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Comparative Growth and Distribution of Zn, Cd and Pb in Rice, Vetiver and Sunflower Grown in Contaminated Soils

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ABSTRACT

The effect of soil heavy metal (Zn, Cd and Pb) concentration on the growth and concentration in the plant parts of rice, vetiver and sunflower was comparatively investigated in pot experiments. Each plant species was grown in soils contaminated with four levels of heavy metals, based on a completely randomized design with three replications. Vetiver plants were harvested at 120 d after planting. Rice and sunflower plants were harvested at the yield stage. The results indicated that heavy metal in the soil showed an adverse effect on plant growth performances especially in rice. On moderately and highly contaminated soils, rice could not produce seed, while leaf chlorosis was observed at the tillering stage. In general, the concentration of Zn, Cd and Pb in plant parts increased as the contamination levels in the soil increased and they accumulated more in the roots than in above-ground parts. However, the Cd concentration in sunflower seed was above the maximum level tolerated by livestock. The ability of plants to translocate heavy metals from the roots to the shoots as indicated by their transfer factor (TF) was in the order: rice<vetiver<sunflower. Vetiver and sunflower could move Zn more than Cd and Pb. However, only sunflower had Zn TF values greater than 1 for all levels of contaminated soil. Therefore, sunflower was a promising plant for Zn decontamination.

Keywords: vetiver, heavy metals, zinc, cadmium, lead, phytoremediation

INTRODUCTION

Problems with heavy metal contamination in agricultural land are increasing worldwide, especially in countries that are undergoing rapid economic development, such as China (Yanai *et al.*, 1998; Wei and Chen, 2001) Japan (Makino *et al.*, 2010) Taiwan (Hseu *et al.,* 2010), Vietnam (Kien *et al.*, 2010) and Thailand (Simmons *et al.*, 2005).

Sources of heavy metals in soils result from weathering of parent materials and from human activities including mining, smelting, fertilizers and agrochemical application, as well as wastewater irrigation (Wilson and Pyatt, 2007; Khan *et al.*, 2008). Agriculture in polluted soils has faced major problems due to the transfer of heavy metals into crops and subsequently, into the food chain, which may be deleterious to human health (Puschenreiter *et al.*, 2005). In Japan, the estimated average levels of Cd, Cu and Zn in rice were 75.9, 3.71 and 22.9 mg.kg^{-1}, respectively. Fu *et al*. (2008) investigated heavy metal concentrations in rice samples from Taizhou

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city in Zhejiang province, China and found that the geometric mean of Pb in polished rice reached 0.69 $mg.kg^{-1}$ which was 3.5 fold higher than the maximum allowable concentration (MAC) of 0.20 $mg.kg^{-1}$ according to the safety criteria for milled rice. In 31% of rice samples, the Cd concentration exceeded the national MAC (0.20 $mg.kg^{-1}$) and the arithmetic mean also slightly exceeded the national MAC. In Phra That Pha Daeng sub-district, Mae Sot district, Tak province, Thailand, water for irrigation comes from Mae Tao Creek that passes through an actively mined Zn-mineralized zone. Simmons *et al.* (2005) revealed that the Cd concentration in rice grain from the 524 fields sampled ranged from 0.05 to 7.7 $mg.kg^{-1}$ with more than 90% of samples containing Cd at a concentration exceeding the Codex Committee on Food Additives and Contaminants (CCFAC) draft maximum permissible level for rice grain of 0.2 $mg.kg^{-1}$.

Phytoremediation is a green technology that uses plants to degrade, assimilate, metabolize, detoxify or immobilize environmental contaminants in soils, water or sediments (Susarla *et al*., 2002). Plants used in phytoremediation should have high biomass, high tolerance to the contaminant, high capability to accumulate significant concentrations of contaminants in their tissues and be able to adapt to a variable environment (Raskin *el al*., 1997; Lasat, 2002; Padmavathiamma and Li, 2007; Jadia and Fulekar, 2009.). Vetiver (*Chrysopogon zizanioides*) is a fast-growing grass with the ability to grow well under adverse conditions. It has been used for soil conservation and has shown potential for phytoremediation of heavy metals (Chen *et al*., 2004; Roongtanakiat, 2009). Sunflower (*Helianthus annuus* L.) also has shown a high tolerance to heavy metals and therefore has been used in phytoremediation applications (Schmidt 2003; Nehnevajova *et al*., 2005). Sunflower was successfully employed for decontamination of polluted soil with heavy metals and radionuclides (Dushenkov *el al*., 1997; Prasad, 2007). The ability of sunflower to accumulate uranium was reported by Salt *et al.* (1998) and Roongtanakiat *et al.* (2010). However, Madejon *et al.* (2003) revealed that the potential of sunflower plants for phytoextraction was very low.

The aims of this study were to determine the effects of some heavy metals on the growth of vetiver, rice (*Oryza sativa* L.) and sunflower, growing in contaminated soils. The distribution of the heavy metals in plant organs and the translocation ability of the heavy metals from roots to shoots were also compared.

MATERIALS AND METHODS

The tested plants were vetiver (Ratchaburi ecotype), rice (cultivar Pathum Thani) and sunflower (cultivar Valentine). A pot experiment based on a completely randomized design with four treatments and three replications was performed for each plant species. Three levels of heavy metal contaminated soils (S1, S2 and S3) were collected from 0–15 cm soil depth from an area in the vicinity of the zinc mine in Mae Sot district, Tak province. An uncontaminated soil (S0) sample at the Huai Sai Royal Development Study Center, Cha-am district, Phetchaburi province was used as a control treatment. The soil samples were air dried, crushed to pass through a 4 mm sieve and then mixed thoroughly for analysis. The chemical and physical properties of the soil samples are presented in Table 1. The soil pH was measured in a 1:1 water-to-soil mixture. The cation exchange capacity (CEC) of the soil was determined using the ammonium acetate saturation method (Department of Agriculture, 2001). The Walkley-Black method was used to determine the soil organic matter (Department of Agriculture, 2001). Soil texture analysis was performed using the hydrometer method (Department of Agriculture, 2001). The extracting solution for available P measurement was Bray II (Bray and Kurtz, 1945) and for the extractable K, extractable Ca and extractable Mg was ammonium acetate (Pratt, 1965).

Table 1 Properties of soil samples used in the study.

Soil property	Soil sample			
	S0	S1	S2	S3
pH	6.29	5.89	7.35	7.41
CEC (cmole.kg^{-1})	4.39	6.31	8.62	7.92
Organic matter (g.kg^{-1})	11.70	20.40	24.40	23.70
Soil texture	Sandy loam	Sandy loam	Sandy clay loam	Loam
	72	67	57	51
	15	20	20	28
	12	13	23	21
Available P (mg.kg^{-1})	98	8	4	4
Extractable K (mg.kg^{-1})	78	37	52	48
Extractable Ca (mg.kg^{-1})	395	575	2,333	2,839
Extractable Mg (mg.kg^{-1})	71	132	298	263
Total Zn (mg.kg^{-1})	14	221	1,984	6,462
Total Cd (mg.kg^{-1})	0.002	3	48	277
Total Pb (mg.kg^{-1})	0.001	14	105	345
Extractable Zn (mg.kg^{-1})	1	61	174	397
Extractable Cd (mg.kg^{-1})	Trace	1	21	35
Extractable Pb (mg.kg^{-1})	Trace	5	18	30

S0 = Uncontaminated soil, S1 = Low level of contamination in soil, S2 = Moderately contaminated soil, S3 = Highly contaminated soil, CEC = Cation exchange capacity.

Soil samples of 8, 10 and 15 kg were used to fill the plastic pots for vetiver, rice and sunflower cultivation, respectively. Uniformly sized seedlings of each plant were selected and transplanted into individual pots. The plants were watered daily and weeding was done by hand when necessary. The plant height and the number of new tillers of vetiver and rice were recorded before harvest at 120 d after planting. The number of flowers and the height of each sunflower plant were recorded before harvest at 75 d after planting. After harvest, each plant was divided: into shoot and root parts for vetiver; into grain, straw and root parts for rice; and into seed, flower, straw (stem plus leaf) and root parts for sunflower. All plant parts were gently washed with tap water and rinsed with distilled water before drying at 70 ^{o}C for 72 h to determine the dry weight. Dried samples were milled and digested with a mixture of $HNO_3/HClO_4$ (2:1 volume per volume) before heavy metal analysis using atomic absorption spectrophotometry (Baker and Amacher, 1982; Burau, 1982)

Data on the plant growth and concentration of heavy metals were analyzed using analysis of variance and least significant difference for mean comparisons. The transfer factor of each heavy metal was determined as the ratio of the heavy metal concentration in the shoot to that in the root.

RESULTS AND DISCUSSION

Plant growth and biomass

The growth and development of rice plants were strongly influenced by heavy metal in the soil. The plant height, number of new tillers, straw and root biomass of rice grown in contaminated soils significantly decreased as the level of contamination increased (Table 2). In highly contaminated soil (S3), the numbers of new tillers, straw and root dry weights decreased by 86–90% compared to those of the control (S0). Leaf chlorosis in rice grown on moderately (S2) and highly contaminated soils (S3) was observed at the tillering stage and plants could not produce seed under these treatments. In the soil with the low level low of contamination (S1), the presence of heavy metal did not affect the plant height but the seed yield was reduced by 39% compared to the control. The inhibition of rice growth by heavy metals has been reported by many researchers (Moya, *et al*., 1995; Zhou *et al*., 2003; Rascio *et al*., 2008). Mahmood *et al*. (2007) reported that increasing the concentration of heavy metals significantly inhibited the early growth of rice seedlings. A higher concentration of heavy metals has been reported to retard cell division and differentiation, reduce elongation and affect plant growth and development (Soares *et al.*, 2001 cited by Chaves *et al.,* 2011).

Vetiver grew well in the studied contaminated soils, except for the plants cultivated in the highly contaminated soil (S3) which had significantly lower heights than under the other treatments (Table 3). Vetiver was reported as one of the best choices for revegetation of Pb/Zn mine tailings in China, due to its high metal tolerance (Xia and Shu, 2001; Shu *et al*., 2002; Shu and Xia, 2003). However, in the current study, heavy metal showed an adverse effect on vetiver tillering and biomass. Vetiver grown on contaminated soils (S1–S3) produced significantly lower numbers of new tillers as well as lower shoot and root dry weights than those of the control treatment (S0), though there was no significant difference among

Table 2 Average height, number of new tillers and dry biomass of rice grown in soils with four levels of heavy metal contamination.

Soil	Height (cm)	Number of new tillers	Dry biomass (g)		
			Grain	Straw	Root
S0	108[a]	28[a]	60.4	65.3[a]	37.3[a]
S1	112[a]	20[b]	36.7	44.4[b]	16.9[b]
S2	67[b]	4[c]	-	13.2[c]	3.9[c]
S3	57[c]	4[c]	-	7.4[c]	3.9[c]

S0 = Non-contaminated soil, S1 = Low level of contamination in soil, S2 = Moderately contaminated soil, S3 = Highly contaminated soil.
Values in the same column with a common superscript letter are not significantly different at the 0.05 probability level.

Table 3 Average height, number of new tillers and dry biomass of vetiver grown in soils with four levels of heavy metal contamination.

Soil	Height (cm)	Number of new tillers	Dry biomass (g)	
			Shoot	Root
S0	128[a]	8[a]	31.1[a]	12.1[a]
S1	125[a]	4[b]	26.2[b]	8.8[b]
S2	126[a]	4[b]	24.6[b]	8.1[b]
S3	119[b]	4[b]	23.6[b]	10.0[b]

S0 = Non-contaminated soil, S1 = Low level of contamination in soil, S2 = Moderately contaminated soil, S3 = Highly contaminated soil.
Values in the same column with a common superscript letter are not significantly different at the 0.05 probability level.

the contaminated treatments. Excess zinc in the contaminated soils might have caused a reduction in vetiver growth especially in the moderately (S2) and highly (S3) contaminated soils where the Zn concentrations were as high as 1,984 and 6,462 $mg.kg^{-1}$, respectively. These concentration levels were above the Zn threshold level (1,500 $mg.kg^{-1}$) in soil for vetiver growth as reported by Troung (1999).

Sunflower plants cultivated in moderately contaminated soil (S2) had a significantly lower height than those under the other treatments (Table 4). However, the flower number under this treatment was not significantly different from the control (S0) and highly contaminated soil (S3) treatments. The highest flower dry biomass was observed on plants grown in the soil with a low level of contamination (S1) which was significantly higher than those in the other treatments. The low concentration of heavy metal might have stimulated the growth of sunflower as demonstrated by Jadia and Fulekar (2009). However, heavy metals had no significant effect on the straw and root dry biomass in the current study. This information showed that sunflower appeared to be quite resistant to heavy metals as also mentioned by Madejon *et al*. (2003), while decreasing height and biomass production as a result of heavy metal were reported by Chaves *et al*. (2011) and Yu *et al*. (2011).

Heavy metal concentration in plant parts

The average concentrations of the studied heavy metals (Zn, Cd and Pb) in the different plant parts of rice, vetiver and sunflower are shown in Tables 5–7. As expected, the three plant species grown in uncontaminated soil (S0) had the lowest heavy metal concentrations in all plant parts. The concentration in the plant increased as the contamination levels in the soil increased. The observed increase in the heavy metal absorption by plants as the soil heavy metal concentrations increased was in agreement with the studies of Jung and Thornton (1997), Roongtanakiat and Chairoj (2001), Chen *et al*. (2004) and Jadia and Fulekar (2008).

The heavy metal concentrations in rice were in the following order: Zn>Pb>Cd. They accumulated more in the roots than in the above-ground parts where there was greater accumulation in the straw than in the grain. This result was similar to the report of Jung and Thornton (1997) who found that rice grain contained relatively low concentrations of heavy metals compared to the rice stalks, while Zhuang *et al*. (2009) revealed that rice tended to accumulate higher Cd and Pb concentrations in the grain. Rice grown in the soil with a low level of contamination (S1) produced Zn, Cd and Pb concentrations in the grain of 17.81, 0.0641 and 1.641 $mg.kg^{-1}$, respectively; which were higher than those in the control treatment.

Table 4 Average height, number of flowers and dry biomass of sunflower grown in soils with four levels of heavy metal contamination.

Soil	Height (cm)	No. of flowers	Dry biomass (g)			
			Seed	Flower	Straw	Root
S0	78.1^{a}	5.9^{a}	9.9^{a}	16.7^{b}	22.4^{a}	3.2^{a}
S1	75.3^{a}	5.1^{ab}	9.5^{ab}	19.3^{a}	26.8^{a}	2.8^{a}
S2	69.5^{b}	5.1^{ab}	7.7^{b}	15.6^{b}	22.1^{a}	2.5^{a}
S3	79.5^{a}	4.4^{b}	7.8^{b}	14.1^{b}	21.0^{a}	2.6^{a}

S0 = Non-contaminated soil, S1 = Low level of contamination in soil, S2 = Moderately contaminated soil, S3 = Highly contaminated soil.
Values in the same column with a common superscript letter are not significantly different at the 0.05 probability level.

Unlike Zn, Cd and Pb are non-essential elements for plant growth and their high concentrations in grain could cause a risk if consumed by humans and animals. However, the rice grain from S1 had a low concentration of Cd and Pb (0.0641 and 0.1642 mg.kg^{-1}, respectively) in comparison to the MAC (0.2 mg.kg^{-1}) and thus was acceptable for consumption.

In the vetiver plants, the concentration of Zn was highest while Cd and Pb had similar

Table 5 Average concentration of Zn, Cd and Pb in grain, straw and roots of rice grown in soils with four levels of heavy metal contamination.

Heavy metal per plant part	Concentration of heavy metal (mg.kg^{-1}) in rice grown in soil			
	S0	S1	S2	S3
Zn				
Grain	14.62	17.81	-	-
Straw[2/]	28.55^{c}	28.96^{b}	32.41^{b}	63.99^{a}
Root	30.11^{c}	123.74^{b}	519.63^{b}	1434.52^{a}
Cd				
Seed	0.0005	0.0641	-	-
Straw	0.027^{c}	1.121^{b}	1.480^{b}	3.126^{a}
Root	0.01^{c}	2.55^{c}	11.92^{b}	28.02^{a}
Pb				
Seed	0.0014	0.1642	-	-
Straw	0.031^{b}	1.702^{b}	9.598^{a}	11.955^{a}
Root	0.03^{c}	7.292^{c}	67.109^{b}	98.796^{a}

S0 = Non-contaminated soil, S1 = Low level of contamination in soil, S2 = Moderately contaminated soil, S3 = Highly contaminated soil.
Values in the same row with a common superscript letter are not significantly different at the 0.05 probability level.

Table 6 Average concentration of Zn, Cd and Pb in shoots and roots of vetiver grown in soils with four levels of heavy metal contamination.

Heavy metal per plant part	Concentration of heavy metal (mg.kg^{-1}) in vetiver cultivated in soil			
	S0	S1	S2	S3
Zn				
Shoot[2/]	16.1^{d}	145.9^{c}	228.9^{b}	250.2^{a}
Root	17.1^{d}	211.8^{c}	260.0^{b}	435.2^{a}
Cd				
Shoot	0.003^{c}	3.832^{b}	3.686^{b}	5.783^{a}
Root	0.07^{d}	4.12^{c}	18.89^{b}	30.75^{a}
Pb				
Shoot	0.005^{c}	2.473^{b}	4.186^{a}	4.215^{a}
Root	0.06^{d}	5.59^{c}	11.32^{b}	22.88^{a}

S0 = Non-contaminated soil, S1 = Low level of contamination in soil, S2 = Moderately contaminated soil, S3 = Highly contaminated soil.
Values in the same column with a common superscript letter are not significantly different at the 0.05 probability level.

concentration levels (Table 6). All heavy metal concentrations in the roots were higher than those in the shoots. These results were similar to the reports of Yang *et al*. (2003) and Rotkittikhun *et al*. (2007). Lai and Chen (2004) found that the Zn and Cd concentrations in vetiver shoots ranged from 390 to 520 mg.kg^{-1} and ranged from 20 to 30 mg.kg^{-1}, respectively, when vetiver was planted in artificially contaminated soils. In the current study, the concentrations of Zn (145.9–250.2 mg.kg^{-1}) and Cd (3.8–5.8 mg.kg^{-1}) in the shoots were lower than those obtained by Lai and Chen (2004). The difference in the heavy metal concentrations using vetiver might have been due to the difference in the vetiver species as Alloway (1995) reported that plant species and varieties differ widely in their absorption and accumulation of heavy metals.

The Pb concentration in vetiver shoots grown in soil with low, medium and high levels of contamination was 2.5, 4.19 and 4.2 mg.kg^{-1}, respectively. These concentrations were lower than the results of Chen *et al.* (2004), who reported vetiver shoot Pb concentrations of 42, 160 and 243 mg.kg^{-1} in soils with 500, 2500 and 5,000 mg Pb kg^{-1}, respectively, which were as low as the Pb concentrations in the contaminated soils used in the current study (14–345 mg Pb kg^{-1}). Even the Cd and Pb concentrations in the shoots were quite low, being 1,277–1,927 times and 495–843 times higher, respectively, than those under the control treatment, while Chen *et al.* (2000) reported that the concentrations of Cd and Pb in the shoots of vetiver were 120–260% and 500–1,200% higher in contaminated plots than in the control.

In sunflower plants, the results showed that the heavy metals were accumulated in the following order: Zn>Cd>Pb. Among plant parts, the highest concentrations of these metals were in the roots followed by the straw, flowers and seed for Cd and Pb. For Zn, the highest concentration

Table 7 Average concentration of Zn, Cd and Pb in seed, shoots and roots of sunflower grown in soils with four levels of heavy metal contamination.

Heavy metal per plant part	Concentration of heavy metal (mg.kg^{-1}) in sunflower cultivated in soil			
	S0	S1	S2	S3
Zn				
Seed[2/]	30.5^{c}	53.2^{b}	59.6^{b}	76.7^{a}
Flower	11.7^{c}	81.9^{b}	115.4^{b}	206.5^{b}
Straw	11.5^{c}	273.7^{b}	342.1^{a}	382.6^{a}
Root	17.6^{c}	206.5^{b}	223.9^{b}	317.2^{a}
Cd				
Seed	0.01^{d}	0.69^{c}	4.23^{b}	5.54^{a}
Flower	0.02^{c}	1.32^{c}	19.23^{b}	24.52^{a}
Straw	0.02^{c}	1.41^{c}	21.77^{b}	28.12^{a}
Root	0.07^{c}	1.63^{c}	29.14^{b}	39.95^{a}
Pb				
Seed	0.004^{d}	1.001^{c}	1.666^{b}	2.306^{a}
Flower	0.036^{c}	2.588^{b}	3.647^{a}	4.220^{a}
Straw	0.019^{c}	3.008^{b}	4.255^{b}	6.343^{a}
Root	0.041^{c}	4.333^{b}	5.800^{b}	12.135^{a}

S0 = Non-contaminated soil, S1 = Low level of contamination in soil, S2 = Moderately contaminated soil, S3 = Highly contaminated soil.

Values in the same column with a common superscript letter are not significantly different at the 0.05 probability level.

was found in the straw followed by the roots, straw, flowers and seed. According to Jadia and Fulekar (2008), the shoots of sunflower represent the major organ of heavy metal accumulation and a significant accumulation of Zn in the above-ground parts of sunflowers (*Tithonia diversifolia* and *H. annuus*) compared to the roots was revealed by Adesodun *et al*. (2010). However, Yankov and Tahsin (2001) reported that Zn and Pb were selectively accumulated in the roots and shoots, while Cd was localized in the roots and seed. Sunflower plants with a higher Cd concentration in the roots and a lower concentration in the shoots were also reported by Pritsa *et al*. (2008). The highest concentrations of Zn, Cd and Pb in the sunflower seed reached 76.7, 5.54 and 2.31 $mg.kg^{-1}$, respectively. Only the Cd concentration in the sunflower seed was above the maximum level tolerated by livestock (0.5 $mg.kg^{-1}$) according to Chaney (1989) as cited by Murillo *et al*. (1999). These results agree with those of Rojas-Cifuentes *et al*. (2012), who reported that sunflower accumulated high Cd levels in the seed.

Transfer factor

The transfer factor (TF; the ratio of shoot heavy metal concentration to root heavy metal concentration) was used as an index to evaluate the ability of plants to translocate heavy metals from the roots to shoots and the accumulative capacity of heavy metals by plants. The ability of rice plants to move the three heavy metals (Zn, Cd and Pb) was very weak, with TF values for Zn, Cd and Pb ranging from 0.045 to 0.234, from 0.112 to 0.439 and from 0.121 to 0.233, respectively (Figure 1). The rice grown in the S1 soil had the highest TF value, while it reduced with increasing heavy metal concentrations in the S2 soil and then remained stable. The TF value varied from metal to metal and from soil to soil due to soil properties and the metal availability as reported by Smolders (2001) and the crop Cd concentrations were strongly influenced by soil properties that controlled the Cd availability in the soil. For non-essential heavy metals, the TF value of Pb was lower than that of Cd which was a similar result to that of Park *et al.* (2011) who reported that the TF values of Cd and Pb were 0.013 and 0.002, respectively.

Vetiver had the highest Cd transfer factor (0.74) when it was grown in the soil with a low level of contamination. The transfer factor was reduced under medium contamination and then remained constant, similar to the pattern in rice. Pb could be moved from the roots to the shoots more easily in vetiver than in rice, with the mean TF value being 0.32. The Zn TF value ranged from 0.88 to 0.54, which indicated that vetiver could translocate Zn better than Cd or Pb. Considering that a suitable phytoremediation plant species should accumulate more heavy metals in the shoot parts than in root parts (Baker, 1981), a TF factor greater than one is desirable. The TF of Zn (0.88) was close to this desired value and vetiver could produce high biomass with a high C4 photosynthetic efficiency (Maffei, 2002). Therefore, it could be suggested that vetiver is a competent plant for the cleanup of Zn from soil with a medium level of contamination. Moreover, its long, deep root system will protect land and ground water nearby from Zn contamination.

The concentration of heavy metals in the soil affected the translocation ability in sunflower less than that in rice or vetiver. The TF of Zn, Cd and Pb ranged from 1.21 to 1.53, from 0.70 to 0.87 and from 0.52 to 0.73, respectively. These TF values were higher than those of rice and vetiver grown in soils at all the studied contamination levels, which implied that Zn, Cd and Pb could be transferred from the roots to the shoots of sunflower better than with rice and vetiver. The mean Cd TF value of sunflower was 0.77, which was about twice as high as that reported by Pritsa *et al.* (2008). However, Kamnev and van der Lelie (2000) reported that sunflower had a low efficiency in translocation of Cd from the roots to the shoots. In sunflower, the TF values of Zn were greater than 1 for all studied levels of contamination in

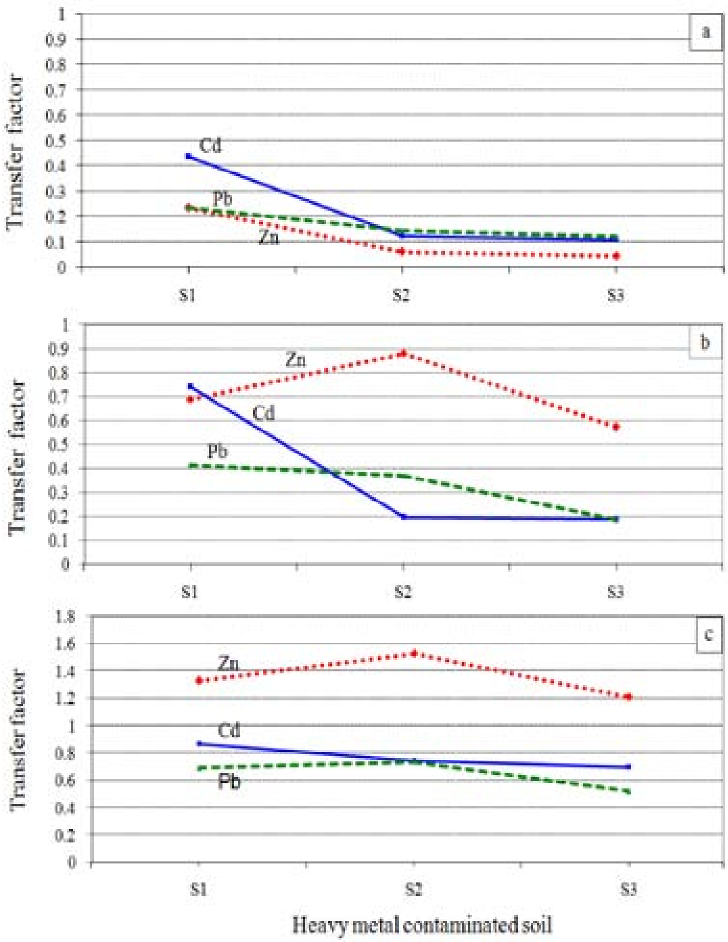

Figure 1 Transfer factor values of Zn, Cd and Pb in: (a) rice; (b) vetiver; (c) sunflower grown in soils with different levels of heavy metal contamination (S0= Non-contaminated soil, S1 = Low level of contamination in soil, S2 = Moderately contaminated soil, S3 = Highly contaminated soil).

soils, which supported the findings of Lai *et al.* (2009) and Adesodun *et al.* (2010) who reported that sunflower had TF values of 3.15 and 1.28, respectively. The differences in TF values might have been due to the effect of soil properties (Pritsa *et al.,* 2008) and plant variety (Adesodun *et al*., 2010). The high TF value of sunflower confirmed that it was a promising plant for heavy metal decontamination (Prasad, 2007).

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