly absorb ammoniac nitrogen dissolved in water. Phosphorus was removed by 74% (Xia 1998).

8. Removal of Nutrients and Heavy Metals and Prevention of Eutrophication in Streams and Lakes by VGT

Because vetiver grass can withstand prolonged submergence in water, it also behaves as a wetland plant. It can efficiently absorb dissolved nitrogen (N), phosphorus (P), mercury (Hg), cadmium (Cd), lead (Pb) and all other heavy metals from the polluted streams, ponds and lakes and its efficiency increase with age. Works done in China have confirmed that vetiver can effectively remove dissolved nutrients, specially the N and P from wastewater and reduce the growth of blue green algae (which cause eutrophication) within two days under experimental conditions. Phosphorus (P) is removed up to 99% after 3 weeks and nitrogen (N) 74% after 5 weeks (Zheng et al. 1998).

Vetiver has the potential of removing up to 102 tonnes of nitrogen and 54 tonnes of phosphorus / year / hectare of vetiver. This can be achieved by both planting vetiver on the edges of the streams or on the shallow parts of the lakes where usually high concentrations of soluble N and P occur. An innovative idea is to grow vetiver hydroponically on floating platforms which could be moved from one place to the other, and to the worst affected parts of the lakes and ponds. The advantage of the platform technology is that the top portions of the grass can be harvested easily for stock feed or mulch and the roots can also be removed for oil production.

9. Wastewater / Storm water Treatment by VGT in Constructed Wetlands

Constructed wetland technology (CWT) using aquatic and wetland plants in artificially created wetlands for municipal wastewater / storm water treatment and purification are also considered as a part of phytoremediation technology. Vetiver can easily thrive in wetlands and can be used in the constructed wetlands for removal of nitrogen (N) and phosphorus (P) and heavy metals from the polluted storm water, municipal and industrial wastewater, and effluents from abattoirs, feedlots, piggeries and other intensive livestock industries. Works done in Thailand show that VGT can also effectively remove substantial quantities of cadmium (Cd), mercury (Hg), chromium (Cr), arsenic (As) and lead (Pb) from municipal wastewater. Chinese study also revealed successful use of vetiver as a wetland plant to remediate animal waste from a piggery (Hengchaovanich, 2003). Vetiver roots can accumulate several times of some of the heavy metals present in the wastewater (Truong and Baker, 1998a).

9.1 Environmental - Economics of VGT

Environmental - economics works highly in favor of VGT. It can reduce point source erosion from highways and building sites at much reduced costs, often less than 90% of the cost of the ‘hard engineering’ solutions. The cost-benefit analysis of VGT done in China (developing country), where labor cost is cheaper, indicates that the soft engineering solution costs approximately 10% of the corresponding hard engineering solution for environmental problems. In Australia (a developed nation), where the labor cost is higher, the VGT would cost between 27 to 40% of the hard engineering solution (Hengchaovanich 2003). In the U.S., VGT costs around one-tenth to one-third of conventional engineering technology and its use is likely to increase by more than 10 fold in future.

9.2 Economic Importance of Vetiver Grass

The root of vetiver produces an essential oil called ‘vetiver oil’ which is used in perfumery industry. The south Indian genotype is specially useful in the oil production. The Department of Natural Resources in Australia is producing a world class perfume ‘Guerlain’. Vetiver oil is also an ‘insect repellant’. Vetiver grass also has herbicide / weedicide properties. Methanol extracts of ground stem and root were found to be very effective in preventing the germination of a number of monocot and dicot weed species (Techapinyawat et al. 1996).

10. Conclusion

Phytoremediation by VGT is a low cost technology as compared to conventional (engineering) methods for site remediation. It is also virtually maintenance free, the grasses regrow very quickly and its efficiency improves with age (Truong 1999). Social acceptance of a particular technology in remediation of contaminated lands and water bodies has also become an important issue, as it directly affects the life of community. Biological technologies based on the use of plants are more acceptable to people, as it creates a green and aesthetic view and also provides some useful materials. Several plants are being identified and trialed to be used in the phytoremediation task. Important among them are other grasses like the Bermuda grass (*Cynodon dactylon*), Bahia grass (*Paspalum notatum*), Rhodes grass (*Chloris guyana*), the tall wheat grass (*Thynopyron elongatum*), common reed grass (*Phragmites australis*), the munj grass (*Sachharum munja*) and *Imperata cylindrica*. Other plants are the marine couch (*Sporobolus virginicus*), cumbungi (*Typha domingensis*) and *Sarcocrina* spp. They are highly salt and toxicity tolerant and have extensive root binding system. They were tried in the rehabilitation works, but none succeeded so well as vetiver. There is need to educate the society, the general people and the planner about the ecological and economic value of this ‘wonder grass’.

References

Anderson TA, Guthrie EA, Walton BT (1993) Bioremediation in the rhizosphere. Plant roots and associated microbes clean contaminated soils. Environ Sci Technol 27:2630-2636

Cunningham SD, Ow DW (1996) Promises and prospects of phytoremediation. Plant Physiol 110:715-719

Greenfield JC (1989) Vetiver grass: The ideal plant for vegetative soil and moisture conservation, The World Bank, Washington D.C., USA

Grimshaw Dick (2000) Vetiver and the Environment-The Future, Paper presented at the 2nd International Conference on Vetiver, Thailand, January 19-22, 2000

Hengchaovanich Diti (2003) VGT: A Bioengineering and Phytoremediation Option for the New Mellennium, APT Consult Company Limited, Bangkok, Thailand

Knoll C (1997) Rehabilitation with Vetiver, Journal of African Mining, Vol. 2(2), pp 43

Kim I (1996) Harnessing the green clean. J Chem Eng 103:39-41

Mackova M, Macek T, Ocenaskova J, Burkhard J, Demnerova K, Pazlarova J (1996) Selection of the potential plant degraders of PCB’s. Chemistry Listy 90:712-713

Pinthong J, Impithuksa S, Ramlee A (1998) The capability of vetiver hedgerows in decontamination of agrochemical residues: A case study on the production of cabbage at Nong Hoi Development Centre, Proceedings of 1st International Conference on Vetiver, Chiang Rai, Thailand, Feb 4-8, 1996, pp 91-98

Radloff B, Walsh K, Melzer A (1995) Direct Revegetation of Coal Tailings at BHP Saraji Mine, Australian Mining Council Environment Workshop, Darwin, Australia

Rice PJ, Anderson TA Anhalt JC, Coats JR (1997) Phytoremediation of atrazine and metachlor contaminated water with submerged and floating aquatic plants, Proc. Of the 12th Annual Conference on Hazardous Waste Research, Kansas City, Missouri, May 19-22, 1997; pp 52

Rugh CL, Wilde HD, Stack NM, Thompson DM, Summers AO, Meagher RB (1996) Mercuric ion reduction and resistance in transgenic *Aribidopsis thaliana* plants expressing a modified merA gene; Proceeding of the National Academy of Science; U.S.A.; Vol. 93, pp 3182-3187

Sinha RK (1996) Global Biodiversity; INA Shree Publications, Jaipur, India; ISBN 81-86653-04-X, pp 396

Sinha RK, Herat S and Tandon PK (2003) A Review of Phytoremediation as a Cost-effective, Ecologically Sustainable and Socially Acceptable Bioengineering Technology, Proceedings of National Environment Conference (NEC), Brisbane, June 18-20, 2003

Tamaya (2003) Removal of cadmium (Cd) from contaminated soil by Vetiver (*Vetiveria zizanioides*), 20 CP Project Report, School of Environmental Engineering, Griffith University, Brisbane, Australia (Supervised by Sinha RK).

Techapinyawat S, Sripen S, Komkris T (1996) Allelopathic effects of vetiver grass on weeds, Paper presented at the 1st International Conference on Vetiver; Chiang Rai, Thailand, Feb. 4-8, 1996

Truong, P, Baker, D (1996) Vetiver grass for the stabilisation and rehabilitation of acid sulfate soils, Proceedings of 2nd National Conference on Acid Sulfate Soils; Coff's Harbour, NSW, Australia, pp 196-198

Truong P, Baker D (1998a) Vetiver Grass System for Environmental Protection, Technical Bulletin No. 1998/1; Pacific Rim Vetiver Network, Bangkok, Thailand

Truong P, Baker D (1998b) The role of vetiver grass for the stabilisation and rehabilitation of toxic and contaminated lands in Australia, Proceedings of International Vetiver Workshop, Fuzhou, China, Oct. 21-26, 1997

Truong P (1999) Vetiver Grass Technology for Mine Rehabilitation, Technical Bull. No. 1999/2; Pacific Rim Vetiver Network; Bangkok, Thailand

Watanabe M (1997) Phytoremediation on the brink of commercialization. Environ Sci Technol 31:182A-186A

Xia H, Ao H, Lui S, He D (1998) A preliminary study on vetiver's purification for garbage leachate, Proceedings of International Vetiver Workshop, Fuzhou, China, Oct. 21-26, 1997

Zheng CR, Tu C, Chen HM (1998) Preliminary experiment on purification of eutrophic water with vetiver, Proceedings of International Vetiver Workshop, Fuzhou, China, Oct. 21-26, 1997