8
Phytoremediation of Heavy Metal Contaminated Soils and Water Using Vetiver Grass

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Abstract Phytoremediation includes utilization of plants to remediate polluted soils. In this chapter, application of Vetiver grass in phytoremediation of heavy metal contaminated soils is discussed. Case studies in Australia, China, and South Africa are presented. The future application may be in the areas of mine site stabilization, landfill rehabilitation, leachate treatment, wastewater treatment, and other land rehabilitation. It is a low-cost remediation method.

1. GLOBAL SOIL CONTAMINATION

Due to ever increasing industrial, agricultural, and mining activities worldwide, heavy metal pollution of land and water is becoming a globally important environmental, health, economic, and planning issue. There is an increase in world population, and unpleasant disposal of industrial effluents, especially in the developing countries, causing soil pollution. Utilization of these lands for agricultural purposes and urban developments requires a safe

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and efficient decontamination process. With the increasing use of agrochemicals to maintain and improve soil fertility, unwanted elements such as cadmium into soils due to contaminated sources of fertilizers, especially in developing countries, are being introduced into agricultural soils, which poses a potential threat to the food chain (1, 2). Mining and industrial operations also lead to significant challenges for the management of the natural environments during and after these activities.The increased public awareness of the environmental impact of such activities demands an interdisciplinary, inter-organizational, and international effort (3). Soil and water contaminated with heavy metals pose a major environmental and human health problem that needs an effective and affordable technological solution (4).

2. REMEDIATION TECHNIQUES

2.1. Physical and Chemical Techniques

Various physical and chemical techniques to decontaminated soils have been undertaken during the last 25 years (5–8) and millions of dollars being spent by governments all over the world on preventive measures. However, all of them are labour intensive and costly, and cannot be applied to thousands of hectares of land contaminated with inorganic heavy metals (8, 9). These technologies results in rendering the soil biologically dead and useless for plant growth as they remove all flora, fauna, and microbes including useful nitrogen fixing bacteria and P-enhancing mycorrhizal fungi (10).

Many sites around the world remain contaminated with no remediation in sight simply because it is too expensive to clean them up with the available technologies (11). If these wastes cannot be economically treated or removed, steps must be taken to prevent off-site contamination of the food chain processes through wind and water erosion, leachate generation (9).

2.2. Bioremediation Techniques

Microbial bioremediation technology, well known for decontamination of organics (12), is not available for large-scale biodegradation of inorganic heavy metals. The health hazards caused by the accumulation of toxic metals in the environment together with the high cost of removal and replacement of metal-polluted soil have prompted efforts to develop alternative and cheaper techniques to recover the degraded land (10).

2.3. Phytoremediation

The restoration of derelict land by establishing a plant cover is important before it poses serious health hazard by transferring the trace metals into the surroundings. Current research in this area includes utilization of plants to remediate polluted soils and to facilitate improvement of soils structure in cases of severe erosion, the innovative technique being known as phytoremediation (1, 8, 10, 13).

Phytoremediation is widely considered to be not only an innovative but also an economical and environmentally compatible solution to many engineering and environmental issues across the world. Although essentially simple, this new technology branches further and into a variety of different fields and techniques. A review of tropical hyperaccumulator of heavy metal plants and concluded that there is a lack of investigation for the occurrence of hyperaccumulator plant species. No botanical or biogeochemical exploration of trace metal tolerant and/or accumulating plant species has yet taken place in many parts of the world. Many plant species, which can accumulate high concentrations of trace elements, have been known for over a century (17). Renewed interest in the role of these hyper-accumulating plants in phytoremediation has stimulated research in this area (8, 17). Several plant species or ecotypes, associated with heavy metal enriched soils, accumulate metals in the shoots. These plants can be used to clean up heavy metal contaminated sites by extracting metals from soils and accumulating them in aboveground biomass (10, 13, 14).

2.3.1. *Phytoextraction*

This is a technique that utilizes plants known as heavy metal hyper accumulators and metal accumulating plants with large biomass to extract heavy metals such as Pb, Zn, Cu, and Cd. The plants are then harvested to allow the removal of contaminants from site (15).

2.3.2. *Phytofiltration*

This technique uses plant roots, grown in aerated water to concentrate and precipitate heavy metals from polluted effluents. Plants that can adapt to wetland conditions are the most suitable (15).

2.3.3. *Phytostabilization*

This technique relies on plants to stabilize contaminants in soils, rendering them harmless. Plants with low metal accumulating properties but that are tolerable to high heavy metal concentrations are most suited to this technique (15).

2.3.4. *Phytovolatilization*

This technique is useful for the removal of volatile metals such as Hg and Se. Plants extract these metals and volatilize them from the foliage.

2.3.5. *Phytomining*

There are several plant species or ecotypes, associated with heavy metal enriched soils, accumulate metals in the shoots. These plants can be used to clean up heavy metal contaminated sites by extracting metals from soils and accumulating them in aboveground biomass (13, 14). The metal enriched biomass can be harvested and smelted to recover the metal.

2.3.6. *Limitations of Phytoremediation*

Although phytoremediation is the least destructive method among the different types of remediation because it utilizes natural organisms and the natural state of the environment can be preserved, it has its limitations like all other biological methods: it has not yet been found to remove or reduce contaminants completely (16). Furthermore, any vegetative method of remediation may be more suited to a long-term application due to the time it takes for the plants to grow.

The use of a vegetative and effective erosion and sediment management program has proven to be viable. 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 (9).

2.3.7. Plants for Phytoremediation

Plants that are used to extract heavy metals from contaminated soils have to be the most suitable for the purpose, i.e. tolerant to specific heavy metal, adapted to soil and climate, capable of high uptake of heavy metal(s), etc. Plants either take up one or two specific metals in high concentrations into their tissues (hyperaccumulator) with low biomass (1), or extract low to average heavy metal (not metal specific) concentrations in their shoots with high biomass. Low biomass hyperaccumulators, generally, have a restricted root system (17). In contrast, nonaccumulators, high biomass producing and tolerant plants have physiological adaptation mechanisms, which allow them to grow in contaminated soils better than others (18). The tolerance and specific behaviour at the root level must be taken into consideration while selecting plants for phytoremediation (19). Root system morphology allows some plants to be more efficient than others in nutrient uptake in infertile soil or stressed soil conditions (20).

Phytoremediation is considered an innovative, economical, and environmentally compatible solution for remediating some heavy metal contaminated sites (4) among others. The next step is to find suitable species of vegetation with the ability to develop this technology on a large scale. This chapter deals with some experiments conducted in Australia using Vetiver.

3. VETIVER GRASS AS AN IDEAL PLANT FOR PHYTOREMEDIATION

The success of phytoremedial efforts is dependent largely upon the choice of plant species. Among the plants involved in phytoremedial measures, Vetiver grass (*Chrysopogon zizanioides* L (Roberty), formerly *Vetiveria zizanioides* L. (Nash)), should receive special attention (Fig. 8.1).

Fig. 8.1. Vetiver – Shoot and Root. *Left* Vetiver grass has stiff and erect stems with sterile flower heads, reaching 3 m high under good growing conditions. *Right* Deep, extensive and penetrating root system, capable of extending to 3.3 m in the first year of growth, and to 4.5 m in 3 years.

Vetiver is one of those few plants which possess both economical and ecological capabilities, i.e. essential oil distilled from its roots in over 70 countries (21) and its conservation properties, such as up to 2 m high plant with a strong dense and mainly vertical root system often measuring more than 3 m, useful in soil erosion control (15, 22–25). It is propagated vegetatively and is noninvasive (26). It is extremely resistant to insect pests and diseases (27) and is widely used worldwide for soil and moisture conservation and soil restoration. It is immune to flooding, grazing, fires, and other hazards (28). Vetiver grass is regarded as a tool for environmental engineering (32) and as one of the most versatile crops of the third millennium (33).

3.1. Unique Morphology and Physiology

Vetiver is a fast growing, perennial grass native to the South and South-East Asian regions. It will grow to approximately 1–2 m in height and has long been used in Asia for slope stabilization in agricultural lands because of a deep (up to 3 m), strong root system. Traditionally, these roots were woven into mats, fans, and fragrant screens (34).

Vetiver is used throughout the world in various cultivars; however, it has been shown that although Vetiver does adapt to its environment over time, most nonfertile genotypes such as Monto, Sunshine, Vallonia, and Guiyang are genetically identical (35). It can then be said that most application with specific results obtained by research can be applied with confidence throughout the rest of the world.

Vetiver grass is both a xerophyte and a hydrophyte and, once established, is not affected by droughts or floods (17)

The unique characteristics of Vetiver can be summarized as follows:

- Adaptability to a wide range of soil and climatic conditions
- Can be established in sodic, acidic, alkaline, and saline soils
- Tolerant to drought due to deep and extensive root system
- Mature plants are tolerant to extreme heat (50°C) and frost (−10°C)
- Vetiver can withstand burning, slashing, and moderate tractor traffic
- Resistant to infestations from most pests, diseases, and nematodes
- Absence runners or rhizomes, and only spreads by tillering

3.2. Tolerance to Adverse Soil Conditions

Extensive researches over a decade by the senior author has uncovered the ability of Vetiver grass to grow on both acidic and alkaline soils and tolerate a wide range of heavy metals at various concentrations. It has been demonstrated that Vetiver has a very high tolerance to heavy metals such as Arsenic, Cadmium, Copper, Chromium, Lead, Mercury, Nickel, Selenium, and Zinc when compared to most other plants

3.3. Tolerance to High Acidity and Manganese Toxicity

Experimental results from glasshouse studies show that when adequately supplied with nitrogen and phosphorus fertilizers, 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 mg/kg, soil pH was as low as 3.3, and plant manganese was as high as 890 mg/kg. Bermuda grass (*Cynodon dactylon*) which has been recommended as a suitable species for acid mine rehabilitation, has 314 mg/kg of manganese in plant tops when growing in mine spoils containing 106 mg/kg of manganese (36). 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.

3.4. Tolerance to High Acidity and Aluminum Toxicity

Results of experiments where high soil acidity was induced by sulfuric acid show that when adequately supplied with nitrogen and phosphorus fertilizers, Vetiver produced excellent growth even under extremely acidic conditions (pH = 3.8) and at a very high level of soil aluminum saturation percentage (68%). Vetiver did not survive an aluminum saturation level of 90% with soil pH = 2.0; although a critical level of aluminum could not be established in this trial, observation during the trial indicated that the toxic level for Vetiver would be between 68 and 90% (37, 38). This level was later confirmed by field observation, where Vetiver survived on a sandy soil with an aluminum saturation level of 86% (Fig. 8.2)

3.5. Tolerance to High Soil Salinity

Results of saline threshold trials showed that soil salinity levels higher than $EC_{se} = 8$ dS/m would adversely affect Vetiver growth, while soil EC_{se} values of 10 and 20 dS/m would reduce yield by 10 and 50%, respectively (Fig. 8.3).

These results indicate that Vetiver grass compares favourably with some of the most salt tolerant crop and pasture species grown in Australia (Table 8.1) (Fig. 8.3).

In an attempt to revegetate a highly saline area (caused by shallow saline groundwater), a number of salt tolerant grasses, Vetiver, Rhodes (*Chloris guyana)*, and saltwater couch (*Paspalum vaginatum*) were planted. Negligible rain fell after planting. So plant establishment

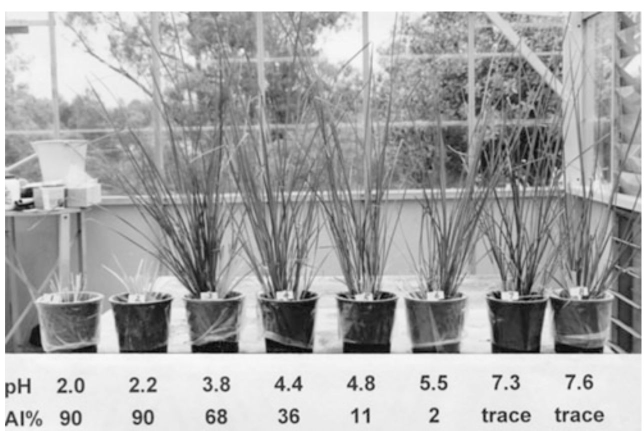

Fig. 8.2. Vetiver growth on aluminum saturated soil. When adequately supplied with N and P fertilizers, Vetiver growth was not affected when soil aluminum saturation extract (ASE) reached 68%, and soil pH at 3.8. ASE higher than 45% is highly toxic to both crop and pasture plants. Field sampling indicated that Vetiver grew on site with ASE at 86%.

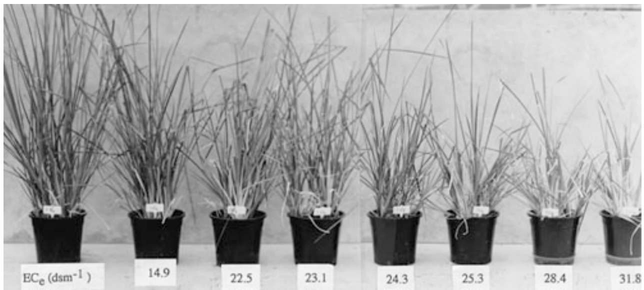

Fig. 8.3. Vetiver growth in highly saline soil. Soil salinity level higher than $EC_{se} = 16\,dS/m$ is considered to be highly saline. Vetiver growth was not greatly affected until soil salinity reached 23 dS/m.

Table 8.1
Salt tolerance level of Vetiver grass as compared with some crop and pasture species grown in Australia

Species	Soil EC_{se} (dS/m)	
	Saline threshold	50% yield reduction
Bermuda grass *(Cynodon dactylon)*	6.9	14.7
Rhodes grass (C.V. Pioneer) *(Chloris guyana)*	7.0	22.5
Tall wheat grass *(Thynopyron elongatum)*	7.5	19.4
Cotton *(Gossypium hirsutum)*	7.7	17.3
Barley *(Hordeum vulgare)*	8.0	18.0
Vetiver (*Chrysopogon zizanioides*)	8.0	20.0

Table 8.2
Soil salinity levels corresponding to different species establishment

Species	Profile soil EC_{se} (dS/m)	
	0–5 cm	10–20 cm
Chloris guyana	4.83	9.59
Paspalum vaginatum	9.73	11.51
Vetiveria zizanioides	18.27	18.06
Bare ground	49.98	23.94

and growth were extremely poor, but following heavy rain during summer (9 months later), vigorous growth of all species was observed in the less saline areas. Among the three species tested, Vetiver was able to survive and resume growth under the higher saline conditions (Table 8.2), reaching a height of 60 cm in 8 weeks (39). These results are supported by observation in Fiji and Queensland, where Vetiver was found growing in highly saline tidal flats next to mangrove.

3.6. Tolerance to Strongly Alkaline and Strongly Sodic Soil Conditions

Vetiver was satisfactorily established on a coal mine overburden and bentonite tailings with ESP (Exchangeable Sodium Percentage) of 33 and 48%, respectively. Soil with ESP higher than 15 is considered to be strongly sodic (40). Moreover, the sodicity of this coal overburden is further exacerbated by the very high level of magnesium (2,400 mg/kg) compared to calcium (1,200 mg/kg).

3.7. Tolerance to Heavy Metals

3.7.1. Tolerance Levels and Shoot Contents 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 8.3 demonstrate that Vetiver is highly tolerant to these heavy metals. For arsenic, the toxic content for most plants is between 1 and 10 mg/kg, for Vetiver, the threshold level is between 21 and 72 mg/kg. Similarly for cadmium, the toxic threshold for Vetiver is 45 mg/kg and for other plants between 5 and 20 mg/kg. An impressive finding was that while the toxic thresholds of Vetiver for chromium is between 5 and 18 mg/kg and that for nickel is 347 mg/kg, growth of most plants is affected at the content between 0.02 and 0.20 mg/kg for chromium and between 10 and 30 mg/kg for nickel. Vetiver had similar tolerance to copper as other plants at 15 mg/kg (28–31).

3.7.2. Distribution of Heavy Metals in the Vetiver Plant

Table 8.4 shows that the distribution of heavy metals in Vetiver plant can be divided into three groups:

Table 8.3
Threshold levels of heavy metals to Vetiver growth (30, 31)

Heavy metals	Thresholds to plant growth (mg/kg)		Thresholds to Vetiver growth (mg/kg)	
	Hydroponic levels (4)	Soil levels (5)	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

NA not available.

Table 8.4
Distribution of heavy metals in Vetiver shoots and roots

Metals	Soil (mg/kg)	Shoot (mg/kg)	Root (mg/kg)	Shoot/root (%)	Shoot/total (%)
Arsenic (As)	959	9.6	185	5.2	4.9
	844	10.4	228	4.6	4.4
	620	11.2	268	4.2	4.0
	414	4.5	96	4.7	4.5
	605	6.5	124	5.2	5.0
Average				4.8	4.6
Cadmium (Cd)	0.67	0.16	7.77	2.0	2.0
	0.58	0.13	13.60	1.0	0.9
	1.19	0.58	8.32	7.0	6.5
	1.66	0.31	14.20	2.2	2.1
Average				3.1	2.9
Copper (Cu)	50	13	68	19	16
Chromium (Cr)	50	4	404	1	1
	200	5	1170	<1	<1
	600	18	1750	1	1
Average				<1	<1
Lead (Pb)	13	0.5	5.1	10	9
	91	6.0	23.2	26	20
	150	13.2	29.3	45	31
	330	41.7	55.4	75	43
	730	78.2	87.8	87	47
	1,500	72.3	74.5	97	49
Average				57	33
Mercury (Hg)	0.02	BQ	0.01	–	–
	0.36	0.02	0.39	5	5
	0.64	0.02	0.53	4	4
	1.22	0.02	0.29	7	6
	3.47	0.05	1.57	3	3
	6.17	0.12	10.80	11	6
Average				6	5
Nickel (Ni)	300	448	1040	43	30
Selenium (Se)	0.23	0.18	1.00	53	15
	1.8	0.58	1.60	36	27
	6.0	1.67	3.60	46	32
	13.2	4.53	6.50	70	41
	23.6	8.40	12.70	66	40
	74.3	11.30	24.80	46	44
Average				53	33
Zinc (Zn)	Control	123	325	38	27
	100	405	570	71	42
	250	520	490	106	51
	350	300	610	49	33
	500	540	830	65	39
	750	880	1,030	85	46
Average				69	40

BQ below quantification.

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

The important implication of these findings is 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 (Table 8.4).

3.8. Tolerance to Extreme Nutrient Levels

Vetiver also tolerates extremely high N and P in the growing medium. Research results indicate that Vetiver grass has a very high capacity of absorbing N at elevated levels of N supply. Vetiver growth will respond positively to N supplied at rates of up to 6,000 kg/ha/year, with no adverse growth effects apparent up to 10,000 kg/ha/year. As a result, vetiver has a very high N uptake as compared with other pasture grasses. (Fig. 8.4).

Vetiver requirement for P was lower than that for N, and no growth response was observed at rates exceeding 250 kg/ha/year. Its growth was not adversely affected at P application rates up to 1,000 kg/ha/year. However, in combination with a high growth rate and high yield, the total amount of P uptake by Vetiver was found to exceed those of other tropical and subtropical grasses (41).

The combination of these features makes Vetiver highly suitable for treating both domestic and industrial wastewater and landfill rehabilitation.

3.9. Tolerance to Agrochemicals

Herbicides applied to farmlands are important for controlling weeds in crops but this practice, if not properly managed, can lead to serious off-site contamination of the surrounding

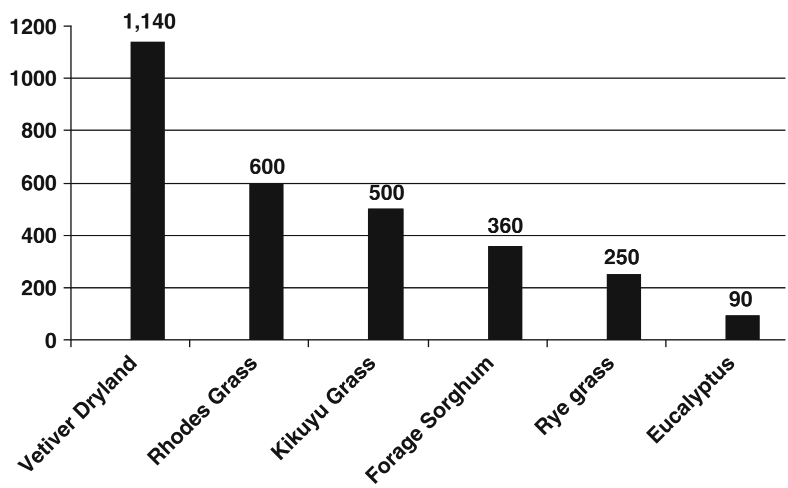

Fig. 8.4. Comparisons between Vetiver and other plants of nitrogen uptake capacity.

environment. In particular, residues of these chemicals can adversely affect flora and fauna in downstream aquatic ecosystems.

A glasshouse trial was conducted to determine the effects of varying concentrations of Atrazine and Diuron on the growth of Vetiver in a simulated wetland environment. Sixty-four to 65 days after planting, the Vetiver plants were exposed to either Atrazine or Diuron at concentrations of 0, 20, 200, or 2,000 μg/L in the free water. Effects on growth were measured for 28–30 days after herbicide application. Growth parameters measured included water use, cumulative leaf area, chlorophyll fluorescence, and whole plant dry weight at harvest.

Results showed that growth of Vetiver was not adversely affected by application of Atrazine or Diuron at rates up to 2,000 μg/L. By contrast, growth in *Phragmites australis* was significantly reduced at the highest rate of application of both herbicides. Not only does Vetiver establish and grow well under wetland conditions, it is also able to tolerate relatively high levels of Atrazine and Diuron (42).

3.10. Breaking Up of Agrochemicals

Wetlands have been recognized for their unique role in the natural landscape. The physical and chemical properties in the wetland environment allow the wetland trap and eliminate or enhance degradation of many agricultural and industrial pollutants. Wetland plants have adaptations, which allow them to tolerate and thrive in this low oxygen environment. These plant species have been shown to play an essential role in enhancing the degradation of Atrazine in the wetland environment.

Experimental results have shown that plots vegetated with iris and Vetiver species significantly reduced total Atrazine levels in the pot environment. The mechanisms responsible for the enhanced degradation have not been clearly identified. However, soils microorganisms 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 sequester a significant amount of Atrazine into its tissues. These results have identified Iris and Vetiver as two species that promote the degradation of Atrazine (43).

Recently, research conducted at the Laboratory for Environmental Biotechnology, Swiss Federal Institute of Technology Lausanne, Switzerland, has confirmed the Australian results that Vetiver is highly tolerant to elevated Atrazine under the hydroponic system. The Swiss research also found that roots were able to hyper accumulate Atrazine and Vetiver resistance toward Atrazine was best explained by conjugation in the leaves and sequestration in the roots. Vetiver oil was also found to concentrate Atrazine, with a comparable value of Atrazine partition into octanol (5).

3.11. Growth

Given adequate nitrogen and phosphorous, Vetiver is a very fast growing grass in most climatic conditions producing large biomass yields when compared to other grasses. Under favourable growing conditions such as high N, P, soil moisture levels in the soil and warmer weather, Vetiver can produce up to 33 T/ha of dry biomass every 3 months (37). This is particularly important in bioremedial applications such as phytoextraction and phytofiltration. Although Vetiver is not classed as a hyper-accumulator, the name given to plants that accumulate contaminants in their tissue at accelerated rates, it compensates by producing large biomass yields.

3.11.1. Root System

Vetiver has a very deep and massive root system that enables it to stabilize soils at varying degrees of slope. Typically, the shoot to root ratio of Vetiver is approximately between 1:1.2 and 1:1.8, which is illustrated by some specimens achieving 2 m-root depth within the first year of growth. Even in soil conditions high in salinity and acid sulphates, the root system can grow to over 1 m deep in the first year (44).

This growth will not occur in every instance of planting as it largely depends on the availability of moisture to the roots. In examples of hydroponics growth, or saturated soil, roots will not grow deeper than they require in search of moisture.

3.11.2. Shoots

Since Vetiver does not possess any runners or rhizomes, coupled with the presence of some nonfertile genotypes such as Monto, Vetiver spreads by what is known as tillering. This is the growth of new shoots, or tillers from the base of the plant giving the grass only limited lateral movement. Because of this tillering quality, Vetiver can be propagated by splitting up young plants into slips with each one containing around three to four tillers. When being buried, Vetiver will start rooting and shooting from the nodes, with this method of growth allows Vetiver to rise with rising soil levels in location where sediment build up can occur. The tillers simply grow begin to shoot at ground level.

3.12. Weed Potential

Vetiver is noninvasive, has no runners nor rhizomes, and only spreads by tillering (34). Although flowering under certain conditions, Monto Vetiver has been rigorously tested and proven to be completely sterile and has been approved for release by the Queensland Environmental Protection Agency. There are certain genotypes of Vetiver available throughout Australia, which do set fertile seeds, therefore should be avoided.

4. PHYTOREMEDIATION USING VETIVER

In Australia, Vetiver has been used successfully for the stabilization and rehabilitation and reclaiming of acid sulphate and trace metals contaminated soils and to stabilize mining overburden and highly saline, sodic, magnesic, and alkaline or acidic tailings of coal and gold mines (9, 45). Chen et al made a comparative study of the effects of chemical methods on the growth and uptake of trace elements by many plants including Vetiver grass and found this perennial grass having a greater ability to remove Cd, Pb, and Zn from soil, the values of Cd accumulation close to those of hyperaccumulator *Thlaspi caerulescens*. The authors discussed the effectiveness of phytoremediation with this grass with great biomass and concluded that ‘Vetiver Grass Technology, VGT, is an effective, low-cost, and environmentally friendly technology to clean Cd contaminated soils’. The authors suggested developing a genetically modified Vetiver grass incorporating genes of hyperaccumulator. In southern China, it was reported that enhanced trace metal extraction in field experiments using Vetiver grasses for re-vegetation of Pb/Zn mine tailing. VGT is emerging as an alternative technology for rehabilitation of degraded, saline, or trace metal contaminated soils, and for purification of water polluted with trace elements, agrochemicals, and industrial-effluent disposals (15).

Plants chosen for mine rehabilitation should also be poor translocators of metal contaminants to aboveground plant tissues that could be consumed by humans or animals. Additionally, the plants must grow quickly to establish ground cover, have dense rooting systems and canopies, and have relatively high transpiration rates to effectively dewater the soil (46). Another important phytoremedial property, particularly in plants that are not hyperaccumulators of contaminants such as heavy metals, is the ability to grow quickly producing large biomass. This enables them to accumulate large amounts of contaminants purely by volume as opposed to faster rate per plant mass. The most conspicuous characters of Vetiver grass include its fast growth, large biomass, strong root system, and medium to high level of metal tolerance; therefore, Vetiver grass is an important choice for stabilization of metal-contaminated soils (4).

On the issue of large biomass, an experimental trial showed that Vetiver could be particularly useful in phytoextraction applications. Although the metal contents in the shoots of *V. zizanioides* were significantly lower than three other grasses (hyper accumulators), the total amount of metals (Lead and Copper) accumulated in the shoots was the highest among the four plants tested, due to its highest biomass (15).

5. CASE STUDIES

5.1. Australia

5.1.1. Gold Mine

A series of glasshouse and field trials were carried out to determine the nutritional requirement of Vetiver grass during establishment phase on three types of gold mine wastes: oxide and barren waste materials, alkaline new tailings, and acidic old tailings on a goldmine in northern Australia. Results indicate that all waste and tailings materials are extremely low in N and P. Old tailings materials are extremely acidic and required high liming rate for satisfactory establishment, while fresh tailings only need N and P fertilisers.

When organic sources of N and P supply were compared, it was shown that there was little difference between organic N and P and chemical fertilizers on Vetiver growth. It was also established that As and Cd contents in Vetiver tops were very low; therefore, animals can safely graze Vetiver grown on theses tailings.

Barren and oxide waste materials: Chemical analyses of the materials show that both N and P levels are rather low particularly in the oxide material (Table 8.5).

Results showed that Vetiver can be readily established on both barren and oxide waste materials provided that DAP (Di-Ammonium Phosphate) at the level of at least 500 kg/ha was applied and adequate soil moisture is available (Table 8.6).

New gold tailings: Fresh gold tailings 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%) (Table 8.7). Vetiver established and grew very well on these tailings without fertilizers, but growth was improved by the application of 500 kg/ha of DAP (Table 8.8).

Table 8.5
Chemical analysis of overburden

Analyses	Barren	Oxide
pH	7.7	9.1
EC (mS/cm)	0.80	0.17
Cl (mg/kg)	77	37
NO_3-N (mg/kg)	13	3
P (mg/kg)	36	8
SO_4-S (mg/kg)	610	9
Ca (meq 100 g^{t1})	16	10
Mg (meq/100 g)	1.4	7.1
Na (meq/100 g)	0.33	1.50
K (meq/100 g)	0.47	0.14
Cu (mg/kg)	4.10	0.87
Zn (mg/kg)	20.00	0.53
Mn (mg/kg)	9.6	5.0

Table 8.6
Vetiver grass dry matter yield after 10 weeks grown on overburden

Fertiliser (DAP kg/ha)	Barren (g/pot)	Oxide (g/pot)
0	14.17	13.89 a
100	13.45	12.82 a
200	12.44	14.59 a
300	16.64	13.82 a
500	14.00	20.16 b
L.S.D 5%	Not significant	Significant difference between a and b

The above results indicate that Vetiver can be established readily on fresh tailings when adequately supplied with N and P fertilizers and water. Therefore when established at appropriate intervals, Vetiver hedges could provide effective wind barrier for dust control on fresh tailing dams. Vetiver was used on a large-scale application to control dust storm and wind erosion on a 300 ha tailings dam. When dry the finely ground tailings material can be easily blown away by wind storms if not protected by a surface cover (Fig. 8.5). As gold tailings are often contaminated with heavy metals, wind erosion control is a very important factor in stopping the contamination of the surrounding environment. The usual method of wind erosion control in Australia is by establishing a vegetative cover, but due to the highly hostile nature of the tailings, revegetation is very difficult and often failed when native species are used. The short-term solution to the problem is to plant a cover crop such as millet or sorghum, but these species do not last very long. Vetiver can offer a long term solution by planting the rows

Table 8.7
Chemical analysis of new gold tailings

Analyses	New tailings
pH	7.8
EC (mS/cm)	0.88
Cl (mg/kg)	131
$NO_3 - N$ (mg/kg)	1
P (mg/kg)	7
$SO_4 - S$ (mg/kg)	830
Ca (meq/100 g)	12.5
Mg (meq/100 g)	0.84
Na (meq/100 g)	1.42
K (meq/100 g)	0.27
P (%)	0.042
K (%)	2.7
S (%)	1.59

Table 8.8
Vetiver grass dry matter yield after 10 weeks growth on new gold tailings

Fertiliser (DAP kg/ha)	New Tailings (g/pot)
0	16.79 a
100	13.70 a
200	15.20 a
300	12.43 a
500	17.60 b
L.S.D 5%	3.55 (significant difference between a and b)

at spacing of 10–20 m to reduce wind velocity and at the same time provide a less hostile environment (e.g. shading and moisture conservation) for local native species to established voluntarily later (Fig. 8.6).

Although excellent establishment was achieved, Vetiver growth varied greatly along the rows, ranging from very poor growth of between 0.2 and 0.3 m in height, to excellent growth of up to 1.5 m. As planting materials and fertilizer rate were similar, this difference in growth can be attributed to the variance in the amount of water supplied by the drip irrigation system. This was a result of the difficulty experienced in ensuring an even distribution over the entire 250 m length. However, the results clearly show that with adequate water and fertilizer supply, optimal Vetiver growth can be achieved with one wet season. It is expected that this poor growth would improve greatly during the coming wet season, if additional fertilizer applications were carried out before the wet season.

Fig. 8.5. Highly erodable gold mine tailings. A typical windstorm on a new gold mine tailings dam spreading fine particles loaded with heavy metals to the environment.

Fig. 8.6. Vetiver hedges minimizing wind erosion on gold tailings. A thick cover crop is commonly used to control this strong wind problem. But establishment of the cover crop is very difficult due to wind erosion. Vetiver planted in rows is the most effective and economical measure to protect the cover crop from wind erosion.

At its optimal growth, 1-year-old Vetiver hedge can form a very effective barrier to slow down wind velocity and control dust storms. The 1-year-old hedge is about 1.3 m high, and a very thick hedge was formed up to 0.8 m level. It is undoubted the hedge height and thickness will increase as the plants mature, providing a more effective barrier later. Although irrigation will not be needed in the future, further fertilizer applications, especially P at the rate of 500 kg/ha/year of DAP or equivalent, are recommended for the next 2–3 years to ensure the best growth in the future.

Fig. 8.7. Vetiver hedges providing protection from wind erosion. Vetiver hedges form a thick barrier protecting the cover crop from wind erosion.

Under the local conditions, 10 m spacing is probably too wide to be effective after 1-year growth. A closer spacing is needed but it is difficult to determine, as the hedges are not mature yet. However, for economical reasons, the application of Vetiver hedges system for dust control purpose should be combined with a ground cover crop, a pasture species such as Rhodes grass and green couch as demonstrated at this site. Therefore, the growth, height, and survival rate of the ground cover species will have to be taken into account to determine the most effective spacing of Vetiver hedges (Fig. 8.7).

When comparing with the wind barrier built on the same site, the main advantages of the Vetiver hedges are:

Low cost: Vetiver hedges would be much cheaper to establish than the fence barrier built with shade-cloth, geo-fabric, wire mesh, and star pickets.

Resistant to wind damage: once established, Vetiver hedges cannot be damaged by strong windstorms, and its tall growth will bend over and with its deep root system, Vetiver cannot be blown off. This is in sharp contrast to the steel reinforced barriers, which were damaged by strong wind.

Low maintenance: once established, Vetiver hedges do not require further maintenance except for the application of maintenance fertilizer once every few years.

Table 8.9
Acidity levels of old gold tailings

Surface conditions	Depth (cm)	pH	EC (mS/cm)	TAA (mole H + /T)	TPA (mole H + /T)
1. White powdery crust	0–5	3.1	14.5	1,063	1,590
2. Same as 1	5–10	3.0	5.2	262	726
3. Yellow hard crust	0–5	2.6	7.0	490	499
4. Coarse sandy	0–5	2.9	0.4	22	222

TAA total actual acidity, *TPA* total potential acidity.

Table 8.10
Heavy metal contents of representative gold mine tailings in Australia

Heavy metals	Total contents (mg/kg)	Threshold levels (mg/kg)
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.

The main disadvantages of the Vetiver hedges are:

Its slow growth in the first year,
The need for an effective irrigation system during the first 3–4 months

Old 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 and often very expensive and the bare soil surface is highly erodible (Table 8.9).

These tailings are often the source of contaminants, both above ground and underground to the local environment. Table 8.10 shows the heavy metal profile of gold mine tailings in Australia.

At these levels, some of these metals are toxic to plant growth and also exceed the environmental investigation thresholds (47) (Table 8.11).

Field trials conducted on two old (8 years) gold tailings sites; one is typified by a soft surface and the other with 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% and both sites were low in plant nutrients (Table 8.12) (Fig. 8.8).

Results from both sites indicated that when adequately supplied with nitrogen and phosphorus fertilizers (300 kg/ha of DAP) excellent growth of Vetiver was obtained on the soft top

Table 8.11
Investigation thresholds for contaminants in soils (47)

Heavy metals	Thresholds (mg/kg)	
	Environmental[a]	Health[a]
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	–

[a]Maximum levels permitted, above which investigations are required.

Table 8.12
Chemical analyses of an 8-year-old gold tailings

Analyses	Soft top	Hard top
pH	2.7	3.5
EC (mS/cm)	5.0	3.3
Cl (mg/kg)	5	19
$NO_3 - N$ (mg/kg)	Below quantifiable	Below quantifiable
P (mg/kg)	207	37
$SO_4 - S$ (mg/kg)	3,740	8,500
Ca (meq/100 g)	24	31
Mg (meq/100 g)	8.2	11.0
Na (meq/100 g)	0.02	0.01
K (meq/100 g)	0.01	0.02
Cu (mg/kg)	28	68
Zn (mg/kg)	237	198
Mn (mg/kg)	449	142
P (%)	0.059	0.078
K (%)	2.78	2.91
S (%)	1.31	3.75

site (pH = 3.6) without any liming. But the addition of 5 t/ha of agricultural lime significantly improved Vetiver growth. On the hard top site (pH = 2.7) although Vetiver survived without liming, the addition of lime (30 t/ha) and fertiliser (500 kg/ha of DAP) improved Vetiver growth greatly (Table 8.13) (Fig. 8.9).

Exchangeable arsenic in tailings and plant arsenic and cadmium: As the total Arsenic levels of old tailings were rather high (Table 8.14), and Vetiver growth did not achieve its full

Fig. 8.8. Vetiver trials on old gold mine tailings. This old gold mine tailings site had a pH of 3.8, high in As (590 mg/kg), Zn, Pb, and Mn. With adequate supply of fertilizers, good growth of Vetiver was noted 11 months after planting.

Table 8.13
Dry matter yield and nutrient contents (mean values of two nitrogen rates)

Liming rate (T/ha)	pH[a]	DM yield (g/pot)	Plant N (%)	Plant P (%)	Plant Mn (mg/kg)	Plant Zn (mg/kg)	Plant Cu (mg/kg)
Soft top							
0	3.60	0.20a	1.59	0.29	IS	IS	IS
5	5.00	5.15b	1.00	0.09	1150	91	5.2
10	6.40	6.72bc	0.99	0.09	1135	52	5.5
15	6.70	8.92c	0.91	0.10	930	52	4.8
LSD 5%		2.55					
Hard top							
0	2.70	0	–	–	–	–	–
5	2.90	0	–	–	–	–	–
15	3.90	0	–	–	–	–	–
30	5.50	3.31	0.95	0.11	430	32	4.9
40	6.40	3.05	0.68	0.07	445	96	4.0
50	7.00	3.40	0.73	0.07	455	95	3.8
60	7.30	4.60	0.78	0.08	410	54	3.0
LSD 5%		n.s.					

IS insufficient samples.
[a]Final pH at 11 weeks.

potential even at very high lime and phosphate rates, the effect of As on Vetiver growth was further investigated.

Table 8.15 shows that soluble Arsenic leached out from the hard top tailings is higher than from the soft-top tailings over the period of 5 weeks. These results support the total As shown in Table 8.14.

Fig. 8.9. Vetiver trials and old gold mine tailings. This old gold mine tailings site had a pH of 2.7, high in As (970 mg/kg), zinc, lead, and manganese. Very good growth was recorded 11 months after planting with adequate supply of lime (20 T/ha) and fertilizers.

Table 8.14
Total As and pH of soft top and hard top gold tailings

Tailings type	pH	As (mg/kg)	EC (mS/cm)
Soft top	3.59	590	2.78
Hard top	2.80	1,100	2.84

Table 8.15
Soluble As and pH levels in tailings under different lime treatments

Liming rate	pH	Soluble As (ppb of leachate)						Total AS leached (μg/kg)
		Week 1	Week 2	Week 3	Week 4	Week 5	Average	
Soft top (control)[a]	3.80	28.6	85.6	45.6	32.2	27.0	43.8	16.1
Soft top (20 T/ha)[a]	4.64	30.5	68.8	59.1	22.9	31.2	42.5	15.6
Hard top (control)[a]	3.09	91.6	287.6	186.2	99.4	34.3	139.82	39.1
Hard top (20 T/ha)[a]	2.73	406.8	587.0	424.9	184.2	55.70	331.72	214.1
Hard top (40 T/ha)[a]	4.62	231.7	116.7	146.3	NA	NA	164.9	49.5
Hard top (Control)[b]	2.96	120.1	81.2	111.7	248.8	153.5	143.06	62.0
Hard top (5 T/ha)[b]	4.89	34.1	19.2	88.8	100.5	53.6	59.24	32.6
Hard top (10 T/ha)[b]	8.10	25.1	35.8	58.7	59.6	36.9	43.22	15.4
Hard top (20 T/ha)[b]	7.98	45.15	115.7	154.3	282.4	223.9	164.29	61.2
Hard top (30 T/ha)[b]	8.10	36.28	155.1	155.2	220.1	93.5	132.03	75.9
Hard top (40 T/ha)[b]	8.14	27.2	178.5	206.4	220.1	88.9	144.22	77.8
Hard top (60 T/ha)[b]	8.08	35.9	155.2	184.1	166.0	88.2	125.88	46.8

NA not available.
[a]Field trial.
[b]Glasshouse experiment.

Table 8.16
Total exchangeable as affected by liming rates

Liming rate (T/ha)	Hard top from field trial		Hard top from glasshouse trial	
	pH	Total exch. As (mg)	pH	Total exch. As (μg)
Control	3.09	39.1	2.96	61.9
20	2.73	214.1	7.98	61.1
40	4.62	49.5	8.14	77.8

Table 8.17
As contents in Vetiver tops and roots as affected by liming rates

Tailings	Liming rate (T/ha)	Tailings As (mg/kg)	Total exch. As (μg)	Shoot As (mg/kg)	Root As (mg/kg)	Shoot As/total As (%)
Soft top	Control	590	16.1	4.5	96	4.5
	20	605	15.6	6.5	124	5.0
Hard top	Control	1100	39.1	9.6	185	4.9
	20	844	214.1	10.4	228	4.4
	40	620	49.5	11.2	268	4.5
Average						4.6

Table 8.18
Cadmium levels in tops and roots of Vetiver as affected by different liming rates

Tailings	Liming rate (T/ha)	Tailing pH	Tops Cd (mg/kg)	Roots Cd (mg/kg)	Tops Cd/total Cd (%)
Soft top	Control	3.80	0.31	14.20	0.9
	20	4.64	0.58	8.32	2.0
Hard top	20	2.73	0.13	13.60	2.1
	40	4.62	0.16	7.77	6.5
Average					2.9

These results also indicate that although liming had a strong effect on soil pH, it had little effect on the level of exchangeable As (Table 8.16)

The As contents in shoot and root of Vetiver plants collected from the field trial sites are presented in Table 8.17. These results indicate that very little As was absorbed by Vetiver plants and liming again had little effect on the amount absorbed. These results confirmed earlier finding that on the average only 4.6% of the amount of As absorbed was translocated to the tops, the majority was retained in the roots (95.4%).

Similar to As content, Cd contents in shoot and root of Vetiver are not greatly affected by liming rates and pH level. Again, most of the Cd absorbed was retained in the roots (97.1%), only 2.9% was translocated to the tops (Table 8.18).

Table 8.19
Chemical analyses of the coal mine overburden in Central Queensland

Soil pH (1:5)	9.6	Calcium (mg/kg)	1,200
EC dS/m	0.36	Magnesium (mg/kg)	2,400
Chloride mg/kg	256	Sodium (mg/kg)	2,760
Nitrate mg/kg	1.3	Potassium (mg/kg)	168
Phosphate mg/kg	13	ESP (%)	33
Sulphate mg/kg	6.1		

ESP exchangeable Na percentage (Na % of total cations).

From the above results, it is quite evident that liming did not greatly affect exchange As in the tailings and also both As and Cd in the Vetiver plants. The distribution of As and Cd in Vetiver tops and roots are quite similar. The majority of the absorbed heavy metals were retained in the roots. In the case of As, only 4.6% was translocated to the tops and only 2.6% for Cd. At these levels, animals can safely graze Vetiver.

In addition, the As contents in Vetiver tops (between 4.5 and 11.2 mg/kg) are well below the As toxic threshold level shown in Table 8.3 (between 21 and 72 mg/kg). Similarly, the Cd contents of Vetiver top (between 0.13 and 0.58 mg/kg) are also well below the toxic threshold level of between 45 and 48 mg/kg shown in Table 8.3. These results clearly indicate that Vetiver, grown on both hard top and soft top tailings, was not affected by either As or Cd toxicities.

5.1.2. Coal Mine

Coal mine overburden: The overburden of open cut coalmine in Central Queensland is generally highly erodible. These soils are usually sodic and alkaline (Table 8.19). Vetiver has established and stabilized successfully the spoil dump with 20% slopes and promoted the establishment of other sown and native pasture species (Figs. 8.10 and 8.11).

Coal mine tailings: In an attempt to rehabilitate an old coalmine tailings dam, (surface area of 23 ha and capacity of 3.5 million cubic metres) a trial was set up to select the most suitable species for the rehabilitation of this site. The substrate was saline, highly sodic, and extremely low in nitrogen and phosphorus. The substrate contained high levels of soluble sulphur, magnesium, and calcium. Plant available copper, zinc, magnesium, and iron were also high. Five salt tolerant species were used: Vetiver, marine couch (*Sporobolus virginicus*), common reed grass (*Phragmites australis*), cumbungi (*Typha domingensis*), and Sarcocornia spp. Complete mortality was recorded after 210 days for all species except Vetiver and marine couch. Mulching significantly increased Vetiver survival, but fertilizer application by itself had no effect. Mulching and fertilizers together increased growth of Vetiver by 2 t/ha, which was almost ten times higher than that of marine couch (48) (Fig. 8.12).

5.1.3. Bentonite Mine

One of the major ecological concerns for Bentonite Mine is the effect of run-off water from disturbed areas to surrounding catchments, particularly with sediment being the principal transport mechanism for a range of pollutants entering watercourses. The site is one of the

Fig. 8.10. Highly erodable coal mine overburden. This stockpile of coalmine overburden with 40° slope is highly erodible. It is saline and sodic and remained mostly bare of vegetation in the last 30 years.

Fig. 8.11. Vetiver applications on coal mine overburden. Vetiver was planted in the gullies to stop further erosion and to encourage the re-establishment of native species. Excellent growth was obtained 6 months later.

Fig. 8.12. Vetiver and marine couch trials on coal tailings dam. Vetiver grass was one of the only two survivors on this coal tailings dam, which is highly saline, sodic, and high in heavy metals. Vetiver biomass was about ten times greater than marine couch.

major disturbed areas on this mine. This consisted of two hectares that has been modified and levelled to provide a support base for stockpiling and solar drying of sodium Bentonite. The entire area required vegetation coverage to protect the soil from erosion. Due to the high sodium content, limited water holding capacity, and low nutritional value of the bentonite waste material, vegetation required for rehabilitation of this site has to be a specifically resilient species.

The natural topsoil of the region is predominantly a shallow, texture contrast soil (Podzolic) with a hard setting sandy loam surface. However, the trial zone has been modified and leveled to suit drying and stockpiling of Bentonite through the use of strongly sodic and semi-impermeable overburden. It is strongly sodic with Exchangeable Sodium Percentage (ESP) as high as 48%, highly dispersive (Montmorillonite clay) and susceptible to erosion if proper conservation practices are not applied. The occurrence of tunnel erosion had initiated in the north-east corner of the trial zone prior to Vetiver planting. The soil contains very low levels of major nutrients, this combines with its extreme reflective nature provides an environment hostile to germinating seedlings, but it is capable of hosting established specimens (Table 8.20).

On the site several rows of Vetiver were planted on contour line. The rows were carefully surveyed to ensure that the rows are levelled with zero fall at either ends to provide a water spreading mechanism. It was envisaged that this method would slow the flow of water, control against surface erosion, and aid in the building of a seed bank along the excess drying area (Fig. 8.13).

The following results were observed 10 months after planting:

Mulching of the areas had encouraged extensive shoot growth, with an average of 3 cm/week over the first 3 weeks. The mulched areas appear to be tolerable to high temperature and other weather changes.

Table 8.20
Chemical analyses of the soil at the trial site

Analyses	Overburden	Bentonite waste
pH	5.4	5.4
EC (dS/m)	0.18	0.14
Cl (mg/kg)	135.0	47.4
NO_3-N (mg/kg)	1.9	0.7
P (mg/kg)	2.0	5.0
SO_4-S (mg/kg)	66.0	101.0
Ca (meq/100 g)	0.19	0.93
Mg (meq/100 g)	4.75	6.44
Na (meq/100 g)	2.7	7.19
K (meq/100 g)	0.16	0.43
Organic matter (%)	0.45	0.35
ECEC (meq/100 g)	8	15
ESP (%)	35	48

Fig. 8.13. Vetiver hedge applications at bentonite mine. Vetiver grass planted on this highly sodic bentonite waste dump to control wind and water erosion, and to promote the establishment of other endemic plants.

Heavy rain had inundated the Vetiver rows, with some plants being submerged for 2.5 weeks. After the water had evaporated, the plants still appeared to be in healthy condition with general height retained; they did not appear to have any growth whilst the soil was water logged.

Runoff water samples were collected and their sediment content was measured by the rate of flow through a 2 mm sieve. Water samples were taken at positions upstream and downstream of the Vetiver hedges during peak flow and compared to those of distilled water. Results in Table 8.21 indicate that the Vetiver hedges trapped almost 100% of solids from clay contaminated storm water.

Table 8.21
Time taken for 300 mL of water to pass through a 2 mm sieve

Water samples	Time
Upstream from row	20.54 s
Downstream from row	11.76 s
Distilled water	11.20 s

Fig. 8.14. Established Vetiver hedge at bentonite mine. Fourteen months after planting, note the establishment of native grasses along the Vetiver hedges.

The amount of sediment trapped by the hedges varied with the conditions of the hedges. When the hedges were complete (with no gaps), up to 200 mm deep of sediment was trapped, with the sediment texture being greatly made up of sand and clay and less than 5% silt.

Random test holes show that the root systems have progressed quite substantially, with positive identification down to 500 mm. The hedges have encouraged 100% soil saturation within a 3.4 m arc along the rows; this has encouraged cracking of the clay to 220 mm (depth) and 30 mm (width). Surface cracking had appeared prior to row planting only to a depth of 30 mm.

Areas with extended growth from the use of fertigation techniques were found to be extremely palatable to cattle and were constantly chewed down to more than 150 mm.

Vetiver has flourished under the harsh conditions of the trial zone including an air temperature range of -3 to 42°C, wet extremes of 1 in 10 year rainfall event and prolonged dry periods. Growth height has averaged 600 mm, and plant base diameter is an average of 100 mm after 10 months (Fig. 8.14).

The grass has formed a semi-impermeable hedge which is slowing the flow velocity of the water, allowing minor rills to fill with sediment and altering the volume of water meeting the storm drain at any one time (time of concentration). Areas where a perfect level was not achieved, some erosion occurred because of the concentrated flow of water; this has now been rectified through placing a concave row at the end of the hedge. The sediment trapped by the Vetiver rows has played host to several annual and perennial species. These species are currently only found on the southern side of the hedges within 1 m from the actual rows.

With the aims of determining the ability of Vetiver grass hedges to establish on extremely sodic soils, the effect of the hedges in spreading concentrated flows, in trapping sediment over major flow areas to provide a support mechanism for other plant growth and in reducing signs of visible erosion.

Current results have indicated that the Vetiver will establish satisfactory on sodic soils when adequately supplied with fertilizers and water. The use of mulches to 100 mm deep will provide a constant growing temperature for the plant roots allowing for a continual growth.

Vetiver Grass Technology (VGT) has achieved all the aims by effectively spreading concentrated flows of water and trapping sediment, providing favourable conditions for the establishment of other species. This process has also reduced the visible signs of erosion.

5.1.4. Bauxite Residue or Alumina Redmud

Bauxite residue is commonly extremely high in alkalinity, sodicity, and salinity as shown in Table 8.22.

These high levels of alkalinity and sodicity were resulted mainly from the addition of sodium hydroxide to the ore processing treatment. The hydroxide ion per se is not toxic to plant growth, but it can interfere with the availability of other plant nutrients such as phosphorus. Na per se is not toxic to plant growth, but it can interfere with the availability of other nutrients. Therefore, the addition of Ca and Mg (dolomite) may be needed to reduce ESP level, and a relatively high level of P application such as super phosphate will be needed. Literature shows that Vetiver can tolerate this level of alkalinity provided P and N are adequately supplied.

The salinity levels of the two samples are extremely high. However, this high salinity could not be attributed to sodium chloride (NaCl) as the chloride levels in both samples are not

Table 8.22
Analytical results of residues from redmud ponds

Analyses	Units	Residue textures	
		Cloddy	Sandy
pH		10.90	10.20
EC	dS/m	9.26	13.32
Cl	mg/kg	258.00	591.00
NO_3-N	mg/kg	BQ	BQ
P	mg/kg	38.00	28.00
Ca	meq/100 g	4.50	1.80
Mg	meq/100 g	0.14	0.19
Na	meq/100 g	1,900.00	2,600.00
K	meq/100 g	0.21	0.20

BQ below quantification.

extremely high (high level of Cl is toxic to plant growth); the high salinity recorded was most likely due to NaOH rather than NaCl. Therefore, plant establishment can be achieved on these tailings when adequately supplied with essential nutrients.

A simple glasshouse trial was conducted with the following treatments:

Control: a mixture of cloddy and sandy residues
Fertilizer treatment: complete NPK and S fertilizer
Fertilizer, dolomite, and low level of sulphuric acid: dolomite was used to supply Ca and Mg to counterbalance the high Na level and sulphuric acid to reduce alkalinity.
Fertilizer and high level sulphuric acid: to further reduce the acidity level

First symptoms of dieback appeared 3 days after planting, leaves became pale green, then yellowish and eventually completely bleached and dry up. Within 10 days after planting most plants were dead in treatment 1 and 2. Soil pH taken after this test showed that pH level of the red mud remained very high at 10.5 in the first two treatments; the acid addition reduced the pH to 8.0 for treatment 3 and 7.6 for treatment 4.

Results at 5 weeks after planting are very encouraging in that although plants in both treatments 3 and 4 suffered initial dieback of leaf tips and young shoots, and growth resumed after 2 weeks in both treatments. It was noted that more young shoots emerged in the dolomite treatment and more growth on older leaves in the acid treatment, with one leaf growing 310 mm in 3 weeks. It observed that the dolomite treatment, although with higher pH (8.0) producing similar growth to the high acid treatment with pH 7.6.

5.1.5. Landfill Rehabilitation and Leachate Treatment

As Vetiver grass has a very high water use and nutrient uptake rates, and it is tolerant to elevated levels of heavy metals and other adverse conditions such as salinity, sodicity, high nutrient load, it is best suited for landfill rehabilitation and leachate disposal. The following case study will illustrate its effectiveness.

Stotts Creek Landfill is a major waste depot of the Tweed Shire receiving wastes from both Tweed Heads and Murwillumbah townships and neighbouring local government areas in northern New South Wales. Disposal of leachate is a major concern of the Shire as the landfill site is close to agricultural areas. An effective and low cost leachate disposal system is needed, particularly during summer high rainfall season.

Leachate quality at Stotts Creek Landfill is low in heavy metals but relatively high in salts and nutrients (Table 8.23).

Currently, leachate and runoff from the landfill site are stored in ponds at the foot of the mound. During dry periods, the leachate is irrigated onto the top of the completed waste mound, where it evaporates or transpires into the atmosphere. During heavy rainfall, the leachate overflows into a system of wetlands and then to a local creek. Following capping and topsoiling, Vetiver has been planted on the surface of the completed waste mound and irrigated with leachate from collecting ponds. So far an area of 6 ha has been planted with Vetiver (Fig. 8.15).

As soon as an area was planted, it was irrigated with leachate by overhead spray irrigation, and almost 100% establishment was achieved. Results to date has been excellent, within

Table 8.23
Long term average levels of pollutants in Stotts Creek leachate

Tests	Units	Levels (ranges)
pH	–	7.2–9.3
Conductivity	μS/cm	199–11,150
Alkalinity (as $CaCO_3$)	mg/L	256–1,262
Redox potential	mv	−86 to +144
Dissolved oxygen	mg/L	0.2–30
Nitrate	mg/L	<0.01−10.5
Nitrite	mg/L	1.4–5.9
Ammonia	mg/L	0.01–410
Total N	mg/L	31.8–48.1
Total phosphorus	mg/L	0.04–3.5
Chloride	mg/L	215–1,700
Fluoride	mg/L	0.2–1.1
Sodium	mg/L	153–2,680
Calcium	mg/L	<1−658
Potassium	mg/L	78–1,650
Magnesium	mg/L	20–96
Sulphate	mg/L	3.8–134
BOD_5	mg/L	<2−640
Total suspended solids	mg/L	6–3,243
Total organic carbon	mg/L	43–1,440
Aluminium	mg/L	<0.1−1.0
Arsenic	mg/L	<0.01−0.12
Boron	mg/L	0.5–2.1
Cadmium	mg/L	<0.01−0.03
Copper	mg/L	<0.01−0.06
Chromium	mg/L	0.01–0.34
Iron	mg/L	0.09–7.0
Lead	mg/L	<0.01−0.03
Manganese	mg/L	0.01–1.74
Mercury	mg/L	<0.0001−0.001
Zinc	mg/L	<0.1−0.4

18 months, Vetiver growth had reached almost 3 m in height and have successfully disposed off all the leachate produced at this landfill (49).

5.1.6. Domestic Wastewater Treatment

The Esk Shire Council has recently installed a Vetiver Grass Wetlands System to treat sewerage effluent at Toogoolawah in South East Queensland. The sewerage treatment plant is situated on a 22-ha site on the northern edge of town. The aim of this scheme was to improve water quality before the effluent discharges to the natural wetlands. The biggest problem with

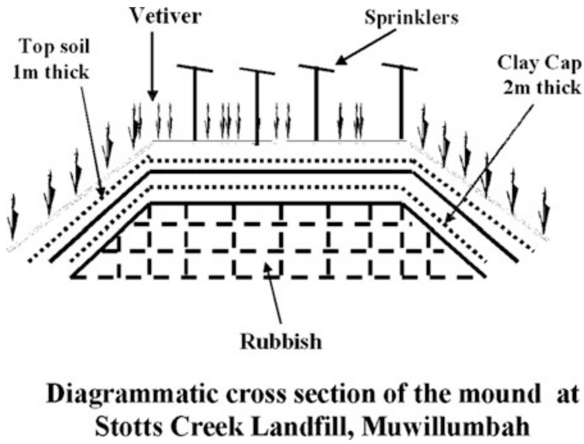

Fig. 8.15. Cross section of the Stotts Creek Landfill Cell.

the quality of the effluent is its high nutrient loading. With the recent changes to license conditions imposed by the Environmental Protection Agency, the existing treatment plant no longer complies with the license and an upgrade of the plant was required.

Instead of traditional upgrades, a new and innovative phyto-remedial technology recently developed in Queensland by the Department of Natural Resources and Mines, is being implemented at Toogoolawah. Under the Vetiver Wetlands System, the effluent is being treated in two stages:

- Preliminary treatment of the pond effluent *in situ* by floating pontoons placed in the ponds, and by Vetiver planting around the edges of the three sewerage ponds.
- Main treatment by Vetiver wetlands, once the effluent exits the sewerage ponds it passes through a Vetiver Grass contoured wetlands constructed over 3 ha of the land. The Vetiver Grass wetlands have been constructed in rows following the contours to allow good contact between the grass and the effluent. The Vetiver Grass takes up the water and in particular, the grass will remove the nutrients from the water that passes through it.

Vetiver grass pontoons: Results of a preliminary trial conducted on site with the first three pontoons show that Vetiver established and flourished (up to 1.5 m in 3 months) under hydroponics conditions. These pontoons have been removed and the grass harvested to produce about five new tillers of grass from each original tiller placed on the pontoons. The pontoons have now become the source of Vetiver grass for the project. Vigorous growth has been seen in the Vetiver grass plants that were placed onto the 21 new pontoons.

Growth on the pond edges: Planting Vetiver just above the pond supply level is the second part of the plan to pretreat the effluent in the ponds. At this position, the extensive Vetiver root has full access to the high nutrient load of the pond effluent.

Growth in the ephemeral wetlands: For the wetlands, the growth of the Vetiver grass has been varied for the first 3 months. Where the grass was able to dry out between watering, the growth was good. The growth was poor in places where the water laid around the grass. Growth was much reduced during winter and frost only burnt some of leaf tips of young

Table 8.24
Effluent quality before and after Vetiver treatment

Tests	Plant influent	Previous results 2002/03	New results (effluent) 2004
pH (6.5–8.5)[a]	7.3–8.0	9.0–10.0	7.6–9.2
Dissolved oxygen (2.0 minimum)[a]	0–2 mg/L	12.5–20 mg/L	8.1–9.2 mg/L
5 day BOD (20–40 mg/L max)[a]	130–300 mg/L	29–70 mg/L	7–11 mg/L
Suspended solids (30–60 mg/L max)[a]	200–500 mg/L	45–140 mg/L	11–16 mg/L
Total nitrogen (6.0 mg/L max)[a]	30–80 mg/L	13–20 mg/L	4.1–5.7 mg/L
Total phosphorous (3.0 mg/L max)[a]	10–20 mg/L	4.6–8.8 mg/L	1.4–3.3 mg/L

[a]Licence requirements (N and P levels are possible future requirements).

plants. Good growth resumed in spring and continued to grow vigorously in early summer. Ten months after planting, most plants were at least 1.5 m tall.

Irrigation schedule: In the early stage, best Vetiver growth is obtained when the wetland is irrigated on a 4-day cycle, one wet day, and three dry days. When the plants are fully mature and more Vetiver grass is planted in the bay, it is expected that a 2-day cycle will be possible.

Water quality: Even at this early stage, there is already evidence that the quality of the effluent is improving in respect to nutrient loads. The total Phosphorous level for the plant influent varies between 10 and 20 mg/L and the effluent results have dropped to between 1 and 3 mg/L. Similarly, the total N influent results are 30–80 mg/L, and the effluent results are now 4–6 mg/L. Table 8.24 show that the levels of nutrient in the effluent after passing through the Vetiver treatment were well within the EPA guidelines.

It is expected that it will take a further 12 months of growth before the wetland grass is properly established. However, the results so far already show that the Vetiver Grass wetlands can improve the effluent quality to the same quality as a high tech BNR sewerage treatment plant.

Conclusion: As Vetiver Grass system is very effective in removing nutrient loads, results to date has been excellent, within 18 months, Vetiver growth had reached over 2 m in height and have successfully disposed off all the sewerage effluent from the treatment plant except in times of heavy rainfall.

The Vetiver Grass wetland has already shown itself to be a suitable alternative to more expensive solutions to upgrade existing sewerage treatment plants. A high technology solution is not necessarily the best available option.

This scheme will provide a large-scale prototype of possible sewerage treatment schemes that can be used throughout western Queensland and other locations, where there is plenty of land and where the local government does not want to pay for installing and operating high cost solutions (50).

5.1.7. Industrial Wastewater Treatment

The disposal of industrial wastewater in Queensland, Australia is subjected to the strict environmental guidelines enforced by the Environmental Protection Authority. The most common method of treating industrial wastewater in Queensland is by land irrigation, which is presently based on tropical and subtropical pasture plants. However, with limited land area available for irrigation, these plants are not efficient enough to sustainably dispose of all the effluent produced by the industries. Therefore, to comply with the new standards, most industries are now under strong pressure to upgrade their treatment processes.

The conventional solutions such as chemical treatment plant and transportation to sewage treatment plant were considered, but both of which are impractical and, most importantly, very costly to build and to operate. Therefore, a more innovative and natural solution was needed.

The GELITA factory extracts gelatine from cattle hide using chemical processes involving strong acids, lime, and hydroxides. Tree planting was one of the earlier options considered, it has been trialled for several years but has not provided an effective solution to the problems faced by the company. Preliminary findings have established that an estimated 16.5kg/ha/year dry matter yield of pasture will result in an N export of 458 kg/ha/year from between tree rows if an assumed N level of 2.9% occurs.

Due to the limit of the land area, TEYS Bros abattoir in Beenleigh, Queensland, which processes in the order of 210,000 cattle per year for both domestic consumption and export. TEYS Bros abattoir will pipe excess effluent output to the Logan City Council for treatment. The cost of treating this effluent is based on both quantity and quality of the effluent.

Over the past 2 years, a series of research projects conducted at GELITA and Teys Bros. abattoir in Beenleigh to determine a viable means to achieve these goals. The Vetiver System has been identified as having the potential to meet all the criteria:

- Vetiver has the potential of producing up to 132 kg/ha/year of dry matter yield as compared to 23 and 20 kg/ha/year for Kikuyu and Rhodes grass respectively (Fig. 8.16).
- With this production, Vetiver planting has the potential of exporting up to 1,920 kg/ha/year of N and 198 kg/ha/year of P as compared to 687 of N and 77 kg/ha/year of P for Kikuyu and 399 of N and 26 of P for Rhodes grass respectively (Fig. 8.17).

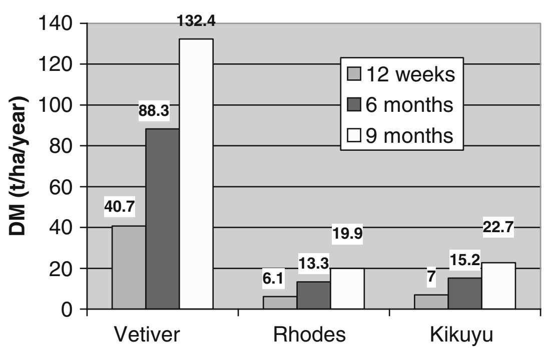

Fig. 8.16. Potential dry matter yield of the three grasses over time.

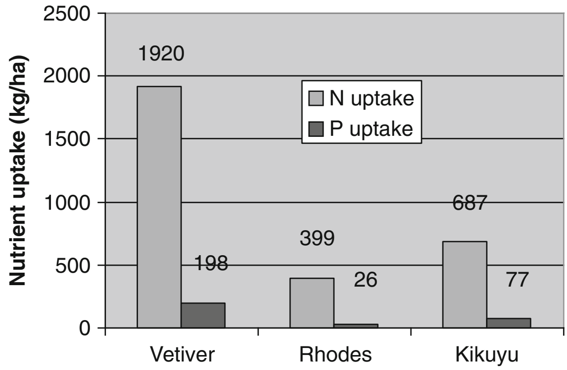

Fig. 8.17. Potential N and P uptakes by the three grasses over 9-month period.

Table 8.25
Effectiveness of Vetiver planting on quality of effluent seepage

Analytes	Nutrient levels		
	Inlet	Mean levels in monitoring bores	
		20 m down slope from inlet	50 m down slope from inlet
pH	8.0	6.5	6.3
EC (μS/cm)	2,200	1,500	1,600
Total Kjel. N (mg/L)	170	11.0	10.0
Total N (mg/L)	170	17.5	10.6
Total P (mg/L)	32	3.4	1.5

- Vetiver growth can respond positively to N supply up to 6,000 kg/ha/year, and to ensure this extraordinary growth and N uptake, P supply level should be at 250 kg/ha/year (Table 8.25).
- Based on the above results, the two companies have developed long term implementation plans for effluent and other solid waste product disposal (51).

5.2. China

It is well known that metalliferous mining activities produce a large quantity of waste materials, such as tailings and wastewater such as acid mine drainage (AMD) which is of major environmental concern due to potential hazards of surface or groundwater pollution. They contain excessively high concentrations of heavy metals and therefore result in severe pollution problems and lots of land degradation.

The first mine using Vetiver in Guangdong was the Lechang Pb/Zn mine located in the north of the province, where the first experiment comparing growth and performance of Vetiver and three other grasses, Bahia (*Paspalum notatum*), Bermuda (*Cynodon dactylon*), *Imperata cylindrica*, in the mine tailings was carried out. The result indicates that the height and biomass of Vetiver are significantly greater than those of the other three grasses; moreover, the growth performance of Vetiver is the best among the four species. Thereafter, a pot experiment showed that Vetiver has strong uptake ability to two heavy metals, Pb and Zn, stronger than Bahia; but it is inferior to Bahia with regard to uptake of Cu. In addition, Vetiver roots had a larger retention capacity to heavy metals than Bahia roots, inferring that Vetiver keeps relatively more amounts of heavy metals in its roots than Bahia (4).

To rehabilitate the degraded ecosystem of a shale oil waste dump of Maoming Petro-Chemical Company located in Southwest of Guangdong Province, Vetiver, Bahia grass (*Paspalum notatum*), St. Augustine grass (*Stenotaphrum secundatum*), and Bana grass (*Pennisetum glaucum* × *P. purpureum*) were used. Among them, Vetiver had the highest survival rate, up to 98.6%, followed by Bahia and St. Augustine, 96.5 and 90.9% respectively, whereas Bana has the lowest survival rate of 61.7%. The coverage and biomass of Vetiver were also the highest 6-month after planting. Fertilizer application significantly increased biomass and tiller number of the four grasses, of which St. Augustine was most pronounced, up to 70.1%, while Vetiver was least pronounced, only 27.4%. Two heavy metals, lead and cadmium tested in this trial had different concentrations in the oil shale residue, and also had different contents and distributions in the four grass species. Concentrations of Pb and Cd in the four grasses presented a disparity of only 1.6–3.8 times, but their uptake amounts to the two metals were apart up to 16–35 times, which was chiefly due to the significantly different biomasses among them. In summary, Vetiver may be the best species used for vegetation rehabilitation in oil shale disposal piles (4).

5.3. South Africa

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. Vetiver grew vigorously on the alkaline kimberlite; containing run off, arresting erosion, and creating an ideal microhabitat for the establishment of indigenous grass species. Rehabilitation using Vetiver was particularly successful on kimberlite fines at Cullinan mine where slopes of 35° are being upheld. It is clear that Vetiver is likely to play an increasingly important role in rehabilitation and, as a result of this; nurseries are being established at several mines (52).

At Premier (800 mm annual rainfall) and Koffiefontein (300 mm rainfall) diamond mines where surface temperature of the black kimberlite often exceeds 55°C, at this temperature most seeds are unable to germinate. Vetiver planted at 2 m VI (Vertical Interval) provided shades that cool the surface and allowing germination of other grass seeds.

Vetiver has also been used successfully in the rehabilitation of slimes dams at the Anglo American platinum mine at Rastenburg and the Velkom, President Brand gold mine.

6. RECENT RESEARCH IN HEAVY METAL PHYTOREMEDIATION USING VETIVER

A small scale trial was undertaken in 2004 at the Environmental Engineering Department, Queensland University of Technology to reconfirm earlier findings and to ascertain the capability of Vetiver to provide a practical solution to remove heavy metals in contaminated soils

Table 8.26
Trial concentrations As compared with previously determined toxicity thresholds

Contaminant	Trial concentration (mg/kg)	Toxicity thresholds (mg/kg)	Qld EPA exposure setting (Table 9.1 of contaminated land guidelines)
Copper	50 and 100	Up to 100	A
Chromium	25 and 50	Up to 600	Environmental investigation
Lead	150 and 300	Up to 800	A
Zinc	100 and 200	Up to 180	Environmental investigation

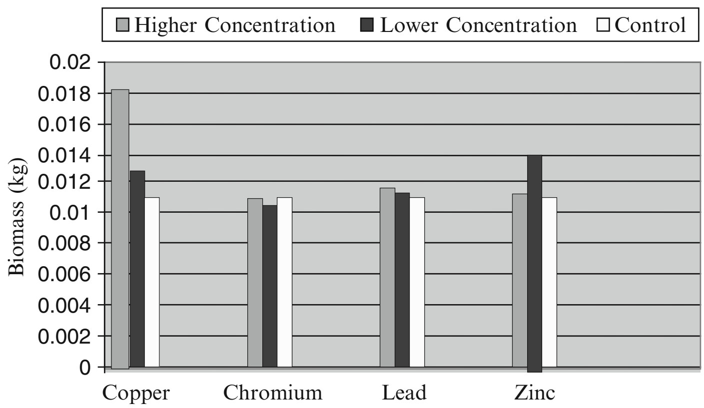

Fig. 8.18. Comparisons of dry biomass yields between Vetiver grown in contaminated soils.

in agricultural land, landfills and industrial sites and to comply with the standards, shown in Table 9.1 of the of the Department of Environment Draft Guidelines for the Assessment and Management of Contaminated Land in Queensland (53).

Remediation capability of Vetiver on Cu, Cr, Pb, and Zn was tested under the concentrations outlined in Table 8.26. These concentrations were chosen to relate back to the environmental and health-based thresholds described in Table 9.1, referred in Table 8.26.

The soil was supplied with 3,000 kg/ha/year of Nitrogen (Ammonium Nitrate) and 500 kg/ha/year of Phosphorous (Potassium di-Phosphate). Previous research indicated that under average growing conditions, Vetiver developed best at these levels of N and P.

6.1. Growth

During this trial, Vetiver achieved growth at the same level as control plants in terms of dry biomass for all heavy metal treatments. The average growth yields in dry biomass are summarized graphically in Fig. 8.18.

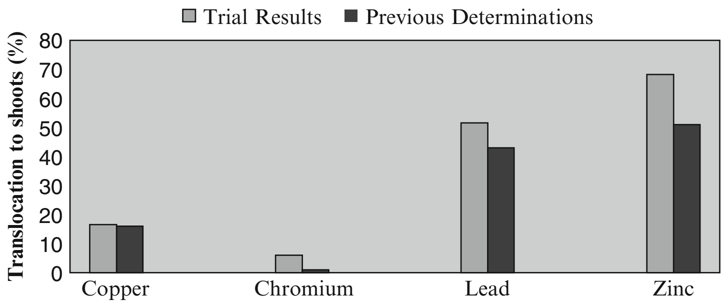

Fig. 8.19. Comparisons between shoot translocation results and previously recorded levels. Translocation: shoot content/total uptake (shoot + root content).

6.2. Results

On the whole, results obtained from this trial confirmed earlier findings that

Vetiver growth was not affected when exposed to Copper, Chromium, Lead, and Zinc at concentrations below previously determined toxic thresholds of these heavy metals.

Although the results indicated that there may be a case for Vetiver being able to translocate higher percentages than previously determined, but it must be noted that this trial had a smaller number of samples. Therefore, in the broader translocation relationship, these results supported previous research findings (see Fig. 8.19). That is

- Minimal translocation of Chromium
- Moderate translocation of Copper and
- Fairly even distribution of Lead and Zinc throughout the root and shoot

This information reconfirms the quality of Vetiver in terms of animal grazing suitability. It can be said that when using Vetiver for the rehabilitation of sites contaminated with Chromium only, the land could be used for grazing animals or use as feedstock or mulch; however, for contaminated land containing Copper, Lead, and Zinc, this application will be limited to animals' thresholds to the individual contaminants.

In addition to the above findings, this trial also showed that:

Plant tissue concentration: Vetiver growth did not appear to be affected by uptake of all contaminants at higher levels within the plant tissue than previously determined, in particular Lead concentrations for up to 360 mg/kg and Zinc at concentrations of up to 3,500 mg/kg within the plant tissue as compared with 78 and 880 mg/kg respectively as outlined in Table 8.27.

Leaching potential of harvested shoots: Shoot tissue samples of Vetiver that were exposed to Zinc at both 100 and 200 mg/kg were found to contain significantly high heavy metal concentrations (2,280 and 3,530 mg/kg respectively) and were subsequently returned to the laboratory for TCLP testing. This was to determine the suitability of disposing the shoots for further use as mulch at landfills. The results of this testing indicates the following:

It can be seen in Fig. 8.20 that the Vetiver shoots containing up to 3,530 mg/kg of Zn only leach approximately 20 and 2% of the allowable limit for unlined and lined landfills

Table 8.27
Threshold levels of Vetiver for heavy metals trialled (30, 31)

Heavy metals	Threshold to Vetiver growth (mg/kg)	
	Soil	Plant tissue
Copper	50–100	13–15
Chromium	200–600	5–18
Lead	>1,500	>78
Zinc	>750	880

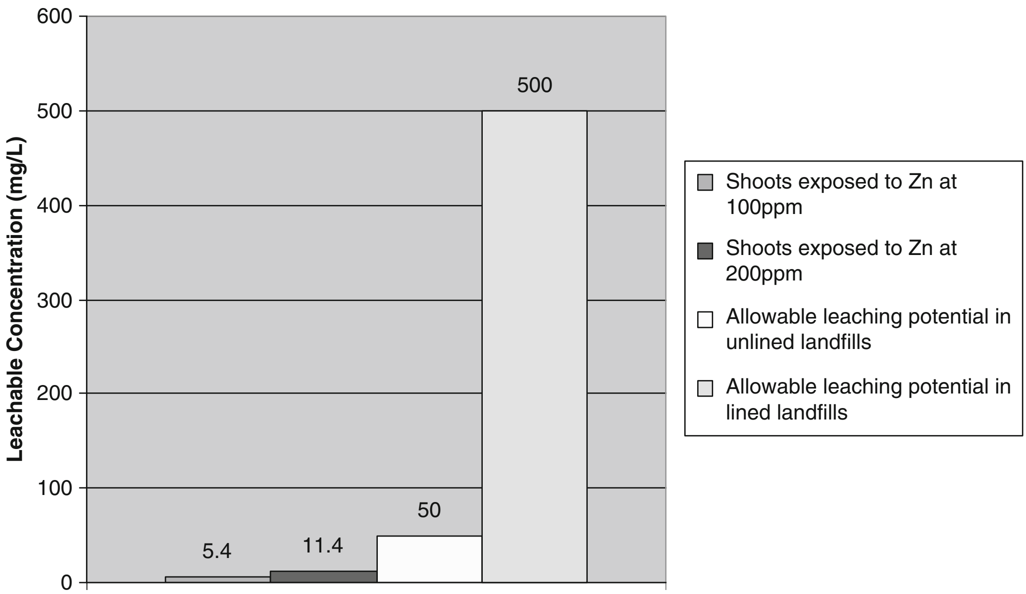

Fig. 8.20. Leaching potential compared with ANZECC (1994) national guidelines for the management of wastes – National manifest and classification system.

respectively. This allows the possibility of further investigation into using Vetiver as mulch or a cover material additive in modern waste management practice.

7. FUTURE LARGE SCALE APPLICATIONS

The future of phytoremediation will become increasingly applied, explored, and refined. The general consensus throughout all of the literature is that Vetiver, due to its diverse, unique physiological and morphological properties, is an ideal candidate for a range of effective phytoremedial applications, particularly in heavy metal contaminated mediums (54).

7.1. Phyto-extraction

Although Vetiver grass is not classified as a hyper-accumulator, as is the case for other plants used for this application, the ability of Vetiver to grow quickly with large biomass, coupled with tolerance to a wide range of adverse soil conditions suggests Vetiver grass is ideal in this application (15) also raise the potential for the use of chemical or chelating agents, a new development whereby a chemical is added to the plant encouraging increased uptake of contaminants such as heavy metals.

7.2. Phyto-stabilization and Mine Site Rehabilitation (55–57)

Vetiver can be employed to reduce the spreading of contaminants because of wind or water erosion. This application is particularly useful for barren mining land, where Vetiver can tolerate its harsh soil conditions. It is well known that metalliferous mining activities produce a large quantity of waste materials, such as tailings and wastewater. They contain excessively high concentrations of heavy metals and therefore result in severe pollution problems and lots of land degradation (4).

7.3. Landfill Rehabilitation and Leachate Treatment (58, 60)

Landfill rehabilitation has become an increasingly popular application of Vetiver. In Australia and China, landfill and industrial waste sites are usually contaminated with heavy metals such as Arsenic, Cadmium, Chromium, Nickel, Copper, Lead, and Mercury, which are highly toxic to both plants and humans. The movement of heavy metals and other toxic leachate from landfills can be controlled by a Vetiver system uniquely tailored to individual sites.

7.4. Wastewater Treatment (59)

The main advantages of using Vetiver grass in wastewater treatment are that it is low cost, simple, effective, and an environmentally friendly solution to an increasingly serious problem in both industrialized and developing countries. In fact using Vetiver grass in wastewater treatments a recycled process, where wasted nutrients are turned into useful fodder or organic mulch. This is in sharp contrast with other processes, such as chemical treatment, which often introduces another waste problem. Therefore, phytoremediation using Vetiver is expected to be very popular in both industrialized and developing countries.

7.5. Other Land Rehabilitation

In Australia, Vetiver is highly successful in the rehabilitation of both old and working quarries, where very few species can be established because of the hostile environment. Vetiver is able to stabilize the lose surface first, so other species can colonize the areas between the hedges later. Most recently, quarry rehabilitations also being carried out successfully in China (59, 60).

8. BENEFITS OF PHYTOREMEDIATION WITH VETIVER GRASS

As the world gears toward increasingly sustainable technology, the use of environmentally friendly, or better yet, naturally occurring technology is indeed the direction that environmental scientists and engineers should explore. This remediation technology not only has the ability, with today's scientific advances, to be manipulated but is only a fraction of the cost of other physical and chemical remediation methods, and does not require manufacture and large scale machinery and equipment.

The financial benefit of implementing Vetiver for phytoremediation can be quantified readily as in the case of the Toogoolawah sewage treatment plant.

9. CONCLUSION

The use of Vetiver for phytoremediation is not only highly effective but also a step in the right ecologically sustainable direction. As beneficial research and development advances and worldwide exposure is increased, further research opportunities must be identified and implemented.

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