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# Phytoremediation plants of metals in leached urban solid waste Phytoremediation in landfill


## Abstract

Leachate is among the main pollutants in landfills, specifically because its components can cause danger to the environment. One of the treatment options is phytoremediation, which is an efficient technique with low environmental impact and reduced costs. The potential for phytoremediation of heavy metals in plants exposed to Urban Solid Waste leachate from a final disposal site located in Tabasco, Mexico was evaluated. Five plant species predominant in the landfill coverage were selected and identified: *Pennisetum purpureum, Cyperus esculentus, Canna indica, Dactylotenium scindicun* and *Echinochloa colona*. Subsequently, leachate samples were collected from each plant and adjacent soil for determination of Heavy Metals through ICP-OES (n=3). The metals with the highest concentration in the leachate were Ba and Zn. Independently of the species, Barium was absorbed at a higher concentration. The higher Bioconcentration Factor was observed in Thallium by *D. scindicum* and *C. indica*, and the Translocation Factor identified hyperaccumulating species: *E. colona* (Zing and Barium) *C. indica* (Zing and Barium), *P. purpureum* (Thallium) and *D. scindicum* (Barium and Thallium).


**Keywords:** Leached, Hyperaccumulator, Heavy metal, Phytoremediation, landfill, phytosorption.

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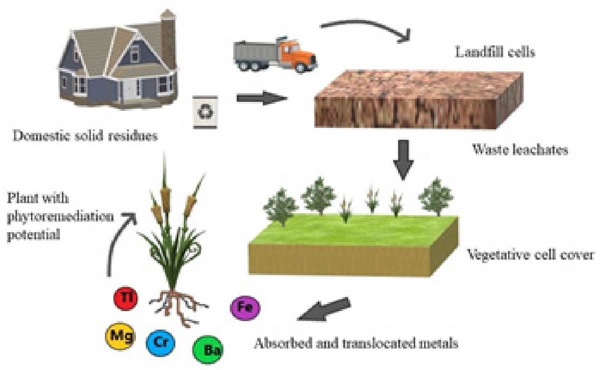
## Graphical Abstract




The leachate from domestic solid urban waste contains metals which are contained in the landfill cells, but the cover plants grow without any problems, which are irrigated with this leachate, so it is important to detect the phytoremediation potential of some of the species found in the landfill.

## Introduction

The generation of solid waste has been one of the main environmental problems worldwide. Disposal of waste in landfills remains the most common method of waste management because it is simple and relatively inexpensive.[1] This disposal method involves engineering work to reduce environmental impacts. However, this technique also generates other wastes, greenhouse gases and liquid effluents called leachate.

Leachates are highly toxic liquids,[2] their composition depends on the type of confined waste, the level of waste degradation and the volume produced[3] and they are characterized by complex mixtures produced by the chemical and biological degradation of the matter contained in the waste, as well as by rainwater infiltration.[4] In its heterogeneous phase, persistent organic pollutants,[5,6] organic and ammoniacal nitrogen, presence of heavy metals,[7,2] high Chemical Oxygen Demand (COD), high salinity[8] and a range of organisms[5,6] can generally be found. According with the interaction of these components and the environment, there are many studies showings that leachate causes significant environmental concerns and risks to human health.[9,10]

On the other hand, the heavy metals in high concentrations they could be toxics for the human health.[1] These metals can pass through blood brain barrier, disturb the central nervous system, affect ion channels, compete with enzyme cofactors, and finally cause oxidative stresses in body,[11] causing some health problems known as bone and organ loss, vascular diseases, developmental abnormalities (mutation) and cancer induction (carcinogenesis).[12-16]

In this respect, one of the pollutants that poses the greatest threat is heavy metals, since in high concentrations they can have toxic effects.[1] Leachate production and management is recognized as one of the biggest problems associated with the environmentally sound operation of landfills.[17]

Phytoremediation is an important technology for landfill remediation as through this technique it is possible to stabilize the soil and simultaneously remedy leachate, in addition, landfill remediation systems can potentially be combined with landfill cover (phytocapping) to minimize water filtration in waste as mentioned by Kim and Owens.[1]

Mexican Industry Promotora Ambiental, S.A. de C.V. (P.A.S.A.) employed *Chrysopogon zizanoides* called vetiver to phytoremediate leached. Vetiver plant is considered as a phytoremediation plant and shown a perfect resistant plant at extreme climate and tolerant high acidity and alkalinity ground, to high levels of aluminum (Al), manganese (Mn), sodicity and higher mix of heavy metals arsenic (As), cadmium (Cd), chromium (Cr), cooper (Cu), mercury (Hg), nickel (Ni), lead (Pb), selenium (Se), zinc (Zn).[18] However, in the study area exists another kind of plants, growing up under some environmental conditions exposed to leached. The aim of this paper was evaluated five potential species for phytoremediation of heavy metals from leached landfills of P.A.S.A. by technique ICP-OES.

The purpose of the present study is to explore further scientific knowledge and will support environmental application and economic technologies in management industry area.

## Materials and methods

This research was realized at the Promotora Ambiental S.A de C.V. landfill located on the Villahermosa-Teapa Km. 25 highway, Tabasco, Mexico. At coordinates 17°48'29.3" N, 92°59'33.9" W (Figure 1). The final disposal site receives an average of 800 tons/d of solid urban waste and special handling.

**Figure 1** Study area. Sanitary Landfill *Promotora Ambiental* S.A. of C.V.

The samples were directed and defined in an area of 100 m x 50 m of the study site. Five species of plants were selected, considering those most exposed to leachates and collected in triplicate for identification and storage in the Herbarium of the Universidad Juarez Autonoma de Tabasco (UJAT).

*Collected species plants were Pennisetum purpureum*, *Cyperus esculentus, Canna indica, Dactyloctenium scindicum* and *Echinochloa colona.* Species plants consideration as a control were collected according to distribution area and site (Table 1).

**Table 1** Control distribution of plants

| Metal | Concentration (mg/L) |
|---|---|
| Cr | 0.55±0.03 |
| Ba | 3.23±0.42 |
| Cu | 1.75±0.22 |
| Zn | 2.43±0.21 |
| Pb | 0.14±0.06 |
| Tl | 1.55±0.24 |

*(The values represent the average of three samples). The metals in highest concentration were Ba and Zn.*

**Plants**: The plant samples were washed with free water for three minutes and after were washed with distilled water, to remove particles and adhering residues, then the leaves and roots were separated and kept drying under shade at room temperature for two weeks, in the case of *C. indica* that it had thicker structures, was left at 65 º C for 24 h.

**Soil:** Subsequently the samples were cut, powdered, and sieved with a 0.5 mm sieve. Soil samples (rhizosphere) were also taken from each plant that was collected and these were dried at room temperature, then ground and sieved with 2 mm mesh screens.

Both plant and soil samples were stored in clean polyethylene bags and kept until laboratory analysis.

**Analysis of plants and soil:** Then, samples were cut, ground, and sieved (2 mm). Both samples (plants and ground) were kept inside polyethylene bags and were conserved until lab analysis. It was collected a leached sample in dark flasks and conserved at 4ºC until their analysis. Sample was filtered with 11 mm of pore filter and was added $HNO_3$ (High-Purity, #QCS-7, in recipients were digested according to microwave digestion MARSX press by CEM Corporation to be analyzed total heavy metals.[19] For ground were digested (0.14 g) each sample, plants (0.25 g) and leached (5 mL) according to plant, ground and liquid heating program, digestion products were cooled and afforded in 25 volumetric flasks with deionized water.

Finally, were analyzed heavy metals (method ICP-OES, IRIS Advantage) manufacturing by Thermo Jarrell Ash. Limit detection rank was 001-10 ml /L in calibration curve analyze. Cr, Ba, Cu, Zn, Ni and Tl from the analytical standard catalog QCS-7, high purity standard.

Results were analyzed according to Sigma Plot for windows 12 software. Statistics aspects (by ANOVA) and media differences were comparing according to the Kruskal- Wallis statistics.

To predict and demonstrate potential of phytoremediation in plants was determinate Bioconcentration Factor (BCF) and Translocation Factor (FT) according with the next equations:

Biological concentration Factor (BCF) = (conc) metal in plant/(conc) metal in ground

Translocation Factor (FT) = (conc) metal in leaves/(conc) metal in roots

The purpose of BCF is determine capacity of incorporated (fixed) metal in plants related with ground concentration,[20] and FT means accumulating concentration in up site comparing with low area (roots) in plants.[21]

## Results and Discussion

Concentrations of Ba, Cr, Cu, Pb and Zn in leached samples are showed in Table 2. Higher concentration were Ba and Zn are lower than reported by[22] of 3.85 mg /L. Although Zn concentration is higher of the ranking in leached (0.5 to 2 mg /L) reported by Jensen[7]. This concentration (0.223 mg /L) is under ranking reported by [23]Arunbabu (2017). These differences are so quite because leached compositions depend on kind of waste degradation level of wastes and produced volume.[3] Heavy metals concentrations in plant samples (leaf and root) were contaminated.

**Table 2** Concentration of heavy metals (mg / L) in leachate samples of urban solid waste from the Promotora Ambiental S.A. de C.V. Sanitary landfill

| Control plant sampling sites | |
|---|---|
| *Pennisetum purpureum* | 3.7 km of landfill |
| *Cyperus esculentus* | Backyard area, Villahermosa City |
| *Canna indica* | Nursery of Villahermosa City |
| *Dactylocterium scindicum* | 468 m of landfill |
| *Echinochloa colona* | Backyard, of Villahermosa City |

Heavy metals concentrations in plant samples (leaf and root) were contaminated. Results are showed in Table 3.

**Citation:** Morales-Hernández S, López-Martínez S, Jiménez-Pérez NC, et al. Phytoremediation plants of metals in leached urban solid waste Phytoremediation in landfill. *Horticult Int J.* 2022;6(4):189–194. DOI: 10.15406/hij.2022.06.00264

*C. indica* fixed in roots, higher concentrations of Cr, Co, Pb and Tl, in leaves, found higher concentration of Ba, while *E. colona* in leaves incorporated higher concentrations of Zn.

Similar results showed root area of *C. indica* that reported,[24] that means higher metal concentration incorporated and fixed in meristems and stalk. Results of showed that *C. indica* can fix concentrations of 27.83 mg/kg in Cr and 43.53 mg /kg in Pb from residuals landfills. Higher contaminants (125.90) mg/Kg of Cr and 151.8 mg/Kg of Pb also upper concentration in heavy metals of ground can improve its specie growth. Debnath and Mukherji[25] detected a protect factor when is losing anthocyanin pigment in flowers of *C. indica* in 20 mM of $BaCl_2$ concentration. However, absorption of Ba was lower than reported by Debnath and Mukherji[25] could means this concentration of Ba improve a kind of plant process that protected flower pigments. While concentration of Cu observed in roots have similar relation with another studies,[24,26] where *C. Indica* showed Cu fixed in roots.

Although, *E. colona* is gramineous plant, with high root resistance in Cr or Ni solutions[27] shown scattered phytoremediation. Other gramineous plants have demonstrated survive in contaminant grounds until 1000 mg/Kg of Zn[28] higher concentration comparing species in this present study.

Heavy metals concentrations in soil showed variations according of sampling point of each plant, these differences can be related with contaminants and heavy metals exposed in soil.[29] Availability of heavy metals depends of pH of soil. Lower pH promotes to the accessibility in ground of heavy metals.[23] Results from De la Cruz.[30] were evaluated the effect of organic acids added on the sanitary landfills PASA showed pH 5.7 value (lightly acidic) (NOM-021-SEMARNAT-2000). Organic material 4.4 % and texture corresponds to classifications of franc-clay. Lightly acidic pH maybe was not favored in availability of heavy metals and light predominance of clays in soil could stop contaminants migration in another kind of site areas[31] (Figure 2).

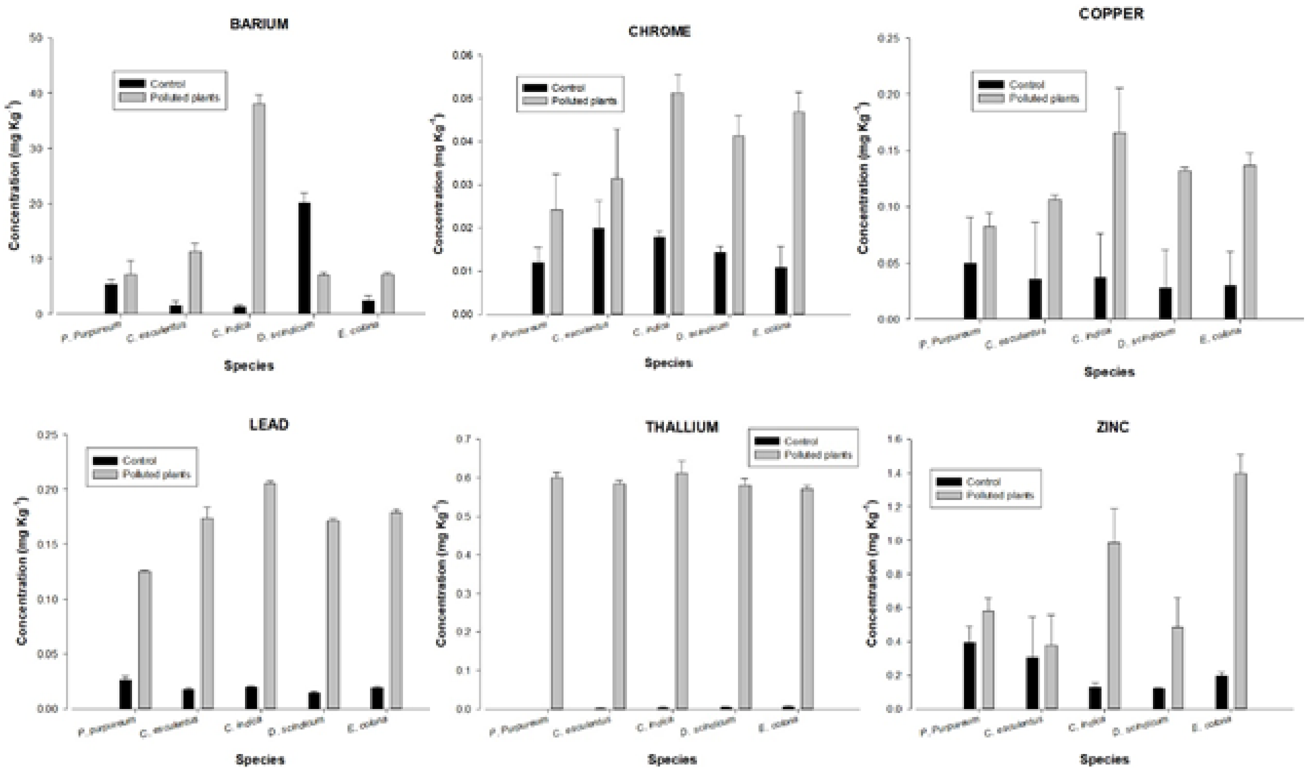



**Figure 2** Comparison between the concentration of heavy metals (mg/kg) in the different species analyzed. The data indicate the concentration absorbed in contaminated species and controls. Data represents the average of three samples. There is a statistically significant interaction between control and contaminated species in the accumulation of Cr, Cu, Tl ($p < 0.01$), Ba and Pb ($p < 0.05$)

Absorption of heavy metals in plants exposed and fixed in leached are also compared with their respective controls. (Data represents average from 3 samples) there are significant statistic differences in heavy metals of Cr, Cu, Tl ($p<0.01$) Ba and Pb ($p< 0.05$) between contaminated and control plants. Heavy metal Tl is not well-known metal in phytoremediation species; however, it is a relevant importance because Tl compounds are dangerous environmental contaminants.[32] Absorption of this metal has been evaluated by *Callitriche cophocarpa* in contaminated water at natural environmental[32] and by *Solanum nigrum L*. in contaminated soils. Thus, getting incorporate 10 mg/Kg from Tl.[33] However, evaluated species of this study showed lower concentration to 1 mg /Kg. Also, were calculated BCF and FT, such BCF<1. These factors were non-fixed or incorporated metal signals. The results showed between 1 and 10 values were considering fixed incorporated signals. These plants showing values higher 10 are considering hyperaccumulator plants.[21] Higher BCF were observed in *D. scindicum* and *C. indica* for Tl (Figure 3).

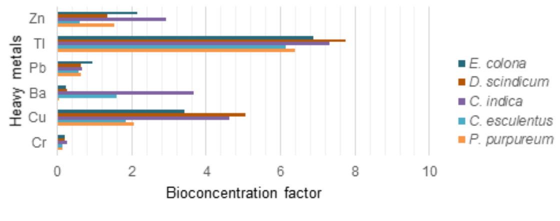



**Figure 3** Bioconcentration factor (BCF) of Cr, Cu, Ba, Pb, Tl and Zn in the plants collected in the sanitary landfill of the State of Tabasco, Mexico.

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According to FT were recognized hyperaccumulator species *E. colona* (Zn and Ba) *C. indica* (Zn and Ba), *P. purpureum* (Tl) and *D. scindicum* (Ba and Tl) (Figure 4).

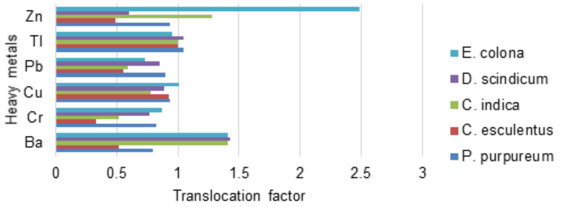


**Figure 4** Translocation factor (TF) of Cr, Cu, Ba, Pb, Tl and Zn in the plants collected in the sanitary landfill of the State of Tabasco, Mexico

*Echinochloa colona* is one of the most problematic weeds in the world,[34] for this reason it is studied mainly for its management, however, there are reports that evidence its potential phytoremediation of metals from mining waste[27] is even proposed for restoration, to produce an effective vegetation cover to improve abandoned lands and reduce erosion. Even with these in situ studies, mining waste is not even close to the liquid leachate extracted from solid urban waste, and more than 200 different compounds have been identified.[35]

In general, there are few studies on the genus *Dactyloctenium*, some on weed control.[36-38] The most studied species is Dactyloctenium aegyptium, it has reports from copper absorption to form nanocomposites,[3] studies on study is to evaluate the nutritional, physicochemical, functional and antioxidant properties of seeds [3] and one of the few works on phytoremediation in situ Gautam and Agrawal.[40] This is the first time that *Dactyloctenium scindicum* has been identified as a phytoremediation plant for leachate from landfills.

*Canna Indica* is a species already reported as a phytoremediation of metals contained in industrial waste [26], including in the phytoremediation of sludge which is one of the main by-products of water treatment plants in China [24]. The international proposals are the use of plants for the purification or absorption of different xenobiotic compounds, with this study this species is proposed for the phytoremediation of leachate product of urban solid waste, which could have another use after the elimination of metals.

*Cyperus escualetos* is a species widely studied but not for its phytoremediation capacity, some work on its oil.[41,42] Others on biological activities for its use in traditional medicine Oluwajuyitan and Ijarotimi.[43] However, species of the same genus are widely reported for their ability to phytoremediate metals,[44, 45] so this species is a good choice and of the few research working with leachates and species such as these weeds as they are called may be useful for the absorption of metals.

*Pennisetum purpureum* a highly studied graminea recent studies on metabolome and transcriptome of this species [46], also studies on the nutritional characteristics of the species as fodder.[47] There are also works on evaluated the physio-biochemical response of Pennisetum purpureum at different concentrations of Pb (II)[48] Das and Osborne, (2018). And where it is evident not only its tolerance but also its remediation of metals [49]. Recent work has demonstrated its capacity for phytoextraction of heavy metals from weeds and native grasses from complex distillery sludge rich in chemical products.[50] With this study we confirm that this species not only survives in contaminated sites, but that it can also remedy complex pollutants, such as leachate.

*This study showed results finding hyperaccumulator plants of Tl (P. purpureum and D. scindicum), Ba (D. scindicum, C. indica and E. colona) and Zn (E. colona and C. indica).*

Results showed that plants have capacity to carry on these contaminants from low part (root) to high part (aereal). However, in this study has not hyperaccumulator plants were not found with FBC because higher values of metal are found in plant substrates.

## Conclusion

Species of the genus *Pennisetum, Cyperus, Canna, Dactyloterium and Echinochloa* were identified growing on the coverage of the sanitary landfill of the company Promotora Ambiental S. A. B. de C. V.

Concentrations of Ba, Cr, Cu, Pb and Zn were quantified in soil, leachate, and plant samples. Ba and Zn were the most predominant metals in the samples analyzed due mainly to the type of confined waste.

The highest concentrations of Cr, Cu, Pb and Tl were observed in the roots of *C. indica* and in the leaves the concentration of Ba was the highest, while *E. colona* accumulated the highest concentration of Zn in the leaves. All species showed affinity with Thallium.

The concentration of metals in the soil was higher compared to the concentration of metals in the leachate due to the physicochemical characteristics of the soil (texture and pH) that prevents the migration of contaminants to other areas and contributes to the low bioavailability of metals.

In the evaluation of the phytoremediation potential of the five selected species, Tl (*P. purpureum, D. scindicum*), Ba (*D. scindicum, C. indica, E. colona*) and Zn (*E. colona, C. indica*) hyperaccumulative plants were identified with the Tl (*P. purpureum, D. scindicum*), which have the capacity to transfer contaminants to the aerial part, however no hyperaccumulative plants with CBF were observed due to the higher concentration of metals in the substrate of the plants.

The FBC index of Tl was higher in *D. scindicum*, compared to the other species evaluated, and FT indicated that the plant can hyperaccumulate Ba and Tl, however the information of the species *D. scindicum*, about phytoremediation of metals, is very scattered, so it is considered an area of opportunity for the evaluation of this species.

*Dactyloctenium scindicum* and *Cyperus escualetos* is the first time that the potential fitorremediador of metals is identified in a work that was carried out in situ in a sanitary landfill and that given the complexity of the contaminant the results are very valuable, not only for the company that financed the project, also for the use of these species because their distribution is not limited and exclusive for Mexico.

Finally, the diagnostic evaluation of plants with potential fitorremediation helps the knowledge of new fitorremediation species to implement efficient and low-cost leachate treatment systems.

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## Conflicts of interest

None

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