RESEARCH AND DEVELOPMENT OF THE VETIVER SYSTEM FOR TREATMENT OF POLLUTED WATER AND CONTAMINATED LAND

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ABSTRACT:

Extensive R&D in Australia, China and Thailand over the last 15 years have established vetiver tolerance to severely adverse conditions and elevated and sometimes toxic levels pollutants. Latest research also shows its exceptional ability to absorb and to tolerate extreme levels of nutrients, capable of consuming large quantities of water under wet conditions and to produce a massive growth. It has been determined that Vetiver grass is:

- **Highly tolerant** to soil high in acidity, alkalinity, salinity, sodicity and magnesium
- **Highly tolerant to** Al, Mn, As, Cd, Cr, Ni, Pb, Hg, Se and Zn in the soil
- **Capable of withstanding extremely** high N supply (10 000KgN/ha/year) and P (1 000KgN/ha/year)
- **Capable of responding** to very high N supply (6 000KgN/ha/year)
- **Highly efficient in absorbing** dissolved nutrients particularly N and P in polluted water.
- **High level of tolerance** to herbicides and pesticides such as Diuron or Atrazine herbicides at concentrations up to 2000 mg/L levels.
- **Vetiver grass is both a xerophyte** (drought tolerant due to its deep and extensive root system) **and a hydrophyte** (wetland plant due to its well developed sclerenchyma [air cell] network). Vetiver thrives under hydroponics conditions.
- **High water use rate** under wetland conditions or high water supply Vetiver can use more water than other common wetland plants.

Keywords: high acidity, alkalinity, salinity, sodicity and magnesium, heavy metals

1.0 INTRODUCTION

Application of the Vetiver System (VS) for wastewater treatment is a new and innovative phytoremedial technology. It is a green and environmentally friendly wastewater treatment technology as well as a natural recycling method. Extensive R&D in Australia, China and Thailand over the last 15 years have established vetiver tolerance to severely adverse conditions and elevated and sometimes toxic levels pollutants such as salinity, acidity, alkalinity, sodicity as well as a whole range of heavy metals and agrochemicals. Latest research also shows its exceptional ability to absorb and to tolerate extreme levels of nutrients, capable of consuming large quantities of water under wet conditions and to produce a massive growth. Also it is highly resistant to pests, diseases, fire, flood and heavy grazing pressure. In addition vetiver grass has a penetrating, massive and deep root system, which can descend 2-3 meters in the first year, with root:shoot ratio of approximately

1:1. It has erect and stiff shoots and when planted close together they form a living porous barrier that acts as a very effective filter, trapping both fine and coarse sediment. It produces neither stolons nor rhizomes and it has flowers but no seed therefore no weed potential. These attributes indicated that vetiver is highly suitable for treating polluted wastewater from industries as well as domestic discharges and mine wastes.

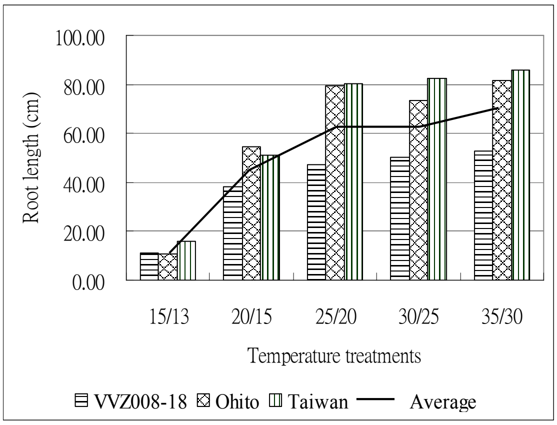
This paper only deals with the research and development aspects of vetiver grass relevant to the treatment of polluted water and contaminated lands.

2.0 SPECIAL ATTRIBUTES OF VETIVER GRASS

2.1 General Characteristics of Vetiver Grass (Truong, 2006).

- ***Cold weather tolerance of vetiver grass*** Although vetiver is a typical C4 tropical grass, it can survive and thrive under subtropical and in some very cold conditions of temperate climate. Under frosty weather its top growth is killed but its underground growing points survived. In Australia, vetiver was not killed by severe frost with ground temperature at $-14^{o}C$ and it survived for a short period at $-22^{o}C$ in northern China. In Georgia (USA), vetiver survived in soil temperature of $-10^{o}C$ but not at $-15^{o}C$. Recent research showed that 25oC was optimal soil temperature for root growth, but vetiver roots continued to grow at 13 ^{o}C. Although very little shoot growth occurred at the soil temperature range of $15^{o}C$ (day) and 13 ^{o}C root growth continued at the rate of 126mm/day, indicating that vetiver grass was not dormant at this temperature and extrapolation suggested that root dormancy occurred at about 5 ^{o}C (Fig.1).

Fig 1. The effect of soil temperature on the root growth of vetiver.(Wang pers. com.)



Temperature treatments: day 15 ^{o}C /night 13 ^{o}C.

- ***Weed Potential*** Vetiver is a non-aggressive plant; it flowers but set no seeds, it produces neither above nor underground stems and it has to be established vegetatively by root (crown) splitting. It is imperative that any plants used for environmental protection purposes will not become a weed in the local environment. A sterile plant such as Vetiver is ideal for this application. In Fiji where vetiver grass was introduced to the country for more than 100 years and has been widely used for soil and water conservation purposes for more than 70 years, vetiver grass has not become a weed in the new environment. Vetiver grass can be killed easily either by spraying with Glyphosate or uprooting and drying out.

• ***Deep and Massive Root System.*** Vetiver grass has a deep and massive root system, which is vertical in nature descending 2-3 meters in the first year, ultimately reaching some five meters under tropical conditions. The depth of root structure provides the plant with great tolerance to drought, permits excellent infiltration of soil moisture and penetrates through compacted soil layers (hard pans) and reduces/prevents deep drainage.

• ***Forming a thick living porous barrier***. The erect and stiff shoots can grow to three meters high and when planted close together they form a porous barrier that retards and spreads water flow and acts as a very effective filter, trapping both fine and coarse sediment in runoff water.

• ***Tolerance to extreme climatic variations*** such as prolonged drought, flood, submergence and temperature levels ranging from -14ºC to 55ºC and to thrive under rainfall ranging from 300 mm to 6000 mm per annum.

• ***Ability to regrow rapidly*** after being affected by drought, frost, fire, saline and other adverse conditions when the adverse effects are removed.

• ***Highly resistant*** to pests, diseases

• ***Highly tolerant to fire***, heavy traffic and high grazing pressure as its new shoots develop from the crown below ground level.

2.2 Special Characteristics of Vetiver Grass Suitable for Wastewater Treatment and Phytoremediation (Truong, 2003, Truong and Hart, 2001).

• ***Highly tolerant*** to soil high in acidity, alkalinity, salinity, sodicity and magnesium

• ***Highly tolerant to*** Al, Mn, As, Cd, Cr, Ni, Pb, Hg, Se and Zn in the soil.

•**Capable of withstanding extremely** high N supply (10 000KgN/ha/year) and P (1000KgN/ha/year)

• ***Capable of responding*** to very high N supply (6 000KgN/ha/year)

• ***Highly efficient in absorbing*** dissolved nutrients particularly N and P in polluted water.

• ***High level of tolerance*** to herbicides and pesticides such as Diuron or Atrazine herbicides at concentrations up to 2000 mg/L levels (Cull *et al*, 2 000).

•***Vetiver grass is both a xerophyte*** (drought tolerant due to its deep and extensive root system) and a hydrophyte (wetland plant due to its well developed sclerenchyma [air cell] network). Vetiver thrives under hydroponics conditions.

• **High water use rate** Under wetland conditions or high water supply Vetiver can use more water than other common wetland plants such as Typha spp, (approximately 7.5 times more) and *Phragmites australis* and *Schoenoplectus validus* (Cull *et al*, 2 000).

3.0 NUTRIENT UPTAKE AND DISPOSAL (Truong, 2006).

3.1 Glasshouse Research

• ***Effect of N:*** Figure 1 shows that vetiver growth increased with the level of N supplied. However very little growth response occurred at rates higher than 6 000kg/ha/year although rates up to 10 000kg/ha of N did not adversely affect vetiver growth.

• ***Effect of P***: Figure 2 shows that vetiver requirement for P was not as high as for N, and no growth response occurred at rates higher than 250kg/ha/year. However its growth was not adversely affected at P application rates up to 1 000kg/ha/year.

•***Interaction of N and P effects***: A significant interaction between the effects of N and P was also observed, with greater N response occurring in the presence of higher levels of P. This suggests that to ensure optimal growth and N uptake, vetiver needs adequate P supply; At least 250kg/ha/year of P must be supplied before any further growth response to N application rates above 4 000kg/ha/year can be observed. (Fig. 3).

Fig. 2. Shoot dry matter yield under very high Nitrogen supply

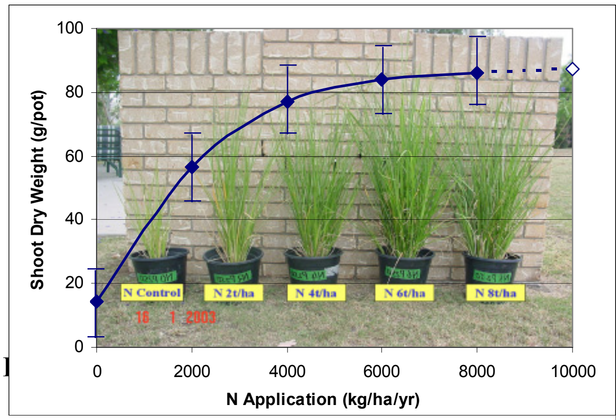


Fig. 3. Shoot dry matter yield under very high Phosphorus supply.

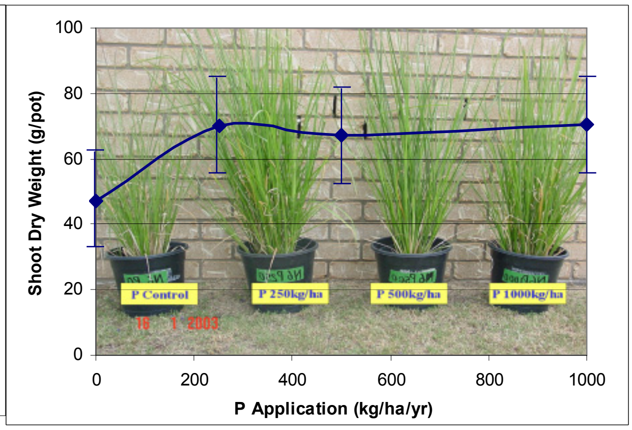
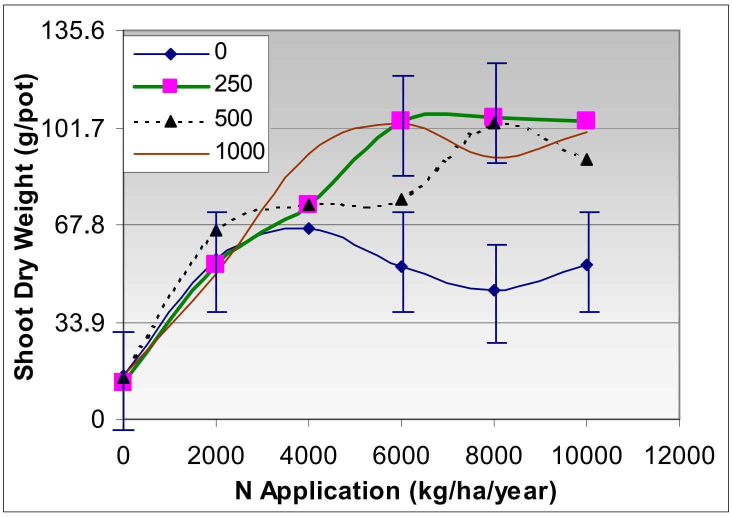


Fig. 4. Interaction of N and P effects



- ***Shoot N concentration**:* As expected, N shoot concentrations increased with increasing N application rate, reaching a concentration of 2.5% when 10 000kg/ha/year of N was supplied (Fig. 4A). However since neither shoot yield or shoot N concentration increased beyond the 6000kg/ha/year level, this suggests that lower N recoveries occurred at these high N application rates.
- ***Shoot P concentration**:* Vetiver has very little requirement for P as compared with temperate grasses. At the optimal P supply level of 250kg/ha/year, vetiver has only 0.1% of P in the shoot as compared with value of 0.15% found in the mature vetiver plants grown in the field experiment. (Fig. 4B).

- ***N and P recovery rates****:* Vetiver has a very high recovery rate for N, about 70% recovered in the shoots for application rates up to 6 t N/ha/year and about 55% for 8t N/ha/year and 45% for 10t N/ha/year. This characteristic makes vetiver highly suitable for treating N in wastewater. However the P recovered in the shoots is only 30% at a supply level of 250kg P/ha/year, and lower at higher supply rates (Table 1).

Fig. 5. (A) N concentration of vetiver shoot dry matter under very high N supply and (B) P concentration of vetiver shoot dry matter under very high P supply**.**

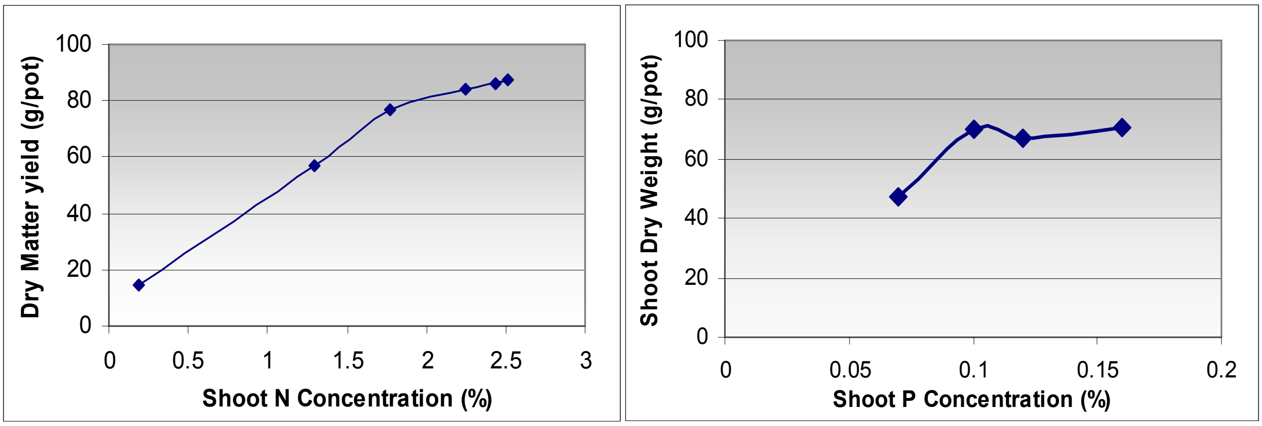


Table 1: Recovery rates of N and P by vetiver grass.

Treatment	%Recovery by Shoot	%Recovery By Root*	% Recovered in Soil	Total
N2	76.3	20.4	0.3	97
N4	72.1	23.1	0.1	95
N6	67.3	21.2	0.4	89
N8	56.1	30.0	0.4	87
N10	46.7	17.0	0.1	64
P250	30.5	23.3	46.3	100
P500	20.5	14.6	48.7	84
P1000	16.5	14.2	40.8	72

* Estimated from one replicate only

- ***Water use:*** Under wetland conditions, vetiver had the highest water use rate as compared with other wetland plants such as *Iris pseudacorus, Typha spp*, *Schoenoplectus validus*, *Phragmites australis*. At the average consumption rate of 600ml/day/pot over a period of 60 days, vetiver used 7.5 times more water than Typha (Truong, 2006).

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

3.2 Field Research and Development (Wagner *et al*, 2003; Hart *et al*, 2003).

Field plot experimentation was conducted to verify glasshouse data and to compare vetiver performance with the other two commonly used grasses, Rhodes and Kikuyu (Truong and Smeal, 2003).

- ***Growth cycle*****:** Results from field trial showed that vetiver growth increased steadily until week 10 and the rate was slightly reduced thereafter until week 12, indicating that under the existing site conditions (soil type, fertility level and irrigation regime etc.), vetiver growth has peaked at week 12. Therefore after 12-week growing period or 3-month, it is probably the best time to harvest vetiver to maximize yield and nutrient export from the field. At this stage vetiver plant is 1.7m tall with a Leaf Area Index higher than 14, and dry matter yield of 4 074g/m2.
- ***Dry matter yield****:* Data collected over the experimental period of 12 weeks show that Vetiver out yielded Kikuyu by almost 6 times and Rhodes over 6 times (40.7, 7.0 and 6.1 t/ha respectively). Based on this data, if harvest were carried out every 12 weeks, the potential vetiver yield for the 6 and 9-month periods would be 88.3 and 132.4 t/ha respectively, and that for Kikuyu would be 15.2 and 22.71/ha and that for Rhodes 13.3 and 19.9t/ha (Fig.5). The 9-month yield was considered instead of 12-month growing period to allow for the much slower growth rate during the winter period.
- ***Potential N and P uptake:*** The potential N and P uptakes of vetiver as compared with the other two grasses are shown in Fig.6, which over the 9-month period, N uptake was 1920, 687 and 399kg/ha for vetiver, Kikuyu and Rhodes grass respectively. Similarly the P uptake was 198, 77 and 26kg/ha respectively for the three grasses.
- ***N Export of the three Grasses****:* N export by vetiver is more than 2.2 times that of Kikuyu and 3.9 times that of Rhodes (1442 kg/ha, 642 kg/ha and 373 kg/ha respectively) (Fig.7). Similarly P export by vetiver is more than twice that of Kikuyu and 6.2 times that of Rhodes (149 kg/ha, 72 kg/ha and 24 kg/ha respectively) (Fig.8).
- ***Conclusions****:* Under field conditions Vetiver planting has the potential of producing up to 132t/ha/year of dry matter yield as compared to 23 and 20t/ha/year for Kikuyu and Rhodes grass respectively. With this production vetiver planting has the potential of exporting up to 1920kg/ha/year of N and 198kg/ha/year of P as compared to 687 of N and 77kg/ha/year of P for Kikuyu and 399 of N and 26 of P for Rhodes grass respectively.

Fig.6: Potential DM yield of the three grasses over time

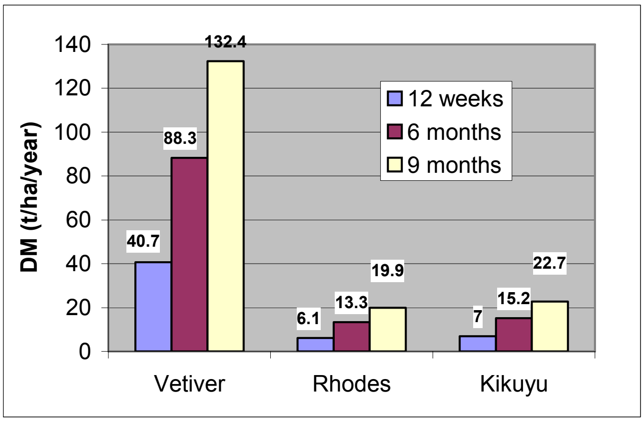
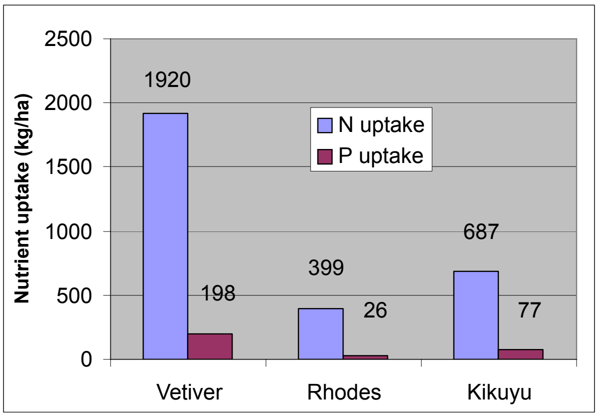


Fig.7: Potential N and P uptakes by the 3 grasses over 9-month period



4.0 TOLERANCE TO ADVERSE CONDITIONS AND HEAVY METALS

There has been increasing concerns world wide about 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. 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 is needed to rehabilitate such sites. 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.

Vetiver grass due to its unique morphological and physiological characteristics mentioned above, is also widely known for its effectiveness in erosion and sediment control, and has also been found to be highly tolerant to extreme soil conditions including heavy metal contaminations (Truong, 2004).

Fig 8: N export by the three grasses over time

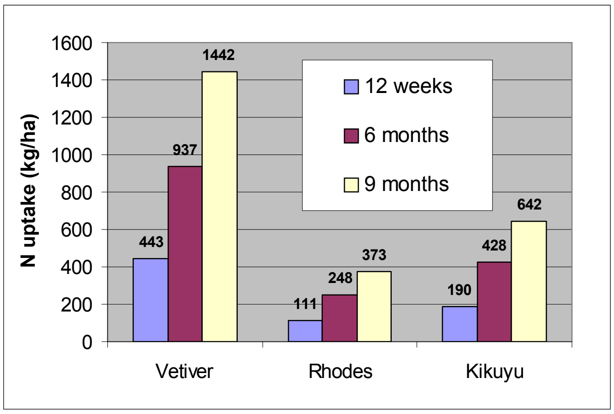
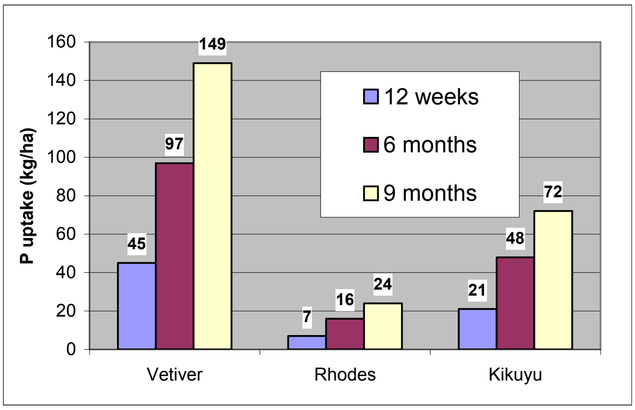


Fig 9: P export by the three grasses over time



4.1 Tolerance to Adverse Soil Conditions (Shu, 2003; Truong *et al*, 2008)

4.1.1 Tolerance to High Acidity and Manganese Toxicity

Glasshouse studies show that when adequately supplied with N and P 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 $mgKg^{-1}$, 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.

4.1.2 Tolerance to High Acidity and Aluminium Toxicity

Research results showed that with N and P fertilisers, vetiver growth was not affected even under extremely acidic conditions (pH = 3.8) and at a very high level of soil Aluminium Saturation Percentage (68%), but vetiver did not survive an Aluminium saturation level of 90% at soil pH = 2.0. Therefore the threshold level must be between 68% and 90%. Field-testing confirmed later that vetiver grew satisfactorily at soil pH=3.0 and Aluminium level between 83-87%, which is extremely high as growth of most plant is affected at level less than 30%. As a result of its high tolerance level to Al and Mn toxicities, vetiver has been used successfully for erosion control in Acid Sulfate Soils with actual soil pH around 3.5 and oxidised pH is as low as 2.8 (Truong and Baker, 1998). Table 3 shows the effects of soil pH on soil Al and Mn levels, plant yield and plant Mn.

Table 3: Effects of soil pH on soil Al and Mn levels, plant yield and plant Mn.

Treatment	pH	Exchangeable Al ($mgKg^{-1}$)	Soil Mn ($mgKg^{-1}$) at Planting*	Plant Yield (g/pot)	Plant Mn ($mgKg^{-1}$)
1	3.3	2.5	578	19.8	890
2	3.6	1.2	403	19.5	462
3	4.2	0.3	169	19.3	486
4	6.2	0.10	47	19.0	244
5	6.7	T	35	18.9	204
6	6.8	T	30	18.7	160
7	7.3	T	29	17.7	140
8	8.0	T	19	17.5	142
LSD (5%)				n.s.	

*Extractable Mn by 25:50 Soil/0.00 5M DTPA T = Trace

4.1.3 Tolerance to High Soil Salinity

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 favorably with some of the most salt tolerant crop and pasture species grown in Australia, Table 2. These results are supported by observation in Fiji and Queensland, where vetiver was found growing in highly saline tidal flats next to mangrove swamps.

Table 2: Salt Tolerance Level of Vetiver Grass as Compared with Some Crop and Pasture Species

Species	Soil EC_{se} (dSm^{-1}) 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 (*Vetiveria zizanioides*)	8.0	20.0

4.1.4 Tolerance to high soil alkalinity and strongly sodic soil.

Vetiver can tolerate extremely high pH level in the soil, as high as pH 11 in Lucknow India. On a coal mine overburden with pH of 9.5 and extremely sodic, with ESP (Exchangeable Sodium Percentage) of 33%. Soils with ESP higher than 15 are 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 $mgKg^{-1}$). While gypsum application had no effect on the growth of vetiver, N and P fertilizers greatly increased its yield. With adequate supply of N and P vetiver grew satisfactorily on Na Bentonite tailings with ESP 48%.

4.1.5 Tolerance to 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 4 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 $mgKg^{-1}$(Table 5).

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

Heavy Metals	**Thresholds in soil ($mgKg^{-1}$)(Available)**		**Thresholds in plant ($mgKg^{-1}$)**	
	Vetiver	**Other plants**	*Vetiver*	**Other plants**
Arsenic	100-250	2.0	21-72	1-10
Cadmium	20-60	1.5	45-48	5-20
Copper	50-100	Not available	13-15	15
Chromium	200-600	Not available	5-18	0.02-0.20
Lead	>1 500	Not available	>78	Not available
Mercury	>6	Not available	>0.12	Not available
Nickel	100	7-10	347	10-30
Selenium	>74	2-14	>11	Not available
Zinc	>750	Not available	880	Not available

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Table 5: 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

4.1.6 Distribution of Heavy Metals in Vetiver Plant

The distribution of heavy metals in vetiver plant can be divided into three groups:

- Very little of the As, Cd, Cr and Hg absorbed were translocated to the shoots (1% to 5%)
- A moderate proportion of Cu, Pb, Ni and Se were translocated (16% to 33%) to the top and
- Zn was almost evenly distributed between shoot and root (40%) (Truong, 2004).

Table 6: Distribution of Heavy Metals in Vetiver Shoots and Roots.

Metals	Soil ($mgKg^{-1}$)	Shoot ($mgKg^{-1}$)	Root ($mgKg^{-1}$)	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
	1500	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

Metals	Soil ($mgKg^{-1}$)	Shoot ($mgKg^{-1}$)	Root ($mgKg^{-1}$)	Shoot / Root %	Shoot / Total %
	350	300	610	49	33
	500	540	830	65	39
	750	880	1030	85	46
Average				**69**	**40**

BQ Below Quantification

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 the levels recorded for vetiver is comparable to other native endemic plants.

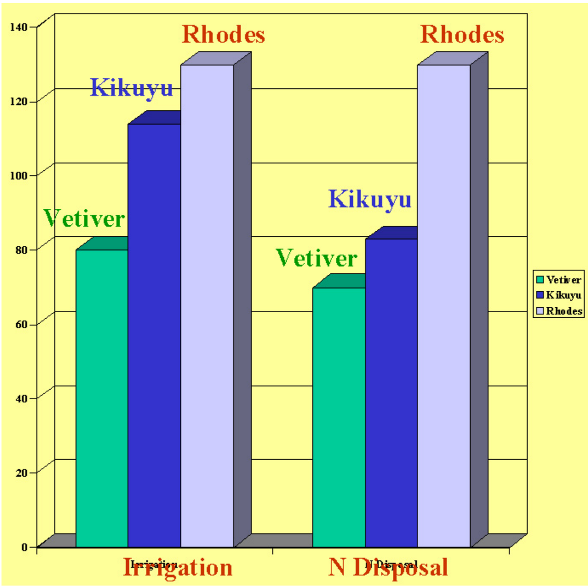
Although vetiver is not a hyper-accumulator it can be used to remove the some heavy metals from the contaminated sites and disposed off safely else where, thus gradually reducing the contaminant levels. For example vetiver roots and shoots can accumulate more than 5 times the chromium and zinc levels in the soil (Table 6).

5 .0 COMPUTER MODELLING (Truong *et al*, 2003)

A number of computer models have been developed in Australia for sewage and effluent disposal of from agri-industrial processors. But to date application of these models in tropical and subtropical Australia has been restricted to a number of tropical and subtropical crops and pasture species and now vetiver grass is being used for these models.

With the extraordinary attributes presented above vetiver grass is an outstanding alternative to the commonly used species. For example at a food processing factory in Queensland with effluent output of 475 ML /year, and N concentration of 300mg/L and P of 1mg/L, the minimum land area needed to dispose all the effluent is 72.5, 104 and 153ha when vetiver, Kikuyu *(Pennesitum clandestinum*) and Rhodes grass (*Chloris guyana*) were used, respectively, (Fig.10).

Fig.10: Comparison of land areas required to dispose of effluent by the three grasses at Gelita



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