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PHYTOREMEDIATION OF CONTAMINATED LAND USING VETIVER GRASS (FITORREMEDIACIÓN DE SUELOS CONTAMINADOS UTILIZANDO PASTO VETIVER)

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ABSTRACT

The Vetiver System (VS), which is based on the applications of Vetiver Grass *(Chrysopogon zizanioides* L), was researched and developed by *The Vetiver Network International* (TVNI) as an environmental protection tool. Application of VS for environmental protection is a new and innovative phytoremedial technology.

Extensive R&D in Australia, China, South Africa, Thailand and recently Venezuela over the last 20 years have established that vetiver grass is non invasive it thrives under most adverse soil and climatic conditions. Vetiver grass is tolerant to elevated and sometimes toxic levels of salinity, acidity, alkalinity, sodicity as well as a whole range of heavy metals and agrochemicals.

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

This paper deals specially with the phytoremediation of contaminated lands:

- **Mining wastes**: waste rocks and tailings of bauxite, coal, copper, gold, lead, platinum and zinc have been successfully stabilised and rehabilitated in Australia, Chile, China, South Africa, Thailand and Venezuela.
- **Industrial wastes**: Industrial wastes contain very high levels of both organic and inorganic compound have been successfully stabilised and treated in Australia, China, Thailand and Vietnam.

Keywords: Vetiver grass, mine tailings, contaminated land, heavy metals, pollution control

1.0 INTRODUCTION

There has been increasing concerns in Australia and worldwide on the contamination of the environment by by-products of rural, industrial and mining industries. The majority of these contaminants are high levels of heavy metals which can affect flora, fauna and humans living in the areas, in the vicinity or downstream of the contaminated sites.

Concerns about the spreading of these contaminants have resulted in strict guidelines being set to prevent the increasing concentrations of heavy metal pollutants. In some cases industrial and mining projects have been stopped until appropriate methods of decontamination or rehabilitation have been implemented at the source.

Methods used in these situations have been to treat the contaminants chemically, burying or to remove them from the site. These methods are expensive and at times impossible to carry out, as the volume of contaminated material is very large, examples are gold and coal mine tailings. If these wastes cannot be economically treated or removed, off-site contamination must be prevented. Wind and water erosion and leaching are often the causes of off-site contamination. An effective erosion and sediment control program can be used to rehabilitate such sites. Table 1 shows the maximum levels of heavy metals tolerated by environmental and health authorities in Australia and New Zealand.

Vegetative methods are the most practical and economical; however, revegetation of these sites is often difficult and slow due to the hostile growing conditions present which include toxic levels of heavy metals.

The Vetiver System (VS), which is based on the application of vetiver grass (*Chrysopogon zizanioides,* Roberty L), was first developed by the World Bank for soil and water conservation in India in the 1980s. Further research and development by *The Vetiver Network International* (TVNI) in the last 20 years have established VS as an innovative phytoremedial technology for environmental protection purposes.

Extensive R&D in Australia, China, Thailand and recently Venezuela have established that vetiver Grass is non invasive it has a high water and nutrient uptake and thrives under most adverse soil and climatic conditions. Vetiver grass is tolerant to elevated and sometimes toxic levels of salinity, acidity, alkalinity, sodicity as well as a whole range of heavy metals and agrochemicals.

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

VS is now being used in more than 100 tropical and subtropical countries in Australia, Asia, Africa and Latin America for the treatment and rehabilitation of contaminated lands especially with mining and industrial contaminated lands.

This paper highlights research results which show the wide ranging tolerance of vetiver to adverse conditions and heavy metal toxicities. All the research and applications reported in this paper were conducted using the genotype registered in Australia as Monto vetiver, but DNA typing has shown that Monto is genetically identical to the majority of non-fertile genotypes such as *Sunshine* (USA), *Vallonia* (South Africa) and *Guiyang* (China) (Adams and Dafforn, 1997). Therefore the following results can be applied with confidence when these cultivars are used for mine rehabilitation.

Table 1: Investigation Thresholds for Contaminants in Soils (ANZ, 1992)

Heavy Metals	Thresholds ($mgkg^{-1}$) Environmental *	Health *
Antimony (Sb)	20	-
Arsenic (As)	20	100
Cadmium (Cd)	3	20
Chromium (Cr)	50	-
Copper (Cu)	60	-
Lead (Pb)	300	300
Manganese (Mn)	500	-
Mercury (Hg)	1	-
Nickel (Ni)	60	-
Tin (Sn)	50	-
Zinc (Zn)	200	-

*Maximum levels permitted, above which investigations are required.

2.0 SPECIAL CHARACTERISTICS OF VETIVER GRASS ESPECIALLY SUITED FOR MINE WASTES AND CONTAMINATED LANDS REHABILITATION

The most significant breakthroughs in the last 20 years in VS researches are firstly research leading to the establishment of benchmark tolerance levels of vetiver grass to adverse soil conditions and secondly its tolerance to heavy metal toxicities. These have opened up a new field of application for the rehabilitation of toxic and contaminated lands (Truong et al. 2008; Danh et al. 2009).

In addition to the general important attributes listed in Truong and Cruz (2010), the followings are some unique characteristics of vetiver grass especially suited for contaminated lands rehabilitation:

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

3.0 TOLERANCE TO ADVERSE SOIL CONDITIONS (Danh et al. 2009)

3.1 Tolerance to High Acidity and Manganese Toxicity.

Experimental results from glasshouse studies show that when adequately supplied with nitrogen and phosphorus fertilisers, vetiver can grow in soils with extremely high acidity and manganese. Vetiver growth was not affected and no obvious symptoms were observed when the extractable manganese in the soil reached 578 $mgKg^{-1}$, soil pH as low as 3.3 and plant manganese was as high as 890 $mgKg^{-1}$. Bermuda grass (*Cynodon dactylon*) which has been recommended as a suitable species for acid mine rehabilitation, has 314 $mgKg^{-1}$ of manganese in plant tops when growing in mine spoils containing 106 $mgKg^{-1}$ of manganese (Taylor *et al*, 1989). Therefore vetiver which tolerates much higher manganese concentrations both in the soil and in the plant can be used for the rehabilitation of lands highly contaminated with manganese.

3.2 Tolerance to High Acidity and Aluminium Toxicity.

Results of experiments where high soil acidity was induced by sulphuric acid show that when adequately supplied with nitrogen and phosphorus fertilisers, vetiver produced excellent growth even under extremely acidic conditions (pH = 3.8) and at a very high level of soil aluminium saturation percentage (68%). Vetiver did not survive an aluminium saturation level of 90% with soil pH = 2.0; although a critical level of aluminium could not be established in this trial, observation during the trial indicated that the toxic level for vetiver would be between 68% and 90% (Truong, 1996; Truong and Baker, 1996). These results are supported by recent works in Vanuatu where vetiver has been observed to thrive on highly acidic soil with aluminium saturation percentage as high as 87% (Miller pers.com.).

3.3 Tolerance to Heavy Metals

3.3.1 Tolerance Levels and Shoot Contents of Heavy Metals.

A series of glasshouse trials was carried out to determine the tolerance of vetiver to high soil levels of heavy metals. Literature search indicated that most vascular plants are highly sensitive to heavy metal toxicity and most plants were also reported to have very low threshold levels for arsenic, cadmium, chromium, copper and nickel in the soil. Results shown in Table 2 demonstrate that vetiver is highly tolerant to these heavy metals. For arsenic, the toxic content for most plants is between 1 and 10 $mgKg^{-1}$, for vetiver the threshold level is between 21 and 72 $mgKg^{-1}$. Similarly for cadmium, the toxic threshold for vetiver is 45 $mgkg^{-1}$ and for other plants between 5 and 20 $mgkg^{-1}$. An impressive finding was that while the toxic thresholds of vetiver for chromium is between 5 and 18 $mgkg^{-1}$ and that for nickel is 347 $mgKg^{-1}$, growth of most plants is affected at the content between 0.02 and 0.20 $mgKg^{-1}$ for chromium and between 10 and 30 $mgKg^{-1}$ for nickel. Vetiver had similar tolerance to copper as other plants at 15 $mgKg^{-1}$ (Kabata and Pendias,1984; Lepp, 1981).

Table 2: Threshold Levels of Heavy Metals to Vetiver Growth

Heavy Metals	***Thresholds to Plant Growth*** **($mgKg^{-1}$)**		**Thresholds to Vetiver Growth ($mgKg^{-1}$)**	
	Hydroponic levels (a)	**Soil levels (b)**	***Soil levels***	**Shoot levels**
Arsenic	0.02-7.5	2.0	100-250	21-72
Cadmium	0.2-9.0	1.5	20-60	45-48
Copper	0.5-8.0	NA	50-100	13-15
Chromium	0.5-10.0	NA	200-600	5-18
Lead	NA	NA	>1 500	>78
Mercury	NA	NA	>6	>0.12
Nickel	0.5-2.0	7-10	100	347
Selenium	NA	2-14	>74	>11
Zinc	NA	NA	>750	>880

(a) Bowen,1979
(b) Baker and Eldershaw,1992
NA Not available

3.3.2 Distribution of Heavy Metals in Vetiver Plant

R&D in Australia found the distribution of heavy metals in vetiver plant can be divided into three groups:

- Very little of the arsenic, cadmium, chromium and mercury absorbed were translocated to the shoots (1% to 5%),
- A moderate proportion of copper, lead, nickel and selenium were translocated (16% to 33%) and
- Zinc was almost evenly distributed between shoot and root (40%).

The important implications of these findings are that when vetiver is used for the rehabilitation of sites contaminated with high levels of arsenic, cadmium, chromium and mercury, its shoots can be safely grazed by animals or harvested for mulch as very little of these heavy metals are translocated to the shoots. As for copper, lead, nickel, selenium and zinc their uses for the above purposes are limited to the thresholds set by the environmental agencies and the tolerance of the animal concerned.

In addition, although vetiver is not a hyper-accumulator it can be used to remove the some heavy metals from the contaminated sites and disposed off safely elsewhere, thus gradually reducing the contaminant levels. For example vetiver roots and shoots can accumulate more than 5 times the chromium and zinc levels in the soil.

3.4 Tolerance to High Soil Salinity

Results of saline threshold trials showed that soil salinity levels higher than EC_{se} = 8 dSm^{-1} would adversely affect vetiver growth while soil EC_{se} values of 10 and 20 dSm^{-1} would reduce yield by 10% and 50% respectively. These results indicate vetiver grass compares favourably with some of the most salt tolerant crop and pasture species grown in Australia.

3.5 Tolerance to Strongly Alkaline and Strongly Sodic Soil Conditions

A coal mine overburden sample used in this trial was extremely sodic, with ESP (Exchangeable Sodium Percentage) of 33%. Soil with ESP higher than 15 is considered to be strongly sodic. Moreover, the sodicity of this overburden is further exacerbated by the very high level of magnesium (2400 $mgKg^{-1}$) compared to calcium (1200 $mgKg^{-1}$).

Results from added soil amendments show that while gypsum had no effect on the growth of vetiver, nitrogen and phosphorus fertilisers greatly increased its yield. DAP (di ammonium phosphate) application alone at 100 $kgha^{-1}$ increased vetiver dry matter yield 9 times. Higher rates of gypsum and DAP did not to improve vetiver growth further. These results were strongly supported by field results.

4.0 VETIVER GRASS FOR MINE SITE TREATMENT AND REHABILITATION

With the above extraordinary morphological and physiological characteristics, vetiver grass has been used successfully for stabilisation of the steep slope of waste rocks dumps and phytoremediation and revegetation of mine tailings in Australia and other countries (Truong, 2004).

4.1 Australian mines

4.1.1 Coal Tailings**:** A very large coal tailings pond, 23 ha (3.5Mm^3), its substrate was saline, highly sodic and extremely low in in N and P, high levels of soluble S, Mg, Ca, Cu, Zn, and Fe. Five salt tolerant species vetiver grass, marine couch (*Sporobolus virginicus*), common reed grass (*Phragmites australis*), cumbungi (*Typha domingensis*) and *Sarcocornia spp.* were used to rehabilitate this tailings pond. Complete mortality was recorded after 210 days for all species except vetiver and marine couch. Vetiver's survival was significantly increased by mulching but fertiliser application by itself had no effect. Mulching and fertilisers together increased growth of vetiver by 2 tha^{-1}, which was almost 10 times higher than that of marine couch (Truong, 2004).

4.1.2 Fresh Gold tailings*:* Fresh tailings are typically alkaline (pH = 8-9), low in plant nutrients and very high in free sulphate (830 mgKg^{-1}), sodium and total sulphur (1-4%). Vetiver established and grew very well on these tailings without fertilisers, but growth was improved by the application of 500 Kgha^{-1} of DAP. Vetiver has been used successfully in a large-scale trial to control dust movement and wind erosion on a 300ha tailings dam. When planted in rows at 10m to 20m spacing, vetiver hedges reduced wind velocity and promoted the establishment of Rhodes grass

4.1.3 Old Gold tailings: Due to high sulphur content, old gold mine tailings are often extremely acidic (pH 2.5-3.5), high in heavy metals and low in plant nutrients. Revegetation of these tailings is very difficult, often very expensive, and the bare soil surface is highly erodible. Field trials were conducted on two old (8 year) tailings sites. One exhibits a soft surface and the other a hard crusty layer. The soft top site had a pH of 3.6, sulphate at 0.37% and total sulphur at 1.31%. The hard top site had a pH of 2.7, sulphate at 0.85% and total sulphur at 3.75%. Both sites were low in plant nutrients. However, when adequately supplied with nitrogen and phosphorus fertilisers (300Kgha^{-1}of DAP), excellent growth of vetiver was obtained on the soft top site (pH=3.6) without any liming. But the addition of 5tha^{-1} of agricultural lime significantly improved vetiver growth. On the hard top site (pH=2.7), although vetiver survived without liming, the addition of lime (20tha^{-1}) and fertiliser (500kgha^{-1} of DAP) improved vetiver growth greatly (Table 3)

Table 3: Heavy metal contents of representative gold mine tailings in Australia**.**

Heavy Metals	*Total Contents* (mgKg^{-1})	*Threshold levels* (mgKg^{-1})
Arsenic	1 120	20
Chromium	55	50
Copper	156	60
Manganese	2 000	500
Lead	353	300
Strontium	335	NA
Zinc	283	200

NA Not available

4.1.4 Bentonite Tailings

Bentonite mine tailings (reject) is extremely erodible as they are highly sodic with Exchangeable Sodium Percentage (ESP) values ranging from 35% to 48%, high in sulphate and extremely low in plant nutrients. Revegetation on the tailings has been very difficult as sown species were often washed away by the first rain and what left could not thrive under these harsh conditions. With adequate supply of nitrogen and phosphorus fertilisers vetiver established readily on this tailings, the hedges provided erosion and sediment control, conserved soil moisture and improved seedbed conditions for the establishment of indigenous species.

4.2 Venezuelan Bauxite mine

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

Vetiver system has been used in this project, for stabilization of various gradient slopes, on the soil-concrete interface to protect infrastructures on the mine site, stabilization of gullies and border drains, reinforcement of lagoon dikes, bio-filter in gullies and around lagoons. For erosion control a total of 26 300m of vetiver barriers have been planted, from 2003 to June 2006. Now CVG BAUXILUM is planning to plant another 7 400m of Vetiver barriers.

Based on the above results, during the past three years, CVG BAUXILUM has successfully adopted the Vetiver System for land rehabilitation and environmental protection to restore this open cut bauxite mining site of Venezuela, to a desirable environmentally friendly level. (Luque et al. 2006; Lisenia et al. 2006)

4.3 Chilean Copper mines

The main economic income of Chile originates from the mining industry, mainly the mining of copper. For this reason Fundacion Chile is carrying out a series of pilot studies using the Vetiver System to remediate the wastes produced by the mining industry, which represents an important source of contaminants to the environment - water, soil and air. Demonstration trials were set up on a number of Copper mines in Central region to:

- Determine whether vetiver can grow on highly contaminated copper waste rock and tailings
- Find out whether vetiver can grow on these extreme climatic conditions: high altitude, cold and wet winter, very hot and dry summer
- Ascertain whether vetiver is effective in stabilising the tailings ponds wall (built with copper tailings material only) and waste rock dump against wind and water erosion
- Determine whether vetiver is effective in preventing wind and water erosion in fresh and old tailings ponds.

One year after planting, results to date are very encouraging; vetiver could be established on both highly contaminated copper tailings dump and waste rock, where it grew to 1.5m in 6 months. Reasonable growth was also observed at a 3 500m altitude site and although covered by 50cm of snow for one month, it has survived winter at this site (Fonseca et al, 2006).

4.4 South Africa Mines

Rehabilitation trials conducted by De Beers on both tailings dumps and slimes dams at several sites, have found that vetiver possessing the necessary attributes for self sustainable growth on Kimberlite spoils. At Premier (800mm annual rainfall) and Koffiefonteine (300mm rainfall) diamond mines where surface temperature of the black Kimberlite often exceeds $55^{o}C$, at this temperature most seeds are unable to germinate. Vetiver planted at 2m Vertical Interval, provided shades that cool the surface and allowing germination of other grass seeds. Vetiver grew vigorously, containing run off, arresting erosion and creating an ideal micro-habitat for the establishment of indigenous grass species (Knoll, 1997).

4.5 Chinese Mines

R&D in China have demonstrated that *C. zizanioides* is one of the best choices for revegetation of Pb/Zn mine tailings due to its high metal tolerance, furthermore, this grass can be also used for phyto-extraction because of its large biomass. Recent research also suggests that vetiver also has higher tolerance to acid mine drainage (AMD) from a Pb/Zn mine, and wetlands planted with this grass can effectively adjust pH and remove SO_4^{2-}, Cu, Cd, Pb, Zn and Mn from AMD. For example, vetiver produced biomass more than twice that of both local and introduced species used in the rehabilitation of the Lechang Pb and Zn mine, where tailings contain very high levels of heavy metals (Pb at 3 231 $mgKg^{-1}$, Zn at 3 418 $mgKg^{-1}$, Cu at 174 $mgKg^{-1}$ and Cd at 22 $mgKg^{-1}$) (Shu, 2003 and Xia *et al*, 2003).

4.6 Thai Mines

Iron ore tailings normally contain high levels of heavy metals with total Fe, Zn, Mn and Cu concentrations of 63,920, 190, 3,220 and 190 mg kg^{-1}, respectively and low contents of primary nutrients and organic matter. R&D was conducted to evaluate the effects of soil amendment on growth, performance and the accumulation of primary nutrients as well as Fe, Zn, Mn and Cu in vetiver. Results indicated that the combination of soil amendment materials, especially DTPA and compost, was more effective than sole chelating agents and sole compost in enhancing vetiver growth, nutrient and heavy metals uptake. The soil amendments used in this study did not affect Fe and Zn translocation from vetiver roots to shoots. However, chelating agent amendment could increase Cu translocation, especially in combination with compost, while it slightly decreased Mn translocation. These results indicated that vetiver is a potential plant for phytostabilization and rehabilitation of iron ore mine areas. (Roongtanakia et al., 2008).

5.0 VETIVER GRASS FOR CONTAMINATED LAND REHABILITATION

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

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

- Surface area 2 150 m^2
- Site depth: Average 3.25m

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

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

In Vietnam, solid wastes and contaminated land surrounding fertiliser and paper factories, and a coal fire power station was successfully stabilised and rehabilitated by re introducing native vegetation

6.0 OVERALL ADVANTAGES OF VETIVER SYSTEM APPLICATION

- **Simplicity**: Application of the Vetiver System is rather simple compared with other conventional methods.
- **Low cost:** Application of the Vetiver System in wastewater treatment costs a fraction of conventional methods such as chemical or mechanical treatment.
- Minimal maintenance: When properly established, the VS requires practicaly no maintence to keep it functioning.

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