JOURNAL OF
ECOLOGY AND ENVIRONMENT
http://www.jecoenv.org

Research Paper
J. Ecol. Environ. 38(2): 123-131, 2015

The response of plants growing in a landfill in the Philippines towards cadmium and chromium and its implications for future remediation of metal-contaminated soils

Patricia Anne G. Nazareno[1*] and Inocencio E. Buot, Jr.[2]

[1]Biology Program and Environmental Studies Program, University of the Philippines Cebu, Cebu City 6000, Philippines
[2]Institute of Biological Sciences, University of the Philippines Los Baños, Los Baños 4031, Philippines

Abstract

During several visits to the Cebu City landfill in the Philippines, plants were observed growing within the area, including on top of the garbage piles. Studying the response of these plants is important in assessing which can be used in remediating metal contaminated soils. This study aimed to determine whether the plants in the Cebu City landfill excluded or accumulated cadmium (Cd) and chromium (Cr) in the plant tissues. The floristic composition of the landfill was analyzed prior to the sample collection. The samples were acid-digested before the desired elements were measured using atomic absorption spectrophotometry (AAS). The Cd and Cr concentrations in the plant root-zone soil were also measured using AAS. The results indicated that the landfill substrate was generally acidic based on the results of the pH measurement. Of the 32 plant species sampled, *Cyperus odoratus* showed potential for Cd uptake and internal transfer; *Cenchrus echinatus*, *Vernonia cinerea* and *Terminalia catappa* for Cr uptake, and *Cynodon dactylon* for Cr internal transfer. The plants in the landfill differed in their response towards the heavy metals. To confirm the behavior of *C. odoratus* towards Cd, and *C. echinatus, C. dactylon, V. cinerea,* and *T. catappa* towards Cr, controlled experiments are recommended, as the plant samples analyzed were collected from the field.

Key words: Cd/Cr uptake, metal contamination, metal transfer

INTRODUCTION

For the past twenty-five years or so, studies have shown that plants growing in contaminated soils can tolerate otherwise toxic levels of certain pollutants. Plant communities respond differently to the presence of metals in the soil. Some plants have developed sensitivity to some metals even at very low concentrations while others have developed resistance to the toxic metal stress, which can be achieved either through avoidance or tolerance (Baker 1987). Tolerant plants can accumulate the contaminant in their tissue and this ability to take up pollutants including a variety of metals differs among the plant species (Freitas et al. 2004, Szarek-Lukaszewska et al. 2004, Fischerova et al. 2006). On the other hand, excluder plants restrict contaminant uptake into their biomass (Chaudhry et al. 1998). Unlike organic compounds, the metals released from the decomposition of the waste are not degraded and can stay in the soil by sorption and precipitation for a long time (Jensen et al. 2000). During landfill stabilization, the metals present may be solubilized and become bioavailable (Cecen and Gursoy 2000). When oxygen and

http://dx.doi.org/10.5141/ecoenv.2015.014

Received 17 November 2014, **Accepted** 26 January 2015

***Corresponding Author**
E-mail: pgnazareno@up.edu.ph
patricia.g.nazareno@gmail.com
Tel: +63-32-233-8398

pISSN: 2287-8327 eISSN: 2288-1220

oxygen-rich rain enters the landfill, metals will gradually be released from where they are bound (Ostman et al. 2006).

Plant species that have colonized an area in which other plants cannot survive have a potential role in remediating the area (Kim and Lee 2007). Studying the behavior of these plants growing on contaminated soils may be effective for selecting plants that can be used in remediating the soil. In the Philippines, studies on the type of vegetation found in landfills and the role they would play in future rehabilitation efforts seem to be limited or have not been conducted at all.

This study aimed to determine the level of cadmium (Cd) and chromium (Cr) in plant root-zone soil and in the roots, stems, and leaves of plants collected from a landfill; Cd and Cr are part of eight metals identified in polluted environments. Being highly urbanized, it is perceived that a big bulk of the waste thrown to the Cebu City landfill is composed of metal-containing household waste, and industrial and laboratory wastes. A study on the heavy metal content of combustible municipal solid waste in Denmark showed that Cd and Cr were present in the waste (Riber et al. 2005). Cd enters the environment through several activities including disposal of municipal solid waste; the metal is toxic and has a long biological half-life (Sankaran and Ebbs 2007). Cr is considered an essential element in trace amounts (Prasad and de Oliveira Freitas 2003), but the hexavalent form of Cr is relatively toxic (Shanker et al. 2005); in a study on the composition of a municipal solid waste deposition cell, it was found that 30% of the total amount of heavy metals including Cd and Cr in the wastes were in an available reactive form (Flyhammar et al. 1998).

The metal concentration values obtained were used to calculate the Bioconcentration Factor (BCF) and Translocation or Transfer Factor (TF), which were used to quantitatively express metal tolerance or avoidance.

MATERIALS AND METHODS

The study area

The Cebu City Landfill is located in Barangay Inayawan, Cebu City (barangay is the smallest administrative division in the Philippines) in the Philippines (Fig. 1). The city is known to remain wet and humid throughout the year due to the rainfalls and the humidity at almost 80% all year; the rainy season is seen from June to December (Weather and climate: Cebu Philippines). The city-owned landfill covered a reclaimed area equivalent to approximately 160,000 m^2. It became operational in 1998 with a projected lifespan of seven years, but stopped operating only in late 2011. Although the landfill was designed as a sanitary landfill, it did not incorporate landfill and leachate treatment systems, and thus was considered a poorly controlled landfill. The soil cover was mainly limestone mixed with the soil from the garbage and drainage. Kim and Lee (2007) described a poorly controlled landfill as one with no landfill gas and leachate treatment system and having a final soil covering of minimal thickness and low quality.

Analysis of Cd and Cr content in the root-zone soil and plant organs

A reconnaissance survey was conducted prior to the vegetation survey conducted in February 2010 to determine the sampling sites. Plant and soil samples were collected during the vegetation survey conducted late 2009 and early 2010, prior to the closure of the landfill. Patches of vegetation on top of the wastepile were identified based on the homogeneity of the existing plant communities, with each 1 m^2 patch considered as a sampling site (Banaticla and Buot 2005). Thirty-two plant species were collected from areas where dumping activities were no longer done (Fig. 2). The collection of plants was similar to the one conducted by Dogan et al. (2014). At each patch, 3 to 4 individuals were randomly collected (Freitas et al. 2004) and were mixed to form a composite of the plant species.

All the reagents used were of analytical grade, and deionized distilled water was used for all dilutions and for the washing of the plant samples. The glasswares used were soaked overnight in 5% nitric acid (HNO_3) solution and rinsed thrice with deionized water prior to use.

Soils were collected from the same sites as the plant samples, from a 0-25 cm depth plant root zone (Baker et al. 1994, Gonzalez and Gonzalez-Chavez 2006); the roots of some of the plants were able to penetrate the garbage under the soil cover. The root-zone soil samples were mixed to form a composite (Sankaran and Ebbs 2007). Soil and debris attached to each individual plant were removed manually and added to the composite soil samples. The soil samples were air-dried for 5-7 days. Residues including tiny roots of plants were removed before the soil was ground and sieved (Wang et al. 2003). The soil samples were microwave-digested prior to the determination of the concentration of Cd and Cr using the Atomic Absorption Spectrophotometer (AAS) (AA-6300; Shimad-

http://dx.doi.org/10.5141/ecoenv.2015.014

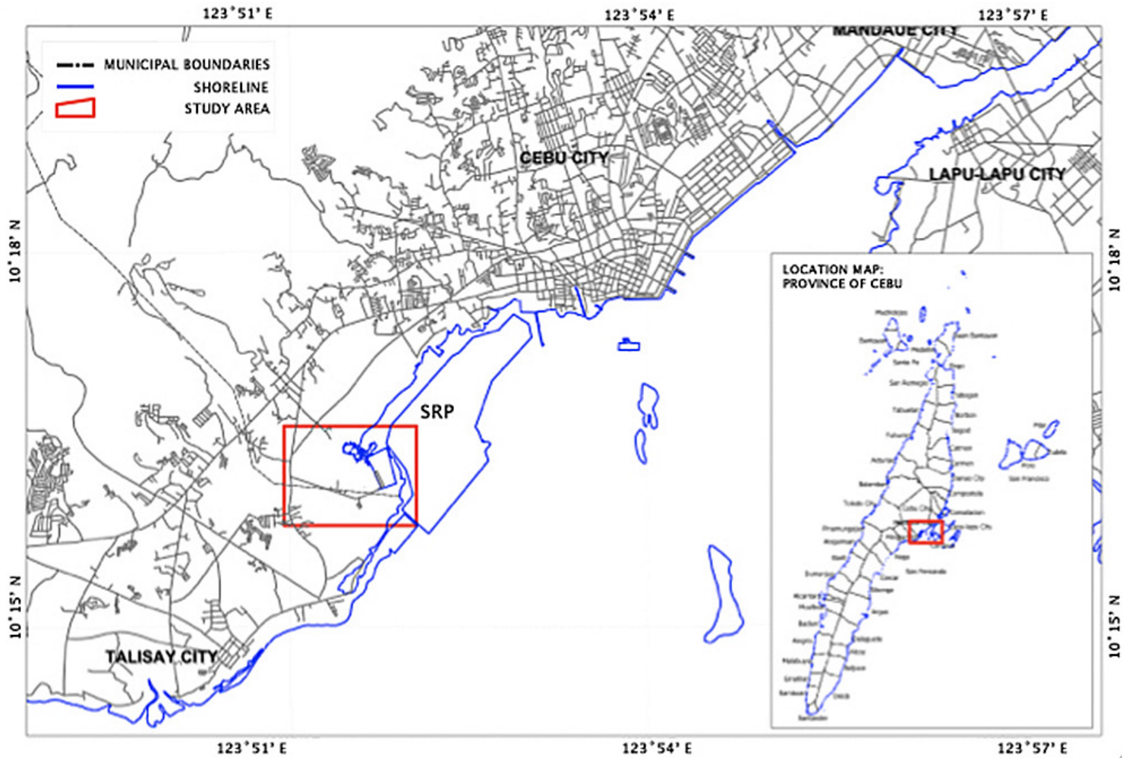

Fig. 1 Barangay Inayawan (boxed) in Cebu City, Philippines where the landfill is located.

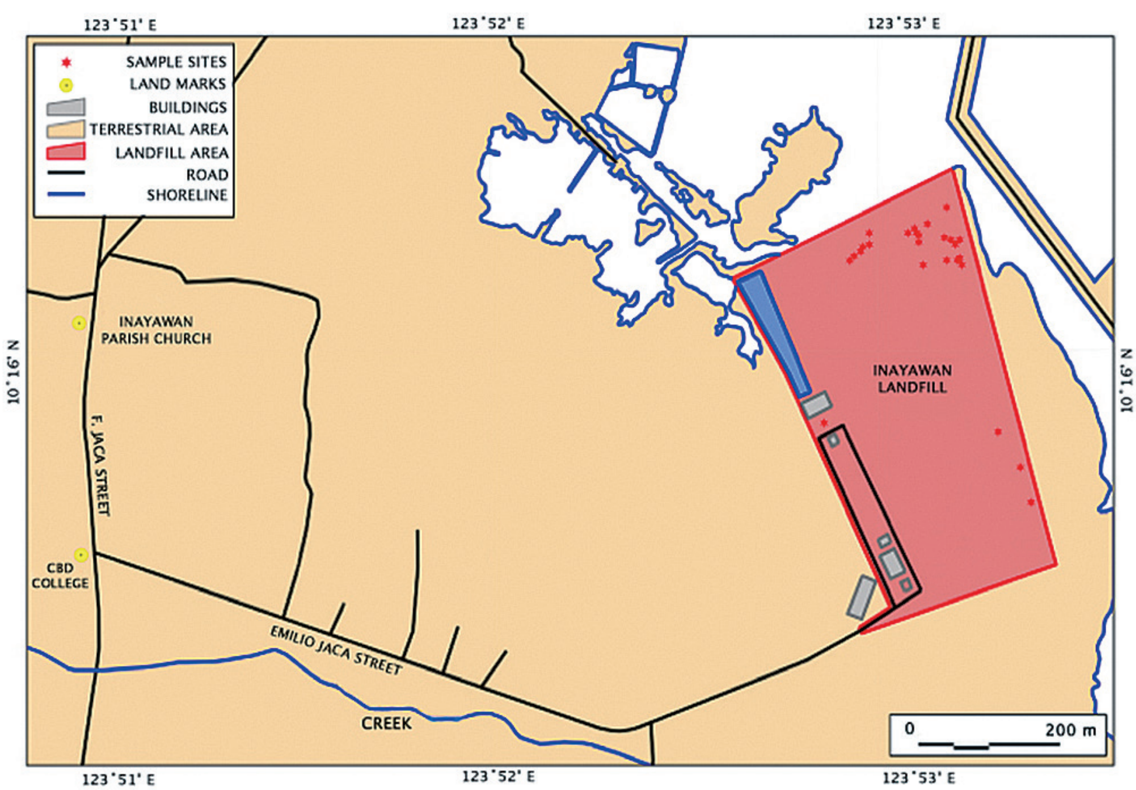

Fig. 2 Location of the sampling sites, Inayawan Landfill, Cebu City in the Philippines.

zu, Kyoto, Japan) flame technique.

Soil pH in the water and in the calcium chloride ($CaCl_2$) solution (Rajakaruna and Bohm 2002) was measured using a pH meter (Basic pH Meter PB-20; Sartorius, Göttingen, Germany). The latter was done in order to mask the variability in salt contents of soils and to maintain the soil in a flocculated condition (Jones 2001). About 2 g of each soil sample was placed in a 125 mL Erlenmeyer flask and was added with deionized water using a 1:5 proportion. After the soil pH in the water was determined, 1-2 drops of $CaCl_2$ were added to the soil-water suspension. The suspension was stirred several times within a period of thirty minutes and was then allowed to stand before taking the pH reading (Rajakaruna and Bohm 2002).

In the laboratory, the samples of the thirty-two plant species identified plants were rinsed with tap water to remove loose materials on the surface and then rinsed twice with ethylene diaminetetraacetic acid (EDTA) for about a minute per rinsing to remove any possible adsorbed metals (Gothberg et al. 2002). Final rinsing with deionized distilled water was done thrice. The plants were then separated into roots, stems and leaves, and then air-dried (Robinson et al. 2000, Gothberg et al. 2002, Remon et al. 2005, Segura-Muñoz et al. 2006). An agate mortar and pestle was used to ground the air-dried samples and for hard plant parts an electronic food mill was used. The samples were then oven-dried at 80°C to constant weight (Carlosena et al. 1997, Robinson et al. 2000, Sharma et al. 2008).

The wet-digestion of the samples that followed was done under a fumehood using the procedure employed by Tüzen (2003). About 2 grams each of the samples were

Table 1. Soil pH and level of Cd and Cr in the plant root-zone soil, Cebu City landfill in the Philippines

Root-zone soil	pH_{H2O}	pH_{CaCl2}	[Cd] (mg kg^{-1})	[Cr] (mg kg^{-1})
Andrographis sp.	6.18	5.99	1.01	19.5
Borreria articularis	6.67	6.50	*bdl	21.4
Cardiospermum halicacabum	6.77	6.51	1.51	17.1
Cenchrus echinatus	6.85	6.76	*bdl	28.6
Chloris barbata	7.00	6.91	*bdl	7.93
Chromolaena odorata	6.59	6.53	*bdl	67.2
Coccinia grandis (L.) Voight	6.69	6.49	1.05	17.9
Commelina benghalensis	6.99	6.66	*bdl	9.89
Corchorus olitorius L.	7.05	6.93	*bdl	14.9
Cucumis melo L.	6.40	6.31	*bdl	82.8
Cynodon dactylon	6.72	6.70	*bdl	22
Cyperus odoratus	6.44	6.67	0.63	22.9
Cyperus sp.	6.31	6.60	*bdl	21.1
Eleusine indica	7.01	6.97	*bdl	16.2
Eragrostis sp.	6.50	6.41	*bdl	22.1
Euphorbia hirta	6.75	6.63	*bdl	26.8
Ficus religiosa	6.46	6.43	*bdl	29.1
Ipomoea triloba	6.75	6.73	*bdl	56.1
Ipomoea sp.1	6.78	6.53	*bdl	23.3
Ipomoea sp.2	6.34	6.18	0.99	124
Leucaena leococephala	6.46	6.43	*bdl	29.1
Portulaca oleracea	6.48	6.46	*bdl	47.3
Phyllanthus amarus Schum.&Thom	7.11	6.93	1.58	27
Ricinus cumunis	7.24	7.02	*bdl	10.8
Saccharum spontaneum	6.65	6.50	*bdl	137
Senna alata	6.80	6.63	*bdl	32.1
Sida cordifolia	6.84	6.56	*bdl	8.36
Stachytarpheta jamaicensis (L.) Vahl.	7.03	6.82	*bdl	10.5
Terminalia catappa	6.46	6.43	*bdl	29.1
Tridax procumbens	6.52	6.49	*bdl	23.9
Vernonia cinerea	6.49	6.43	*bdl	26.5
Zizyphus mauritiana Lam.	6.84	6.67	*bdl	17.2

*bdl - below detection limit

placed in a 250-mL Erlenmeyer flask. Ten mL of concentrated H_2SO_4 was cautiously added and the mixture was shaken until no lumps remained. About 5 mL of concentrated HNO_3 was added to the mixture and mixed. A glass funnel was placed on the Erlenmeyer flask and the reacting mixture was allowed to stand overnight. The reacting mixture was heated cautiously on a hot plate until the vigorous reaction subsided. Each sample was then allowed to cool. Five mL of concentrated HNO_3 was added, replacing the cover and refluxed for about 30 minutes. If brown fumes were still produced, indicating the oxidation of the sample by the HNO_3, the addition of 5 mL concentrated HNO_3 was repeated over until no brown nitrous fumes were given off by the sample, indicating the complete reaction with HNO_3. During this time, a transparent solution was obtained.

The mixture was then heated until white fumes were evolved and the solution was allowed to concentrate to about 5 mL by heating it at 80-85°C without boiling for two hours. A covering of solution was maintained over the bottom of the vessel at all times. The solution was then cooled and 2 mL of deionized water and 3 mL of 3% hydrogen peroxide (H_2O_2) were added. The glass funnel was put back to cover the vessel and the covered vessel was returned to the heater for warming and to start the peroxide reaction. This was done carefully to ensure no losses due to excessive vigorous effervescence. The mixture was heated until the effervescence subsided and the vessel was then cooled. The H_2O_2 solution was continually added in 1-mL aliquots, with warming, until the effervescence was minimal. When the digest was clear, the funnel was removed and the resulting solution was heated at about 80°C nearly to dryness.

Bioconcentration Factor (BCF) and Transfer Factor (TF)

Bioconcentration Factor is defined as the ratio of the total metal concentration in the roots to that in the soil (Elkhatib et al. 2001, Gonzalez and Gonzalez-Chavez 2006, Yoon et al. 2006):

$$BCF = [M]_{roots} / [M]_{soil}$$

where $[M]_{roots}$ is the total metal concentration in the roots, and $[M]_{soil}$ is the total metal concentration in the soil, and wherein for this particular study the metal refers to chromium and cadmium.

Translocation or Transfer Factor (Mocko and Waclawek 2004, Yoon et al. 2006, Sanghamitra et al. 2012) is defined as the ratio of the total Cr or Cd concentration in the shoots to the roots:

$$TF = [M]_{leaves} / [M]_{roots}$$

where $[M]_{leaves}$ is the total Cr or Cd concentration in the leaves, and $[M]_{roots}$ is the total Cr or Cd concentration in the roots.

TF indicates internal metal transportation (Nouri et al. 2009). According to Yoon et al. (2006), both the BCF and TF can be used to estimate a plant's potential for phytoremediation; BCF is used to estimate a plant's ability to accumulate the metal in the roots while TF is used to estimate a plant's ability to translocate metals from the roots to above-ground parts. Plants exhibiting BCF and TF values less than one are unsuitable for phytoextraction (Yoon et al. 2006).

RESULTS AND DISCUSSION

Root-zone soil pH and concentration of Cd and Cr

The results of the determination of the soil pH in both deionized water and in $CaCl_2$ solution, as well as concentration of metals in the plant root-zone soil, are presented in Table 1. Results show that the soil samples were under generally acidic conditions with pH_{H2O} ranging from 6.18-7.24 and pH_{CaCl2} ranging from 5.99-7.02. The mean pH_{H2O} was 6.69 and mean pH_{CaCl2} was 6.58, as presented in Table 2, which also shows the range, mean, and standard deviation for root-zone soil Cd and Cr concentrations. The soil chemical properties significantly affect the distribution of the metals among the different soil fractions (Mocko and Waclawek 2004). For instance, pH is an important factor influencing the availability of metals in the soil for plant uptake (Prasad and de Oliveira Freitas 2003, Bradl and Xenidis 2005). Jones (2001) stated that the pH_{CaCl2} value is lower than pH_{H20} and this was evident in this study. Under acidic conditions (pH 4.0-8.5), metal cations are mobile (Saxena and Misra 2010).

Bert et al. (2002) considered soil to be contaminated if it contains greater than 2 mg kg^{-1} Cd, based on the

Table 2. Summary of results for pH and soil concentrations of Cd and Cr, Cebu City landfill in the Philippines

Parameter	Range	Mean	Standard deviation
pH_{H2O}	6.18-7.24	6.69	0.26
pH_{CaCl2}	5.99-7.02	6.58	0.22
Cd	Not detected-1.58	1.08	0.33
Cr	7.93-137	24.08	29.06

French agricultural approved National Farmers' Union (NFU) 44,041 norm. The concentration of Cd in soil was relatively low, ranging from "below detection limit" to 1.58 mg kg^{-1} (for *Cardiospermum halicacabum* root-zone soil), and with a mean concentration of 1.13 mg kg^{-1}. Of the 32 plant root zone soils, only 6, or about 19%, had Cd. Cd is mainly used in alloys, in electroplating, in pigments, in batteries, and in protecting steel iron and steel against corrosion, and although it has been restricted worldwide due to its environmental impact, it can still be found in many consumer goods (Bradl et al. 2005).

The concentration of Cr in the soil ranged from 7.93 mg kg^{-1} (for *Chloris barbata* root-zone soil) to 137 mg kg^{-1} (for *Rottboellia cochinchinensis* root-zone soil), and with a mean of 27.47 mg kg^{-1}. For Cr, the commonly observed mean concentration in soils is 40 ppm (or mg kg^{-1}) with a range of 10-150 ppm, and in sewage sludge, the average Cr concentration is 74 ppm with a range of 2-1100 ppm (Bradl et al. 2005). Cr is used in a wide variety of industrial applications including the paper industry, chemical industry, in fertilizers, metal works and foundries, leather tanning, and finishing, among others (Bradl et al. 2005). The relatively wide range of Cr concentration can be attributed to the heterogeneity of the waste. An evaluation made of the linear relationship between the concentrations of Cd and Cr in the root-zone soils using Pearson's correlation showed that there was no statistically significant linear relationship between Cd and Cr (r=0.2618, P=0.141).

Behavior of the landfill plants towards Cd and Cr

The plant species in the landfill differed in their Cd and Cr content, which indicated that they differed in their capacities for metal uptake, as also observed in other studies on metal contaminated sites (Freitas et al. 2004, Nouri et al. 2009).

Cadmium. Of the thirty-plant species analyzed, only 3 showed to have Cd either in the roots, leaves or stems. Cd was detected in the roots of *Terminalia catappa* (0.425 mg kg^{-1}), but not detected in the stems, leaves or root-zone soil. The root-zone soil of *T. catappa* was slightly acidic. Studies show that under acidic conditions, Cd solubility increases, and very little adsorption of Cd by soil colloids take place (McLean and Bledsoe 1992). Cd was also detected in the stems of *C. halicacabum* (0.408 mg kg^{-1}), but not in the leaves and roots, and in both the stems (0.828 mg kg^{-1}) and leaves (1.25 mg kg^{-1}) of *Cyperus odoratus,* but not in the roots. As shown in Fig. 3, the highest Cd concentration was in the leaves of *C. odoratus*. *C. odoratus* showed the potential for Cd uptake from the soil to the stems, as expressed in its BCF_{Cd} > 1. And only *C. odoratus* had a TF_{Cd} value equivalent to 1.51. The translocation of Cd from the stems to the leaves of *C. odoratus* was relatively efficient with TF_{Cd} > 1. Studies though have shown that species from the Brassicaceae family are found to be the most tolerant to Cd (Prasad 1995). Based on the survey, there were no plant species in the landfill that belonged to the Brassicaceae family. For Cd, foliar concentration above 100 µg g^{-1} (equivalent to 100 mg kg^{-1}) dry weight is considered exceptional, and is used as a threshold value for Cd hyperaccumulation (Bert et al. 2002, Assuncão et al. 2003). Based on the analysis conducted, no plant species qualified as a hyperaccumulator of Cd.

Chromium. Only *C. dactylon* and *Cenchrus echinatus* showed levels of Cr in both the stems and roots (with 26.38 mg kg^{-1} in the stems and 12.17 mg kg^{-1} in the roots of *C. dactylon;* and 10.02 mg kg^{-1} in the stems and 70.07 mg kg^{-1} in the roots of *C. echinatus*, but none in the leaves). *Vernonia cinerea* and *T. catappa* showed levels of Cr in their stems at 102.4 mg kg^{-1} for *V. cinerea* and 58.2 mg kg^{-1} for *T. catappa,* but was not detected in the roots; while only *Rhynchelytrum repens* showed the presence of Cr in the roots at 18.17 mg kg^{-1}. A number of the plant species that grew in the landfill substrate with a relatively elevated Cr concentration did not have Cr in the roots, stems or leaves. None of the plant species exhibited the potential to hyperaccumulate Cr given that the highest Cr level in plants was only 102.4 mg kg^{-1}. This is unlike reports of relatively high concentrations of chromium in some plant species. For example, chromium has been found to be relatively high in concentration in the leaves of *Dicoma niccolifera* (1,500 µg g^{-1} dry weight) and *Sutera fodina* (2,400 µg g^{-1}) found in Zimbabwe (Hossner et al. 1998). Fig. 4 shows the level of Cr in five of the plant species, showing that the highest Cr concentration was in the stems of *V. cinerea*. None of the plant species exhibited the potential to hyperaccumulate Cr since the highest Cr level in plants was only 102.4 mg kg^{-1}.

C. echinatus is more effective in accumulating Cr in the roots than *C. dactylon*, as shown by the former's BCF, which was greater than 1. Thus, *C. echinatus* is a potential candidate for phytostabilization of Cr in the landfill substrate, since it exhibited the potential to immobilize and contain Cr in the roots. The poor translocation or transfer of Cr from roots to shoots is one of the difficulties in using plants and trees for the mitigation of chromium contamination. A study of temperate trees confirmed that Cr was poorly taken up in the aerial tissues, but was held predominantly in the roots (Shanker et al. 2005, Segura-

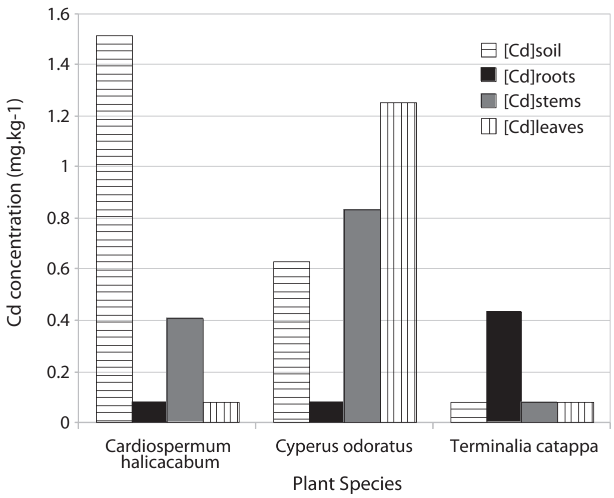

Fig. 3 Level of cadmium in plant and root-zone soil, Cebu City landfill, Philippines.

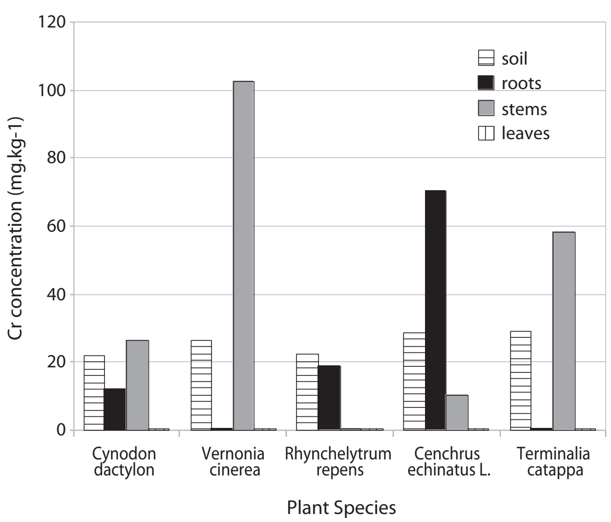

Fig. 4 Level of chromium in plant and root-zone soil, Cebu City landfill, Philippines.

Muñoz et al. 2006).

In a phytosociological analysis of roadside communities in Kerala, India, *C. dactylon*, *V. cinerea,* and *C. halicacabum* were also found in the area being studied; this indicates that these resilient species growing in contaminated environments like roadsides or a landfill, would serve as reliable indicators of pollution (Ray and George 2009). *C. dactylon* is part of the biodiversity list of Prasad and de Oliveira Freitas (2003) exhibiting resistance to metals with potential to clean up toxic metals.

CONCLUSION

The soil in the landfill was generally acidic and under this condition metals are more mobile and become more available vertically upward for plant uptake. Results show that the plant species in the landfill differed in the metal content, which indicated that the plant species differed in their behavior towards the presence of Cd and Cr. Of the 32 plant species sampled, *C. odoratus* showed the potential for Cd uptake and internal transfer; *C. echinatus, V. cinerea*, and *T. catappa* for Cr uptake; and *C. dactylon* for Cr internal transfer.

To confirm the Cd accumulation and internal transfer of *C. odoratus*, the Cr accumulation of *C. echinatus*, the Cr internal transfer of *C. dactylon*, and the Cr accumulation in the stems of *V. cinerea* and *T. catappa*, controlled experiments are recommended, as the plant samples analyzed were collected from the field.

ACKNOWLEDGMENTS

This study is part of a research funded through a research grant from the International Foundation for Science (IFS, Sweden) with the Organization for the Prohibition of Chemical Weapons (OPCW), The Hague, Netherlands, as a co-sponsor.

LITERATURE CITED

Assuncão AGL, Schat H, Aarts MGM. 2003. *Thlaspi caerulescens*, an attractive model species to study heavy metal hyperaccumulation in plants. New Phyt 159: 351-360.

Baker AJM. 1987. Metal Tolerance. New Phyt 106: 93-111.

Baker AJM, Reeves RD, Hajar ASM. 1994. Heavy metal accumulation and tolerance in British populations of the metallophyte *Thlaspi caerulescens* J. & C. Presl (Brassicaceae). New Phyt 127: 61-68.

Banaticla MCN, Buot IE Jr. 2005. Altitudinal zonation of pteridophytes on Mt. Banahaw de Lucban, Luzon Island, Philippines. Plant Ecol 180: 135-151.

Bert V, Bonnin I, Saumitou-Laprade P, de Laguerie P, Petit D. 2002. Do *Arabidopsis halleri* from nonmetallicolous populations accumulate zinc and cadmium more effectively than those from metallicolous populations? New Phyt 155: 47-57.

Bradl HB, Kim C, Kramar U, Stuben D. 2005. Interactions of heavy metals. In: Heavy Metals in the Environment (Bradl HB, ed). Elsevier Ltd, London, pp 28-147.

Bradl HB, Xenidis A. 2005. Remediation techniques. In: Heavy Metals in the Environment (Bradl HB, ed). Elsevier Ltd, London, pp 165-249.

Carlosena A, Gallego M, Valcarcel M. 1997. Evaluation of various sample preparation procedures for the determination of chromium, cobalt and nickel in vegetables. J Anal At Spectrom 12: 479-486.

Cecen F, Gursoy G. 2000. Characterization of landfill leachates and studies on heavy metal removal. J Environ Monit 2: 436-442.

Chaudhry TM, Hayes WJ, Khan AG, Khoo CS. 1998. Phytoremediation – focusing on accumulator plants that remediate metal-contaminated soils. Australas J Ecotox 4: 37-51.

Dogan Y, Baslar S, Ugulu I. 2014. A study on detecting heavy metal accumulation through biomonitoring: content of trace elements in plants at Mount Kazdagi in Turkey. Appl Ecol Environ Res 12: 627-636.

Elkhatib EA, Thabet AG, Mahdy AM. 2001. Phytoremediation of cadmium contaminated soils: role of organic complexing agents in cadmium phytoextraction. Land Contam Reclam 9: 359-366.

Fischerova Z, Tlustos P, Szakova J, Sichorova K. 2006. A comparison of phytoremediation capability of selected plant species for given trace elements. Environ Poll 144: 93-100.

Flyhammar P, Tamaddon F, Bengtsson L. 1998. Heavy metals in a municipal solid waste deposition cell. Waste Manag Res 16: 403-410.

Freitas H, Prasad MNV, Pratas J. 2004. Plant community tolerant to trace elements growing on the degraded soils of São Domingos mine in the south east of Portugal: environmental implications. Environ Int 30: 65-72.

Gonzalez RC, Gonzalez-Chavez MCA. 2006. Metal accumulation in wild plants surrounding mining wastes. Environ Poll 144: 84-92.

Gothberg A, Greger M, Bengtsson BE. 2002. Accumulation of heavy metals in water spinach (*Ipomoea aquatica*) cultivated in the Bangkok region, Thailand. Environ Tox Chem 21: 1934-1939.

Hossner LR, Loeppert RH, Newton RJ. 1998. Literature review: phytoaccumulation of chromium, uranium and plutonium in plant systems. Austin (TX): Amarillo National Resource Center for Plutonium (US). Report No.: ANRCP--1998-3.

Jensen DL, Holm PE, Christensen TH. 2000. Soil and groundwater contamination with heavy metals at two scrap iron and metal recycling facilities. Waste Manag Res 18: 52-63.

Jones JB Jr. 2001. Laboratory Guide for Conducting Soil Tests and Plant Analysis. CRC Press, Boca Raton, FL.

Kim KD, Lee EJ. 2007. Relationship between plant species covers and soil chemical properties in poorly controlled waste landfill sites. J Ecol Environ 30: 39-48.

McLean JE, Bledsoe BE. 1992. Behavior of metals in soils. In: Groundwater Issue. United States Environmental Protection Agency, Washington, D.C., EPA/540/S-92/018.

Mocko A, Waclawek W. 2004. Three-step extraction procedure for determination of heavy metals availability to vegetables. Anal Bioanal Chem 380: 813-817.

Nouri J, Khorasani N, Lorestani B, Karami M, Hassani AH, Yousefi N. 2009. Accumulation of heavy metals in soil and uptake by plant species with phytoremediation potential. Environ Earth Sci 59: 315-323.

Ostman M, Wahlberg O, Agren S, Martensson A. 2006. Metal and organic matter contents in a combined household and industrial landfill. Waste Manag 26: 29-40.

Prasad MNV. 1995. Cadmium toxicity and tolerance in vascular plants. Environ Exper Bot 35: 525-545.

Prasad MNV, de Oliveira Freitas HM. 2003. Metal hyperaccumulation in plants - biodiversity prospecting for phytoremediation technology. Elect J Biotech 6: 285-321.

Rajakaruna N, Bohm BA. 2002. Serpentine and its vegetation: a preliminary study from Sri Lanka. J Appl Bot 76: 20-28.

Ray JG, George J. 2009. Phytosociology of roadside communities to identify ecological potentials of tolerant species. J Ecol Natl Environ 1: 184-190.

Remon E, Bouchardon JL, Cornier B, Guy B, Leclerc JC, Faure O. 2005. Soil characteristics, heavy metal availability and vegetation recovery at a former metallurgical landfill: implications in risk assessment and site restoration. Environ Poll 137: 316-323.

Riber C, Fredriksen GS, Christensen TH. 2005. Heavy metal content of combustible municipal solid waste in Denmark. Waste Manag Res 23: 126-132.

Robinson BH, Mills TM, Petit D, Fung LE, Green SR, Clothier BE. 2000. Natural and induced cadmium-accumulation in poplar and willow: implications for phytoremediation. Plant Soil 227: 301-306.

Sanghamitra K, Prasada Rao PVV, Naidu GRK. 2012. Uptake of Zn(II) by an invasive weed species *Parthenium Hysterophorus* L. Appl Ecol Environ Res 10: 267-290.

Sankaran RP, Ebbs SD. 2007. Cadmium accumulation in deer tongue grass (*Panicum clandestinum* L.) and potential for trophic transfer to microtine rodents. Environ Poll 148: 580-589.

Saxena P, Misra N. 2010. Remediation of heavy metal contaminated tropical land. In: Soil Heavy Metals (Sherameti I, Varma A, eds). Springer-Verlag, Berlin, pp 431-477.

Segura-Muñoz SI, da Silva Oliveira A, Nikaido M, Trevilato TMB, Bocio A, Takayanagui AMM, Domingo JL. 2006. Metal levels in sugar cane (*Saccharum* spp.) samples from an area under the influence of a municipal landfill and a medical waste treatment system in Brazil. Environ Int 32: 52-57.

Shanker AK, Cervantes C, Loza-Tavera H, Avudainayagam S. 2005. Chromium toxicity in plants. Environ Int 31: 739-753.

Sharma RK, Agrawal M, Marshall FM. 2008. Heavy metal (Cu, Zn, Cd, Pb) contamination of vegetables in urban India: a case study in Varanasi. Environ Poll 154: 254-263.

Szarek-Lukaszewska G, Slysz A, Wierzbicka M. 2004. Response of *Armeria maritima* (Mill.) Willd. to Cd, Zn and Pb. Act Biol Cracov Ser Bot 46: 19-24.

Tüzen M. 2003. Determination of heavy metals in soil, mushroom and plant samples by atomic absorption spectrometry. Microchem J 74: 289-297.

Wang QR, Cui YS, Liu XM, Dong YT, Christie P. 2003. Soil contamination and plant uptake of heavy metals at polluted sites in China. J Environ Sci Health, Part A 38: 823-838.

Weather and climate: Cebu Philippines. http://www.weather-and-climate.com. Accessed September 2013.

Yoon J, Cao X, Zhou Q, Ma LQ. 2006. Accumulation of Pb, Cu and Zn in native plants growing on a contaminated Florida site. Sci Tot Environ 368: 456-464.