Vetiver Phytoremediation for Heavy Metal Decontamination

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ABSTRACT

Heavy metal contamination commonly results from human activities which has become a serious environmental problem today. Phytoremediation, a cost effective green technology, appears promising for cleaning up environment. Vetiver, a "Miracle Grass" for soil and water conservation, has great potential to apply this technology because of its characteristic tolerance to heavy metals. Successful vetiver phytoremediation, however, depends on various factors such as vetiver behavior, chemical and physical properties of growth media as well as agronomic practice, all of which must be carefully investigated and properly considered for site specific conditions. This paper describes the application, research experience and future prospects of utilizing vetiver phytoremediation as an appropriate natural tool in promoting sustainable environment.

Keywords: *miracle grass, soil and water conservation, agronomic practice, sustainable environment, wastewater treatment, hyperaccumulator, Chrysopogon nemoralis, Chrysopogon zizanioides*

1. INTRODUCTION

Phytoremediation is a technology of using plant to clean up pollutants in the environment. Besides being an economical, energy efficient and environmental friendly method, phytoremediation can be applied to large areas and is useful for solving a wide variety of contaminants (metal, radionuclide and organic substances) and growth media (soil, sludge, sediment and water). Phytoremediation can be specified into many applications including: phytoextraction, in which plants decontaminate soil through uptake of heavy metals into aerial part and then can be harvested and removed from the site; Phytostabilization, in which plants are used to minimize heavy metal mobility in contaminated soil; and Phytovolatilization, in which plants extract volatile metals from soil and volatilize them from foliage (Cunningham *et al.*, 1995).

Vegetation is important for all phytoremediation applications. It is necessary to use plants that tolerate high levels of toxic pollutants. Vetiver grass is widely known for its effectiveness in erosion and sediment control. After it was found that vetiver can tolerate extreme climatic variations and soil conditions, including heavy metals (Truong and Baker, 1998; Truong, 1999; Roongtanakiat and Chairoj, 2001a; Roongtanakiat and Chairoj, 2001b), the concept of using vetiver for phytoremediation occurred. Many researches reported the potential of utilizing vetiver to decontaminate heavy metals from soil (Truong and Baker, 1998; Roongtanakiat and Chairoj, 2001a; Roongtanakiat and Chairoj, 2001b), garbage leachate (Xia *et al*., 2000; Roongtanakiat *et al*., 2003), wastewater (Kong *et al.*, 2003; Roongtankiat *et al.*, 2007) and mine tailings (Truong, 1999; Yang *et al*., 2003; Roongtanakiat *et al*., 2007). Application of vetiver for phytoremediation, however, depends upon various factors such as physical and chemical properties of growth media as well as agronomic practice. They should be carefully investigated and properly considered in applying for site specific conditions to achieve the desired goal.

2. VETIVER ECOTYPE AND GROWTH PERFORMANCE

There are two species of vetiver in Thailand, namely *Chrysopogon nemoralis* (Balansa) Holttum and *Chrysopogon zizanioides* (L.) Roberty. Both species have distinct ecological characteristics which make them adapt to different habitats. They are commonly found in all regions of Thailand and there are many ecotypes. Thai vetiver ecotypes have been named after the provinces where they were first found, for example, Ratchaburi, Surat Thani, Roi Et, Loei, Kamphaeng Phet. The Department of Land Development has performed a comparative study of 28 vetiver ecotypes, 11 ecotypes of *Chrysopogon nemoralis* and 17 ecotypes of *Chrysopogon zizanioides*. As the result, 10 ecotypes have proven suitable to grow in various soil types and regions (Tables 1 and 2) (ORDPB, 2000).

For remediation purposes, a high heavy metal uptake by plant is needed. Therefore, vertiver ecotype used for this technology has to develope well in contaminated sites, and give high biomass. The experiment conducted to evaluate the Mn, Cu, Cd and Pb uptake potential of three vetiver ecotypes grown in five different levels of artificially contaminated soils, showed that three vetiver ecotypes could grow

Table 1. Suitability of vetiver ecotypes in various soil types

Soil type	*Chrysopogon nemoralis*	*Chrysopogon zizanioides*
Sandy soil	Nakhon Sawan, Kamphaeng Phet 1, Roi Et, Ratchaburi	Kamphaeng Phet 2, Songkhla 3
Clay loam soil	Loei, Nakhon Sawan, Ratchaburi, Kamphaeng Phet 1, Prachuap Khiri Khan	Surat Thani, Songkhla 3
Leterite soil	Prachuap Khiri Khan, Loei	Kamphaeng Phet 2, Songkhla 3, Surat Thani, Sri Lanka

Table 2. Suitability of vetiver ecotypes in different regions

Region	*Chrysopogon nemoralis*	*Chrysopogon zizanioides*
North	Nakhon Sawan, Kamphaeng Phet 1	Sri Lanka
Northeast	Roi Et	Songkhla 3
Central and East Region	Ratchaburi, Kamphaeng Phet 1, Prachuap Khiri Khan	Kamphaeng Phet 2, Songkhla 3, Surat Thani
South		Songkhla 3, Surat Thani

well in soil with all tested levels of heavy metal contamination (Fig. 1). Height of Surat Thani ecotype was significant greater than those of Ratchaburi and Kamphaeng Phet ecotypes. However, Ratchaburi ecotype gave the highest shoot dry weight but there was no significant difference among vetiver ecotypes regarding shoot dry weight. (Roongtanakiat and Chairoj, 2001a). In 2006, an experiment was conducted at Padaeng Industry Public Company Limited in Tak province in order to compare development of two *Chrysopogon nemoralis* ecotypes, Nakhon Sawan and Prachuap Khiri Khan, and two *Chrysopogon zizanioides* ecotypes, Kamphaeng Phet 2 and Surat Thani, grown in zinc mining area (Fig. 2). It was found that both *Chrysopogon zizanioides* ecotypes gave better growth performance than that of *Chrysopogon nemoralis*, while Kamphaeng Phet 2 gave the highest plant height and shoot dry weight.

Similar results were obtained from the experiment of wastewater treatment conducted by Roongtanakiat *et al*. (2007). Three vetiver ecotypes were hydroponically cultured in four samples of industrial wastewater taken from a dairy factory, a battery manufacturing plant, an electric lamp plant and an ink manufacturing facility. The results showed that Kamphaeng Phet 2 and Sri Lanka ecotypes had significantly higher average plant height and total dry weight than Surat Thani ecotype (Fig. 3 and 4).

3. PRIMARY NUTRIENT CONTENT IN VETIVER

Primary nutrients are needed in large quantities for plant growth. LDD (1994) reported that concentrations of N, P and K in vetiver shoot were 2.5, 0.17 and 1.5%, respectively. Our previous studies indicated that vetiver grown in iron ore tailings, had concentrations of 5.31-5.42, 0.45-0.50 and 1.27-1.46%, respectively for N, P and K in shoot. However, the vetiver grown in zinc mine soil, which has lower fertility than iron ore tailings, had lower concentrations of primary nutrients in shoot of 2.12-2.55, 0.44-0.50, and 1.26-1.40%, respectively. Primary nutrient concentrations in shoot and root of three vetiver ecotypes hydroponically cultured in four sources of industrial wastewater which have different contents of nutrients and heavy metals are shown in Table 3 and 4. The data obviously showed that wastewater sources affected the nutrient content in vetiver plant more than the tested ecotypes.

Table 3. Primary nutrient concentrations in shoot and root of vetiver grown in industrial wastewaters from milk factory (W1), battery manufacturing plant (W2), electric lamp plant (W3) and ink manufacturing facility (W4).

Wastewater Source	Nitrogen[1/] (%)		Phosphorus[1/] (%)		Potassium[1/] (%)	
	Shoot	Root	Shoot	Root	Shoot	Root
W1	0.47 b	0.52 b	0.18 b	0.15 b	1.26 a	0.77 a
W2	0.33 c	0.44 c	0.14 c	0.70 d	1.24 a	0.76 a
W3	0.40 bc	0.46 bc	0.46 a	0.22 a	1.15 a	0.66 b
W4	0.49 a	1.60 a	0.14 c	0.09 c	1.20 a	0.39 c

[1/] Figures in the same column with a common letter are not significantly different at 0.05 probability by DMRT.

Table 4. Primary nutrient concentrations in shoot and root of Kamphaeng Phet 2 (K), Sri Lanka (L) and Surat Thani (S) vetiver ecotypes grown in industrial wastewaters.

Vetiver Ecotype	Nitrogen[1/] (%)		Phosphorus[1/] (%)		Potassium[1/] (%)	
	Shoot	Root	Shoot	Root	Shoot	Root
K	0.58 a	0.60 b	0.21 b	0.13 a	1.17 a	0.62 a
L	0.49 b	0.59 b	0.25 a	0.14 a	1.19 a	0.69 a
S	0.57 a	0.66 a	0.23 ab	0.14 a	1.27 a	0.62 a

[1/] Figures in the same column with a common letter are not significantly different at 0.05 probability by DMRT.

Fig. 1 Surat Thani vetiver ecotype grown in soil contaminated with five levels of heavy metals.

Fig. 2 Vetiver grew well on zinc mine area at Padaeng Industry Public Company Limited, Tak province, Thailand.

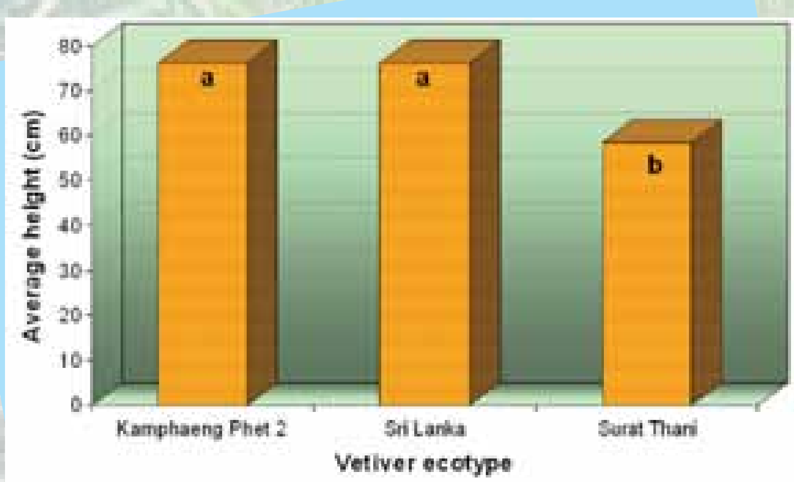


Fig. 3 Average height of Kamphaeng Phet 2, Sri Lanka and Sura Thani vetiver ecotypes grown in industrial wastewaters. *Bars associated with a common letter are not significantly different at 0.05 probability by DMRT.*

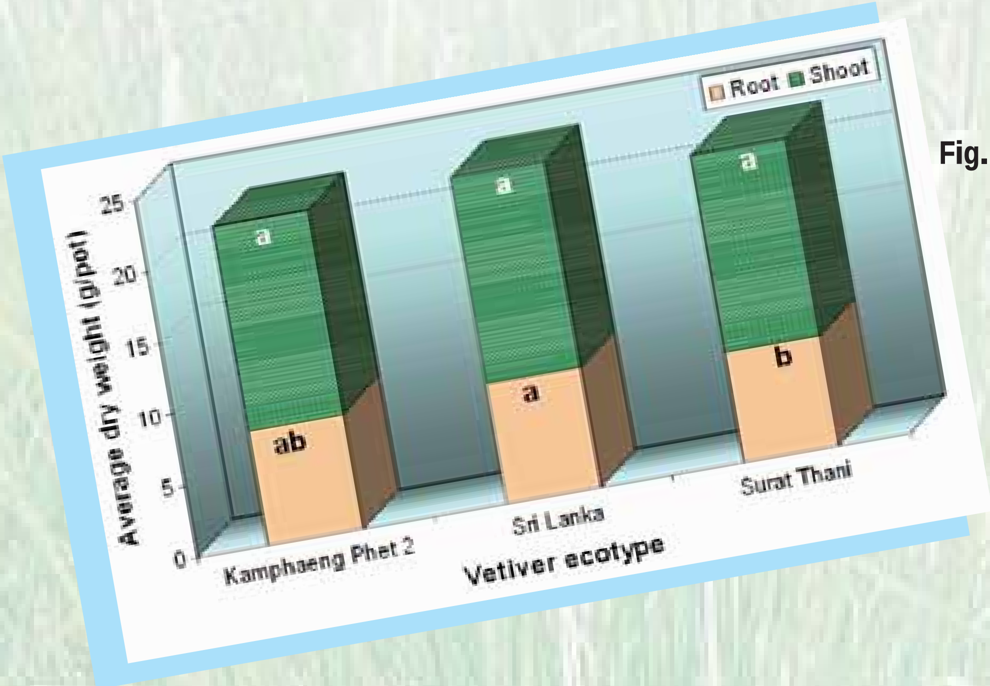


Fig. 4 Average shoot and root dry weight of Kamphaeng Phet 2, Sri Lanka and Sura Thani vetiver ecotypes grown in industrial wastewaters. *Bars associated with a common letter are not significantly different at 0.05 probability by DMRT*.

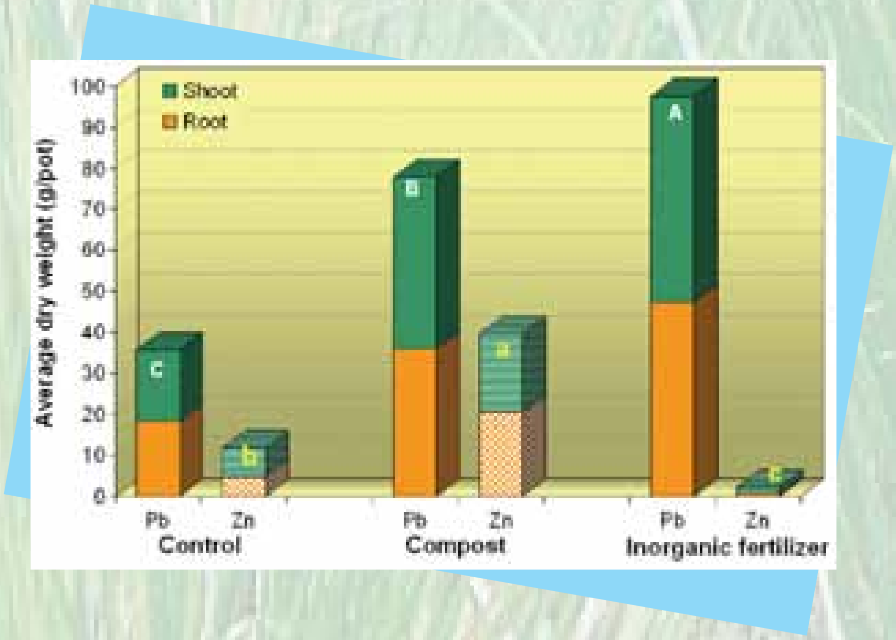


Fig. 5 Shoot and root dry weight of vetiver grown in lead and zinc mine soils treated with compost and inorganic fertilizers. *Bars associated with a common letter are not significantly different at 0.05 probability by DMRT*.

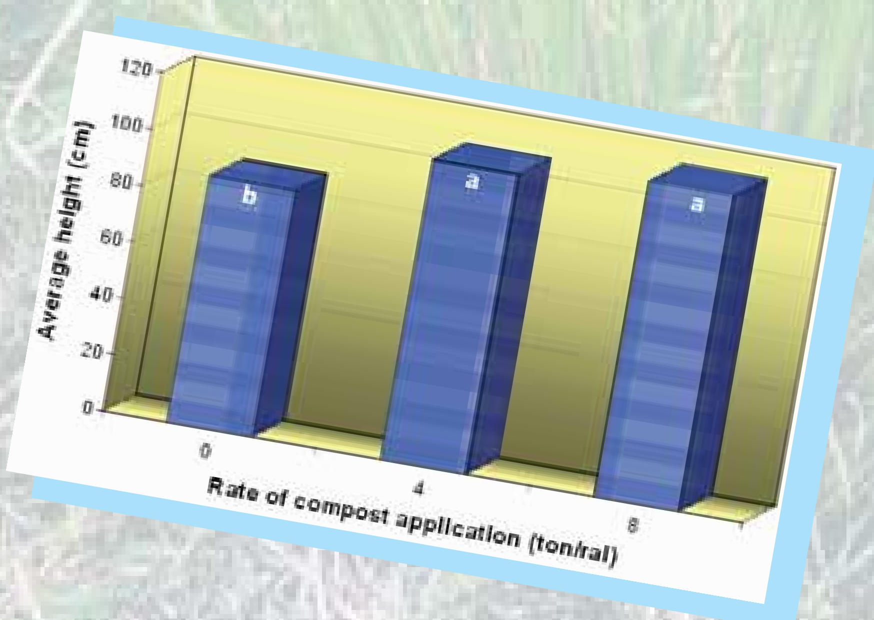


Fig. 6 Average height of vetiver grown in zinc mine area applied with compost at rate of 0, 4 and 8 ton/rai. *Bars associated with a common letter are not significantly different at 0.05 probability by DMRT.*

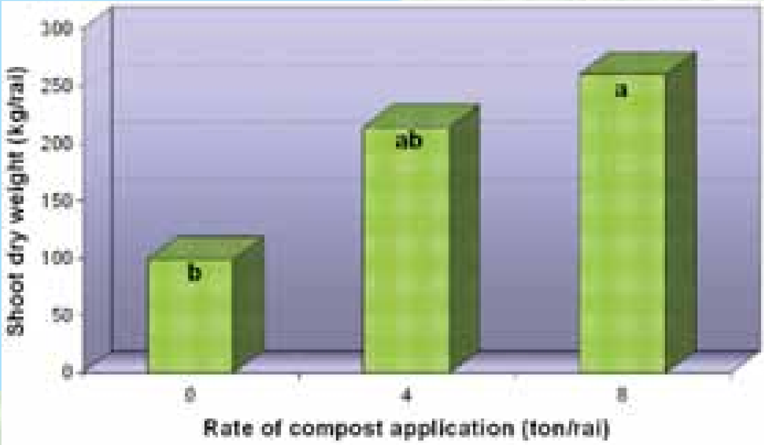


Fig. 7 Average shoot dry weight of vetiver grown in zine mine area applied with compost at rate of 0, 4 and 8 ton/rai. *Bars associated with a common letter are not significantly different at 0.05 probability by DMRT.*

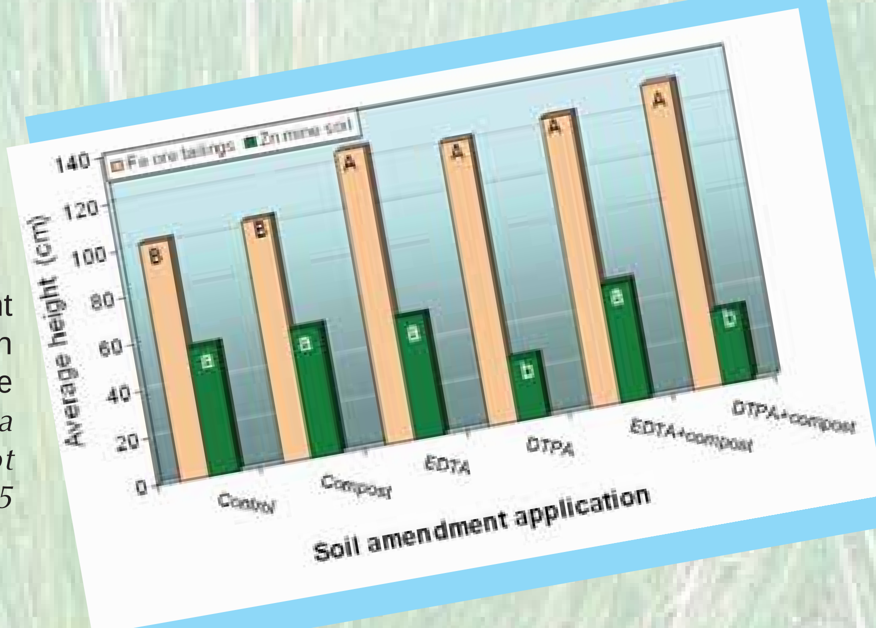


Fig. 8 Influence of soil amendment on height of vetiver grown on iron tailings and zinc mine soil. *Bars associated with a common letter are not significantly different at 0.05 probability by DMRT.*

Fig. 9 Influence of soil amendment on biomass of vetiver grown on iron tailings and zinc mine soil. *Bars associated with a common letter are not significantly different at 0.05 probability by DMRT.*

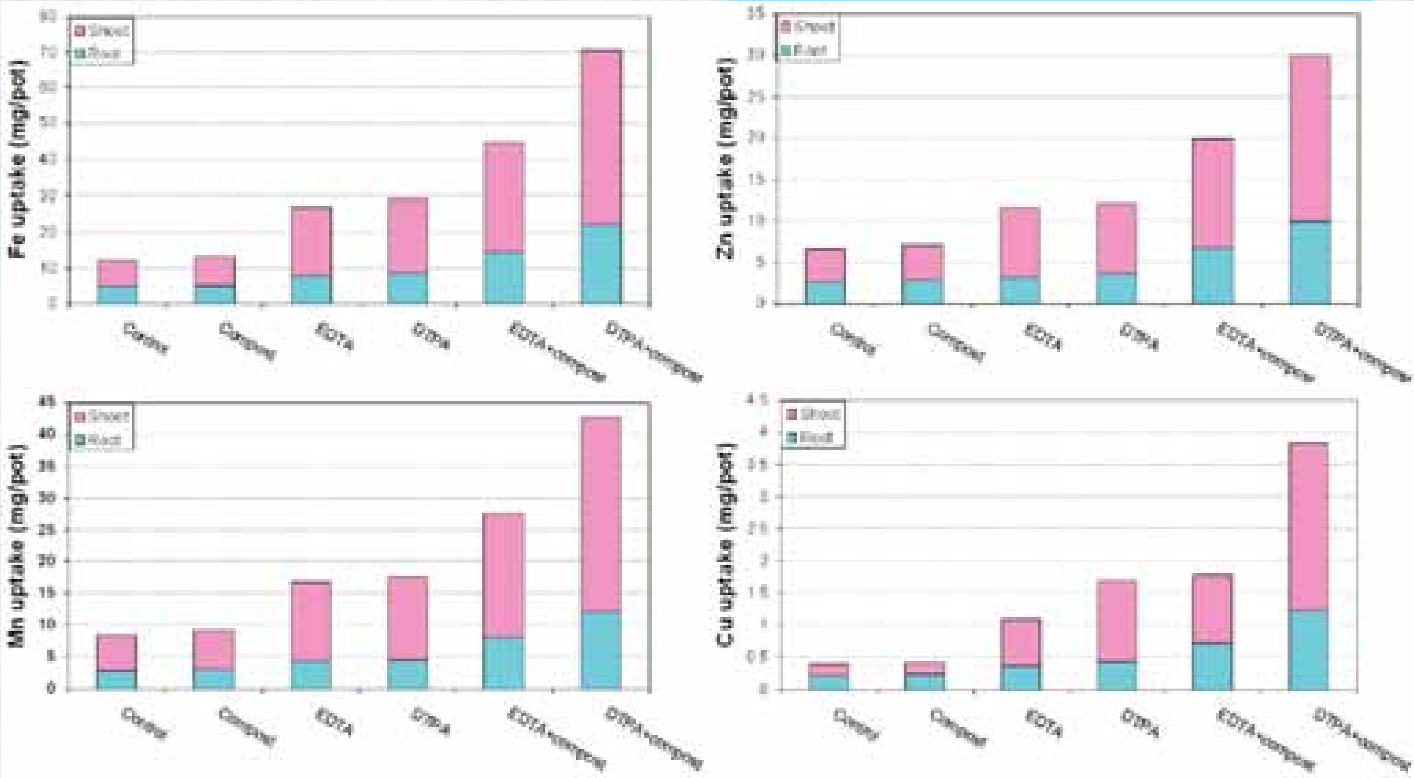


Fig. 10 Uptake of Fe, Zn, Mn and Cu in shoot and root of vetiver grown in iron ore tailings.

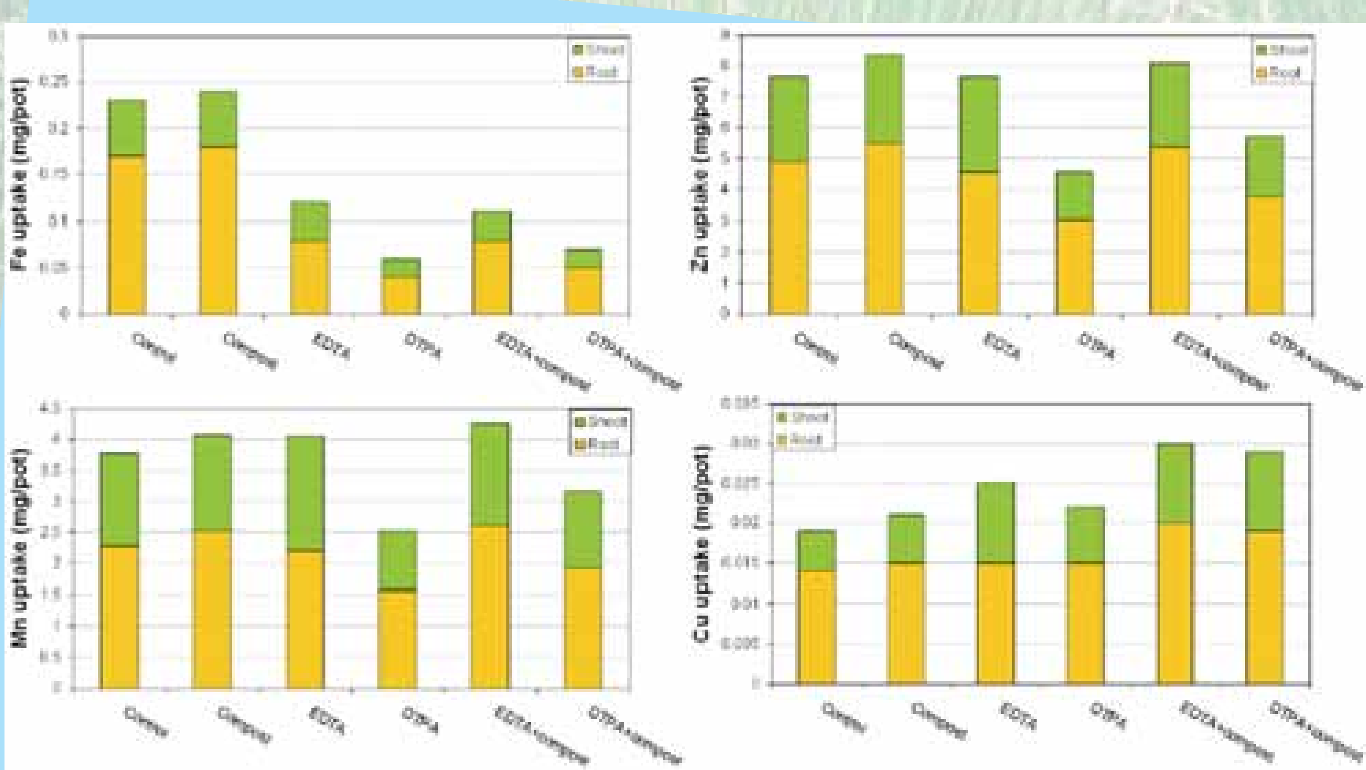


Fig. 11 Uptake of Fe, Zn, Mn and Cu in shoot and root of vetiver grown on zinc mine soil.

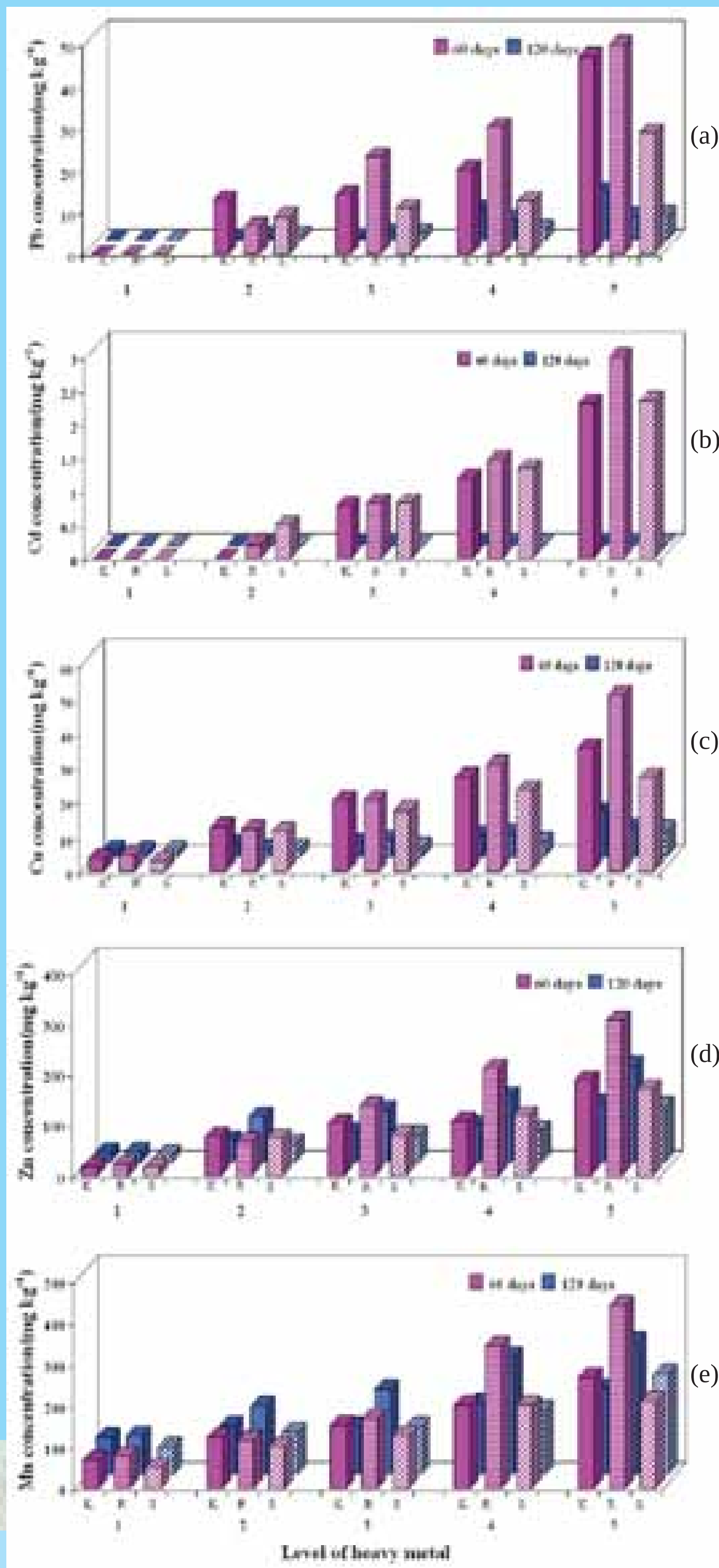


Fig. 12 Concentration of Mn (a), Zn (b), Cu (c), Pb (d) and Cd (e) in shoot of three vetiver ecotypes (Kamphaeng Phet, K; Ratchaburi, R; Surat Thani, S) planted in soils contaminated with different levels of heavy metals at 60 and 120 day harvest.

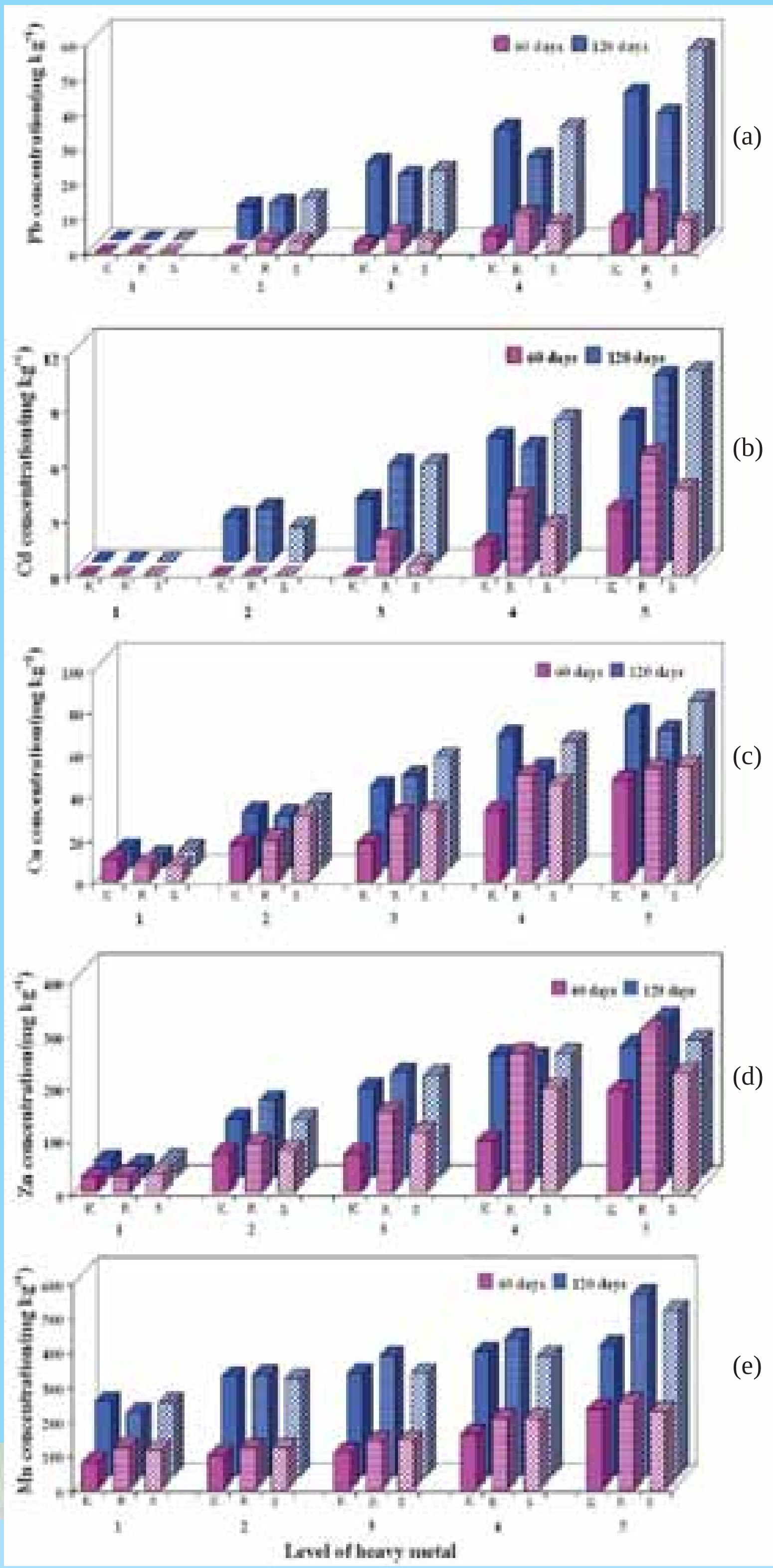


Fig. 13 Concentration of Mn (a), Zn (b), Cu (c), Pb (d) and Cd (e) in root of three vetiver ecotypes (Kamphaeng Phet, K; Ratchaburi, R; Surat Thani, S) planted in soils contaminated with different levels of heavy metals at 60 and 120 day harvest.

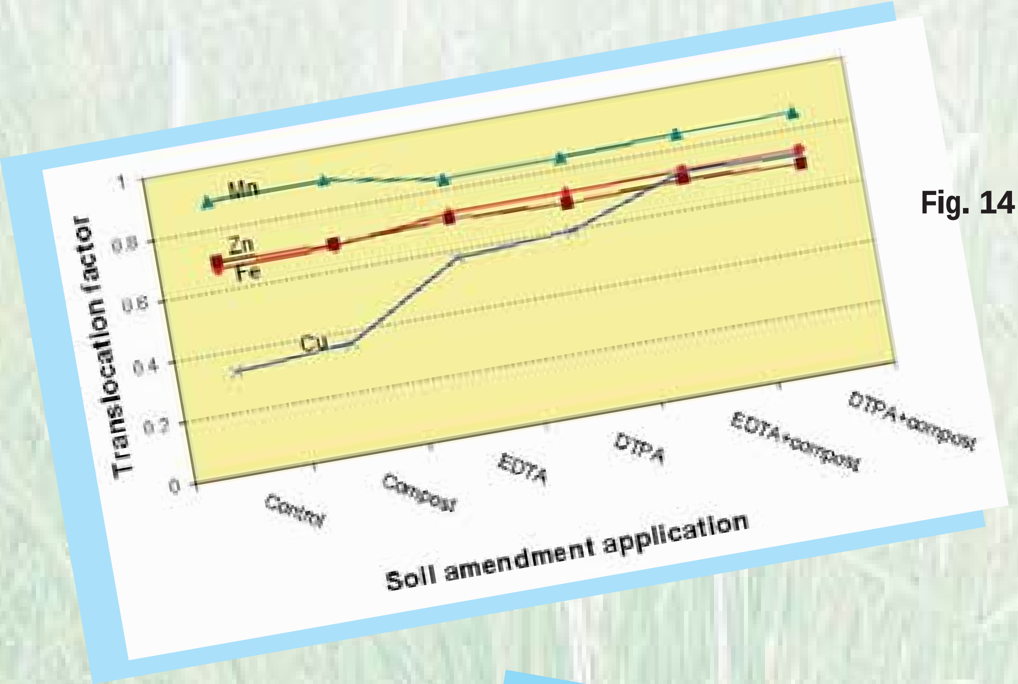
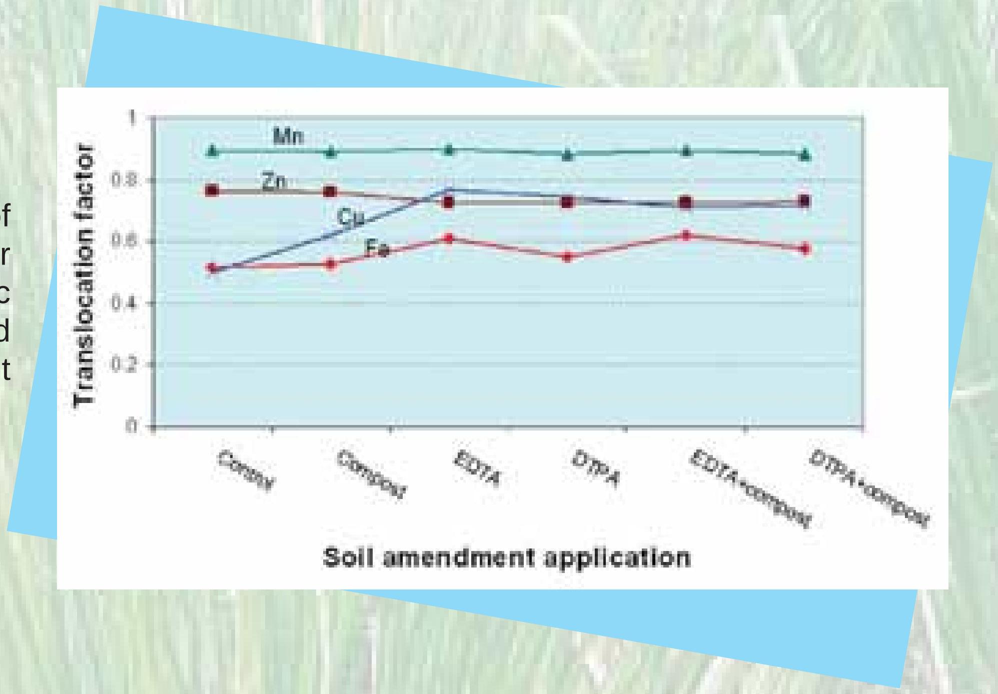


Fig. 14 Translocation factor of Mn, Zn, Cu and Fe for vetiver grown in iron ore tailings amended with chelating agent and compost.

Fig. 15 Translocation factor of Mn, Zn, Cu and Fe for vetiver grown in zinc mine soil amended with chelating agent and compost.



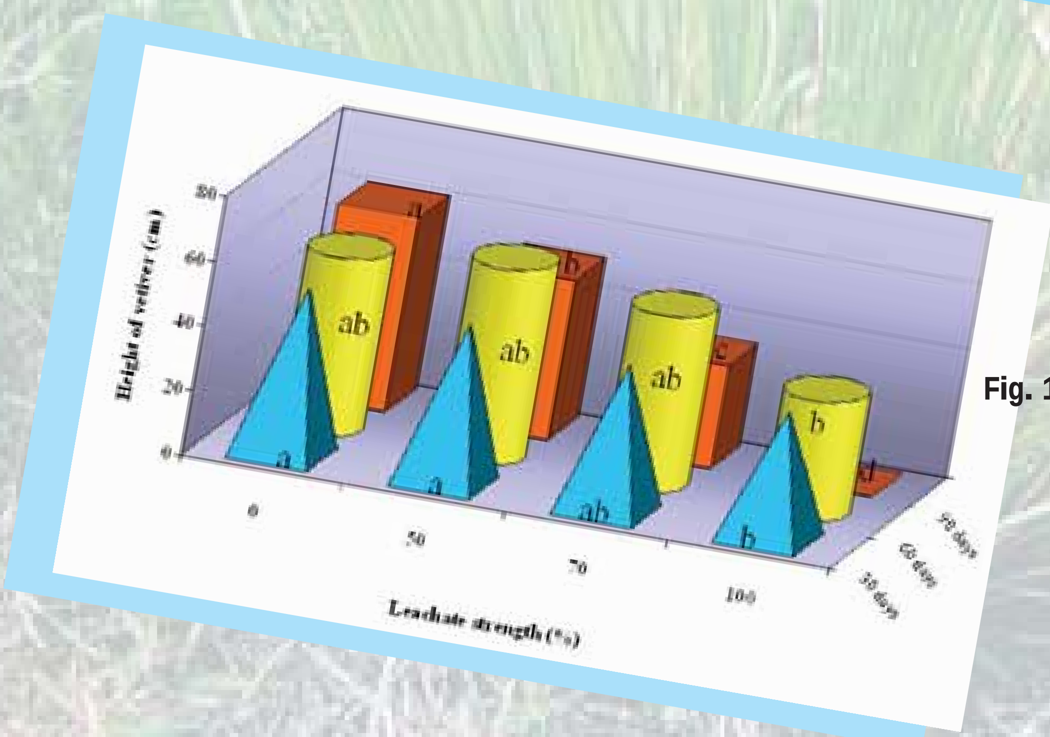


Fig. 16 Average height of vetiver plants treated with 0, 50, 70 and 100 % leachate strength at 30, 60 and 90 days after planting.

Fig. 17 Effect of landfill leachate (a) on growth of veitver planted at landfill site, Kamphaeng Saen, Nahon Phathom province. Vetiver height of the two top rows were higher than those in the three lower rows which received greater leachate strength (b).

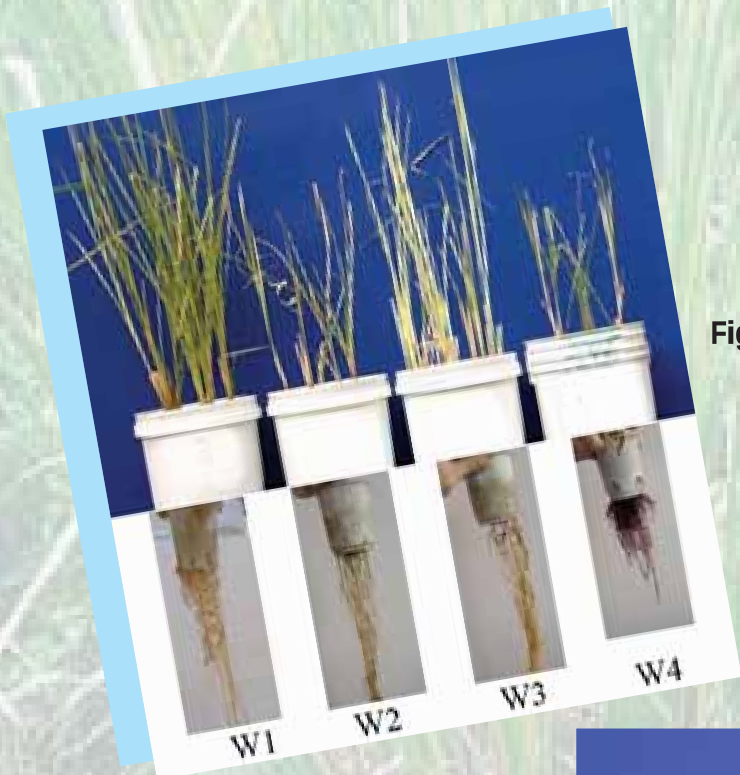


Fig. 18 Growth of vetiver grown in industrial wastewaters from milk factory (W1), battery manufacturing plant (W2), electric lamp plant (W3) and ink manufacturing facility (W4).

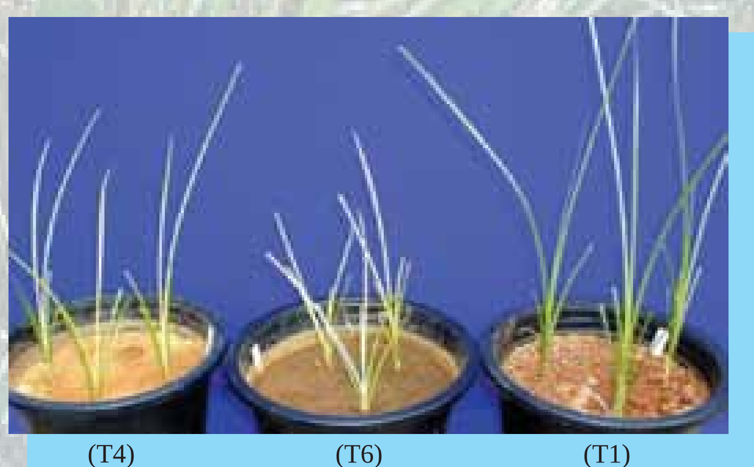


Fig. 19 Chlorosis caused by heavy metal toxicity in vetiver grown in zinc mine soil (T1), amended with DTPA (T4), and amended with combination of compost and DTPA (T6).

4. FERTILIZER AND SOIL AMENDMENTS

Nutrient availability is an important factor governing the success of phytoremediation and can be regulated through the addition of fertilizers (Hutchinson *et al.,* 2001). The influence of organic and inorganic fertilizers on growth of vetiver grown in lead and zinc mine soils had been compared in pot experiment. It demonstrated that in lead mine soil, both organic (compost) and inorganic fertilizer applications could significantly improve vetiver biomass while inorganic fertilizer gave better result than that of compost (Fig. 5). Contrary result occurred to the vetiver grown in zinc mine soil; the compost elevated vetiver biomass while the inorganic fertilizer decreased vetiver growth which gave biomass significantly different to those in control and compost treatments. However, the study of Rotkittikhun *et al.,* 2007 showed that organic fertilizer (pig manure) could improve the biomass of vetiver grown in lead mine soil while inorganic fertilizer application did not effectively improve vetiver growth. For vetiver cultivation on deteriorated land with low fertility, the Land Development Department recommended to fill the bottom of the plant holes with manure or compost. Once the tillers start to sprout, the 15-15-15 inorganic fertilizer should be added to accelerate growth at the rate of 25 kg/rai (0.4 acre), along the contour (ORDPB, 2000).

Besides increasing organic matter and nutrient content in soil, application of organic amendments, e.g., compost to mine tailings, is known to increase water holding capacity, cation exchange capacity and to improve the structure of mine tailings by forming stable aggregates (Ye *et al*., 2000; Stevenson and Cole, 1999; Krzaklewski and Pietrzykowski, 2002). These amendments also mitigate the toxicity of heavy metals and plant failure to grow in their absence (Brown *et al*., 2003). Nevertheless, the rate of application should be considered to achieve beneficial results. A field experiment performed at Padaeng Industry Public Company Limited revealed that application of compost could significantly increase growth and shoot dry weight of vetiver, however, there was no significant difference between 4 ton/rai and 8 ton/rai applications (Fig. 6 and 7). Hence, the application 4 ton/rai of compost was suggested for vetiver plantation in this area, as recommended by LDD (1998).

Since plant uptake requires metals in an environmentally mobile form, the negative charges of various soil particles tend to attract and bind heavy metals which are cations and prevent them from becoming soluble and diffuse to root surface. This causes the lower metal bioavailability in soil, which is the major limiting factor for phytoremediation. Using chelating agents such as ethylenediaminetetraacetic acid (EDTA), diethylenetriaminepentaacetic acid (DTPA), nitrilotriacetic acid (NTA) and cyclohexanediaminetetraacetic acid (CDTA) have been developed to overcome these problems (Huang and Cunningham 1996; Robinson *et al*., 1999; Cooper *et* *al*., 1999). However, the effects of chelating agents on growth performance and heavy metal uptake can differ among chelating agents, heavy metals and soils. A study by Roongtanakiat *et al.* (2009) showed that amended iron ore tailings with compost and chelating agents (EDTA and DTPA), especially the combination of DTPA and compost, could improve vetiver growth (Fig. 8 and 9) and heavy metal (Fe, Zn, Mn and Cu) uptakes (Fig. 10). However, contrary results were obtained in the zinc mine soil with the same treatments. The combination of DTPA and compost application actually reduced growth of vetiver in both height and biomass (Fig. 8 and 9). The EDTA could enhance concentration and uptakes of Zn, Mn and Cu but not Fe while DTPA increased the mentioned heavy metal concentrations but not uptakes (Fig. 11). These studies also revealed that sole compost application to iron ore tailings and zinc mine soil did not affect to heavy metal uptakes by vetiver.

5. TRANSLOCATION OF HEAVY METAL IN VETIVER

Plants absorb contaminants through root systems and store them in the root biomass and/or transport them to the stem and/or leaves. They may continue to absorb contaminants until they are harvested and disposed of safely. For phytoextraction purpose, this process is repeated several times to reduce contamination to acceptable levels. Therefore, apart from taking up large amounts of contaminants, plants should be able to transport the contaminants to the shoots, which then enable their removal. Truong (1999) reported that the distribution of heavy metals in vetiver plant can be divided into three groups: (i) Very little of the arsenic, cadmium, chromium and mercury absorbed, were translocated to the shoots (1-5%); (ii) A moderate proportion of copper, lead, nickel and selenium were translocated (16-33%); (iii) Zinc was almost evenly distributed between shoot and root (40%). However, numerous investigators (Yang *et al.,* 2003, Roongtanakiat *et al.*, 2007 and Singh *et al.*, 2007) concluded that vetiver root accumulated higher heavy metal concentrations than shoot. When vetiver plants were more mature, they could not concentrate higher heavy metal in the shoot. On the contrary the shoot heavy metal concentrations decreased, possibly due to dilution effect of increasing biomass, whilst the root heavy metal concentrations increased (Roongtanakiat and Chairoj, 2001b). These results were illustrated in Fig. 12 and 13 which compared heavy metal concentrations in shoot and root of three vetiver ecotypes planted in different levels of contaminated soils at 60 and 120 day harvest.

The ratio of metal concentrations in shoot to root is defined as translocation factor (TF) which refers to the ability of plant to translocate metals from the root to the shoot. The heavy metal translocation ability of vetiver grown in industrial wastewaters varied depending on the characteristic of growth media and metal types as shown in Table 5. The ability of vetiver to translocate heavy metal was quite low when hydroponically cultured in wastewaters with average TFs of 0.07-0.67. However, vetiver grown on iron tailings and zinc mine soils could translocate higher quantities of heavy metal from root to shoot with TFs of 0.55-0.86 and 0.50-0.89, respectively.

Soil amendments applied to iron ore tailings and zinc mine soil affected the ability of some heavy metal translocations by vetiver (Fig. 14 and 15). It was obviously shown that chelating agents (EDTA and DTPA), especially in combination with compost, could elevate Cu translocation in both mine soils. Application of soil amendments increased Fe translocation slightly in iron ore tailings while Mn

Table 5. Concentration of heavy metal in shoot and root parts and translocation factor of vetiver grown in industrial wastewater from milk factory (W1), battery manufacturing plant (W2), electric lamp plant (W3) and ink manufacturing facility (W4).

Heavy metal	Wastewater source	Concentration of heavy metal (mg kg^{-1}) in		Translocation factor
		Shoot	Root	
Mn	W1	48.12	121.55	0.40
	W2	64.76	88.65	0.73
	W3	58.24	68.73	0.85
	W4	330.26	473.21	0.70
	Average	**125.35**	**188.04**	**0.67**
Fe	W1	62.31	1430.07	0.04
	W2	83.13	791.18	0.11
	W3	64.02	977.36	0.07
	W4	165.75	3688.30	0.05
	Average	**93.80**	**1721.73**	**0.07**
Cu	W1	2.45	4.30	0.57
	W2	4.07	17.95	0.23
	W3	4.23	5.88	0.72
	W4	8.46	87.54	0.10
	Average	**4.80**	**28.92**	**0.41**
Zn	W1	14.27	82.31	0.17
	W2	25.28	192.76	0.13
	W3	18.97	134.76	0.14
	W4	46.58	148.90	0.31
	Average	**26.28**	**139.68**	**0.19**
Pb	W1	0.69	4.50	0.15
	W2	3.76	109.57	0.03
	W3	2.02	5.51	0.36
	W4	2.25	4.88	0.46
	Average	**2.18**	**31.12**	**0.07**

translocation was slightly decreased. The compost and chelating agents did not affect the Zn translocation of vetiver grown in both mine soils. Even soil amendments could enhance some metal translocations; the TFs for studied heavy metals were all less than one.

Plants used for phytoextraction purpose should have the ability to concentrate metals in their tissue, especially in the aerial part. This type of plants is called hyperaccumulator. Baker and Brooks (1989) have defined metal hyperaccumulator as plants that can take up and concentrate in excess of 0.1% a given element (pollutant involved) in their tissues i.e. more than 1000 mg g^{-1} of Cu, Cd, Cr, Pb, Ni, Co or 1% (>10000 mg g^{-1}) of Zn or Mn in the dry matter. These ratios are 10-500 times higher than those in ordinary plants. Some researches identified a plant as hyperaccumulator using the translocation factor. This factor is more than one for hyperaccumulator and less than one for ordinary plant (Raskin and Ensley, 2000; Yanqun *et al*., 2005). Therefore, many authors concluded that vetiver is a non-hyperaccumulator plant (Truong, 1999; Greenfield, 2002; Roongtanakiat, 2006).

6. DEGREE OF HEAVY METAL CONTAMINATION

Phytoremediation process depends on the tolerance of the plant to the contaminant. Truong (1999) demonstrated that vetiver is highly tolerant to many heavy metals. For vetiver growth, the shoot threshold level of As, Cd, Cu, Cr and Zn are 21-72, 45-48, 13-15, 5-18 and > 880 mg kg^{-1}, respectively. Vetiver grown in iron ore tailings could accumulate high concentrations of Cu in shoot (47 mg kg^{-1}) and in root (66 mg kg^{-1}) which was higher than the threshold level (Roongtanakiat *et al*., 2008). Even so, an extremely high degree of heavy metal concentration, in the growth media, could influence the plant and play an important role in vetiver growth, as can be noted from the following experiments.

- An experiment treated with landfill leachate indicated that the growth of vetiver was reduced as the landfill leachate strength increased (Fig. 16). The vetiver treated with 100% leachate could not survive at 80-85 days after planting. At the landfill site in Kamphaeng Saen, Nahon Phathom province, vetiver grew well during the first 1-2 months after planting. They showed a good resistance to the poor environment of the garbage landfill. The average plant heights of the two top rows were higher than those in the three lower rows which received greater leachate strength. The toxicity of leachate was more serious at the fourth month, especially in the lower rows, in which some vetiver plants gradually wilted and finally died as shown in Fig. 17.

- Industrial wastewater treatment by vetiver experiment, vetiver grown in W1 (wastewater from milk factory) had the best growth due to less content of heavy metals, while the worst growth was found in W4 (ink manufacturing facility) in which was not only contaminated with Mn, Fe but also contained Cu as high as 118.92 mg kg^{-1} above the industrial effluent standard (≤ 20 mg kg^{-1}). They appeared unhealthy with stunted plant, few tillers and whitish-yellow old leaves. Roots were stunted, cracked and brown (Fig. 18). This was probably caused by Cu toxicity as its principal effect is on root growth (Osotsapa, 2003; Sheldon and Menzies, 2005).

- In zinc mine soil with extremely high concentration of multi-heavy metals, vetiver appeared with severe chlorosis with light yellowish to white in color on young leave (Fig. 19). It may be the symptom of Zn toxicity due to the concentration of Zn in soil which was as high as 5,039 mg kg^{-1} which is very much higher than the toxic concentration level (900 mg kg^{-1}) in soil (Alloway, 1995).

7. HEAVY METAL UPTAKE

Two factors involving the heavy metal uptake, are the concentration of heavy metal in plant and plant biomass. Suitable vetiver ecotype and agricultural practice for a specific heavy metal are needed to obtain high heavy metal concentration in plant and biomass as previously described. For non-hyperaccumulator like vetiver, improving biomass and propagation are necessary for high efficiency of phytoremediation. Application of organic fertilizer can increase vetiver yield (Fig. 5-7) and may reduce toxicity of heavy metal through the adsorption of the toxic compounds to the organic matter. If chelating agents are needed for enhanced bioavailability of heavy metals, establishment of vetiver growth is required before application. Once the vetiver is fully grown, the aerial growth should be harvested periodically to remove the heavy metals from contaminated site and accelerate new growth for more uptakes.

8. CONCLUSION

Phytoremediation is an interesting alternative to current environmental cleanup methods that are energy intensive and expensive. However, it required hyperaccumulator plants such as alpine pennycress (*Thlaspi caerulescens*), Indian mustard (*Brassica juncea*), Chinese brake (*Pteris vittata* L.) as they concentrate high pollutants. However, some characteristics of these plants, for example, slow growth, low biomass and shallow root system, can limit phytoremediation efficiency. With vetiver phytoremediation, the long and dense root system of vetiver, can absorb heavy metals from the deep soil layers, then transfer to aerial part for harvest and thus reduce the metals concentration in soil. At the same time, vetiver roots can prevent leaching and runoff of heavy metals to nearby areas and ground water by immobilizing and stabilizing heavy metals. Moreover, on land affected by degradation and contamination, this plant can be an excellent pioneer plant to conserve water and improve soil quality. When hydroponic culture is applied for wastewater treatment, vetiver shoots and roots can be harvested easily to remove the pollutants. To clean up soil, the aerial part can be harvested occasionally without replanting. An important advantage of harvested vetiver is that it is not considered hazardous waste, unlike hyperaccumulator residual. It can be used safely for bio-energy production, compost or even as material for handicrafts.

This versatile technology is applicable to sites with low to moderate contamination. For extremely polluted sites, it is more suitable to use in conjunction with other remediation method. However, as previously mentioned, factors affecting vetiver growth and metal uptake must be considered before introducing vetiver. Further studies should be site based and focused on optimizing agronomic management practice. Genetic engineering and mutation breeding to modify vetiver characteristics can also be beneficial to increase utilization of vetiver technology for environmental sustainability.

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