Malaysian Journal of Soil Science 2023 Vol. 27: 138 - 146

Determining the Phytoremediation Potential of Naturally Growing Tropical Plant Species at a Sanitary Landfill

Rajoo, S. Keeren[1,2*], Ismail, Ahmad[3], Karam, S. Daljit.[4], Arifin, Abdu.[5],
Izani, Norul[1], Gerusu, Geoffery James[1,2], Ibrahim, Zahari[6],
Abdullah, Muhammad Amin[1] and Ibrahim, Mohd Hakeem[4]

[1]Department of Forestry Science, Faculty of Agriculture Science & Forestry,
Universiti Putra Malaysia Bintulu Campus, Nyabau Road, 97008 Bintulu, Sarawak, Malaysia
[2]Institute of Ecosystem Science Borneo, Universiti Putra Malaysia Bintulu Campus, Nyabau Road,
97008 Bintulu, Sarawak, Malaysia
[3]Academy Science Malaysia, 50480, Kuala Lumpur, Malaysia
[4]Department of Land Management, Faculty of Agriculture, UPM, Malaysia
[5]Department of Forestry Science & Biodiversity, Faculty of Forestry & Environment, UPM, Malaysia
[6]Forestry Department Peninsular Malaysia, Kuala Lumpur, Malaysia

*Correspondence: *keeren.rajoo@upm.edu.my*

ABSTRACT

Heavy metal contamination poses severe threats to ecosystems and human health, necessitating effective remediation strategies. Phytoremediation, which leverages plants to remove heavy metals, offers a promising solution. However, this approach remains underexplored, particularly in tropical ecosystems like Malaysia. Thus, this study examines the potential of native plant species in addressing heavy metal pollution, at Air Hitam Sanitary Landfill (AHSL). This location was selected due to it being an urban ecosystem that is susceptible to soil heavy metal contamination from municipal waste disposal and atmospheric deposition. Native plant species, namely Pueraria phaseoloides, Dicranopteris linearis, Cyperus rotundus, Acacia spp., and Melastoma malabathricum were found to grow well at AHSL, thus were selected for this study. The phytoremediation potential of these plant species were determined by calculating their translocation (TF) and bioaccumulation factors (BCF). Based on the TF and BCF values of all the plants studied, none of the plant species were potential phytoremediators. However, four plant species were identified as potential bioindicators of Cd. These species were Pueraria phaseoloides, Cyperus rotundus, Acacia spp. and Melastoma malabathricum. In conclusion, this study underscores the importance of understanding phytoremediation potential within challenging environments and its contribution to heavy metal mitigation. By investigating native plant species in AHSL, the research aids in expanding the application of phytoremediation strategies, ultimately fostering ecological restoration, and safeguarding human health.

Keywords: **heavy metals; Malaysia; landfill; municipal solid waste; toxic elements**

INTRODUCTION

The escalating levels of heavy metal soil contamination in our environment pose a grave threat to ecological sustainability and human health. Anthropogenic activities, such as industrial processes, agricultural practices, and waste disposal, have led to the release of toxic heavy metals like cadmium (Cd), iron (Fe), and zinc (Zn), into our soil and water systems. These heavy metals, known for their persistence and detrimental effects, can accumulate over time, resulting in widespread pollution and ecological disruption (Achary *et al*. 2017).

The hazards of heavy metal contamination are multifaceted, encompassing ecological imbalances, compromised agricultural productivity, and adverse human health effects (Archary *et al*. 2017). Heavy metals can disrupt natural biogeochemical cycles, leading to soil and water degradation. As heavy metals enter the food chain, they pose potential health risks to humans through the consumption of contaminated crops and water. This underlines the urgency of finding sustainable approaches to mitigate heavy metal pollution and safeguard both ecosystems and human well-being.

Given the severity of this issue, the development of effective and sustainable strategies for remediating heavy metal contamination has become a pressing concern. Among these strategies, phytoremediation, an eco-friendly and cost-effective approach, has gained prominence. Phytoremediation utilizes the natural abilities of certain plant species that are able to uptake, accumulate, and detoxify heavy metals from soil and water, thereby offering a promising solution to the challenge of heavy metal pollution (Rajoo *et al.* 2013).

Despite being a cost-effective and environmentally friendly approach to managing heavy mental contamination, phytoremediation is still a relatively underutilized strategy (Hernandez *et al.* 2022). This is especially true for tropical ecosystems, where the climatic conditions significantly differ in countries with existing literature in environmental sciences (Lee *et al.* 2014; Rajoo *et al.* 2023). Even worse, phytoremediation studies in tropical countries like Malaysia is limited (Rajoo *et al.* 2013; Hernandez *et al.* 2022). This knowledge gap has resulted in a poor understanding of potential phytoremediators in tropical countries, with limited application of this strategy.

Therefore, this study was undertaken to address this knowledge gap. The objectives of this study are: 1) To identify common plant species in tropical sanitary landfills, and 2) To identify potential phytoremediators of heavy metals in tropical ecosystems. The study focuses on the phytoremediation potential of native plant species thriving in a naturally challenging environment, specifically a sanitary landfill, the Air Hitam Sanitary Landfill (AHSL). The importance of this research lies in its endeavor to elucidate the capacity of these plants to combat heavy metal contamination and contribute to the restoration of compromised ecosystems.

MATERIALS AND METHODS

Study site: Air Hitam Sanitary Landfill (AHSL)

The AHSL site is located near the Air Hitam Forest Reserve in Mukim Petaling, Daerah Petaling, Puchong (longitude 101° 39’ 55’’ E and latitude 03° 0’ 10’’ N) (Figure 1). The Selangor State Government Council approved Worldwide Sita Environmental Management to develop this sanitary landfill, on 22nd March 1995. ASHL was built in 1995 and was the first engineered sanitary landfill site in Malaysia, covering a total of 42 hectares. During the 11 years ASHL operated, it received approximately 6.2 million tons of domestic waste. ASHL is surrounded by residential housing, highways, and manufacturing industries. AHSL was officially closed on 31 December 2006 and the 5-year Landfill Closure and Post Closure Maintenance Plan (LCPCMP) was in place (2007-2011).

AHSL was selected for this study since it is a prime location for soil heavy metal contamination in an urban ecosystem. As a waste disposal site, there is a high likelihood of heavy metal accumulation in the soil. Moreover, since it is surrounded by manufacturing industries and heavy vehicle usage, atmospheric deposition of heavy metals like Cd might be prevalent in this location (Kubier *et al.* 2019).

Figure 1: Location of Air Hitam Sanitary Landfill

Sample collection and analysis

Three sampling locations were selected throughout AHSL, each at a different phase. Six subplots (20 m x 20 m) were randomly established (completely randomized design) at each sampling location. Composite soil samples were obtained using an auger from each subplot at 0cm-20cm, 20cm-40cm, 40cm-60cm, 60cm-80cm and 80cm-100cm using an auger. All soil samples were kept in a sterilised polyethylene bags and air-dried before being analysed. Samples of the soil was air dried for three days, pounded with a mortar and pestle, and then sieved through a 2mm mesh. This is done to produce a homogenous mixture for analyses.

Plants were selected based on abundance. The fresh sample of plants was separated into three parts: roots, stem, and leaves. These plant parts were then be dried in an oven at 60° C for 24 hours and shredded into small piece before further analysis.

Acid digestion was used to determine the concentration of heavy metals in the soil and plant samples collected. After digestion, the total concentrations of heavy metals were determined using Atomic Absorption Spectrometer (AAS) (Gupta 2007). Additionally, basic physico-chemical analyses were conducted to characterize the soil characteristics (Gupta 2007).

Data and Statistical Analysis

In order to evaluate the phytoremediation potential of sampled plant species, two indicators were used: BCF (metal concentration ratio of plant roots to soil), TF (metal concentration ratio of plant shoots to roots). If both the BCF and TF value is above 1, the species has the potential to be a hyperaccumulator for the analysed heavy metal, while a BCF value of above 1 and a TF value below 1 was indicative of a phytostabilizer species (Rajoo *et al*. 2013). These indicators were calculated as follows:

$$\mathrm{BCF} = \left[\frac{\text{Metal Concentration in Roots (mg kg}^{-1}\text{)}}{\text{Metal Concentration in Soil (mg kg}^{-1}\text{)}}\right] \quad \mathrm{TF} = \left[\frac{\text{Metal Concentration in Shoot (mg kg}^{-1}\text{)}}{\text{Metal Concentration in Root (mg kg}^{-1}\text{)}}\right]$$

The data was statistically analysed using the SPSS program (Version 23). Appropriate statistical analyses were conducted to analyse the research data, such as analysis of variance (ANOVA), t-test and regression.

RESULTS AND DISCUSSION

Soil characteristics

The upper layer of AHSL exhibited soil that enveloped the buried municipal waste. This soil type was Oxisol and had undergone significant weathering due to prolonged exposure to environmental conditions. The pH levels of the soil varied between 5.47 and 6.21, with an average pH of 5.94. The pH of the soil plays a role in the availability of heavy metals; typically, lower pH values result in higher availability of these metals due to their cationic nature (USDA NRCS, 2000). At AHSL, the soil's electrical conductivity (EC) ranged from 115.1 to 293.00 µS cm^{-1}, averaging at 219.4 µS cm^{-1}. Soils with an EC below 300 µS cm^{-1} are generally considered to have limited microbial activity and are less conducive to plant growth as essential enzymatic processes required for nutrient synthesis might be lacking (Brady and Weil 1999).

This characteristic suggests that the plants thriving at AHSL are primarily early colonizers, which are species that thrive in disturbed ecosystems. The soil's bulk density spanned from 1.40 to 1.73 g cm^{-3}, accompanied by a moisture content ranging from 11.56 to 12.50%, and porosity ranging from 34.91 to 47.16%. Soil with a bulk density within the range of 1.0 to 2.0 g cm^{-3} is typically indicative of low organic matter content, a trait likely stemming from the extensively weathered and exposed soil at AHSL. The diminished porosity can be attributed to the soil's compaction to conceal the buried municipal waste, thereby explaining the reduced moisture content as well. The concentration of extractable phosphorus across all phases of AHSL was consistently low. This scarcity of phosphorus is often linked to elevated levels of iron (Fe) within the soil, a characteristic trait of Oxisol. Additionally, the dearth of organic matter often corresponds to lower levels of nitrogen, phosphorus, and potassium (NPK) in soils, which is evident in the AHSL context (Cavanagh and O'Halloran 2003).

Soil heavy metal concentrations

The heavy metals evaluated in this study are Cd, Fe and Zn. For Cd, average concentrations ranged from 0.018 ppm to 0.029 ppm across the different AHSL phases, with no significant differences observed between phases or soil depths. Cd concentration primarily originated from atmospheric deposition rather than buried municipal waste. Regarding Fe concentrations, there was a significant time-based effect. Phase 7 exhibited the highest Fe concentration (22.18 ± 2.58 ppm) compared to earlier phases (Phase 1-5: 20.597 ± 1.27 ppm and Phase 6: 20.097 ± 2.952 ppm), but Phase 1-5 had higher mean concentrations than Phase 6, though this difference was not significant.

Similarly, Zn concentrations were significantly influenced by time. Phase 7 had the highest Zn concentration (55.013 ± 5.613 ppm), differing significantly from earlier phases (Phase 1-5: 46.510 ± 4.3 ppm and Phase 6: 51.41 ± 5.46 ppm). Phase 6 also had higher Zn concentrations. Therefore, Zn concentrations decreased over time, similar to other metals.

Linear regression analyses revealed that soil depth had no significant predictive effect on Cd concentration, while for Fe and Zn, soil depth significantly predicted concentration. Fe concentrations decreased with soil depth, and soil depth accounted for 36.8% of the variability. For Zn, soil depth predicted 53% of the variability, and Zn concentrations also decreased with depth.

Plant samples

The plant samples collected were *Pueraria phaseoloides*, *Dicranopteris linearis*, *Cyperus rotundus*, *Acacia spp.* and *Melastoma malabathricum* (Figure 2). These species were selected as they were in large quantities at all the landfill phases. These species were identified as pioneer species, indicating that the ecosystem in the landfill was disrupted and damaged (Leslie 2010). Over time, these pioneer plant species will assist in leading to a more biodiverse ecosystem (Leslie 2010). The Cd concentrations in the plant samples were divided according to different plant parts, which are the stem, leaves, and roots. The combined values of Cd concentrations represent the total Cd concentration of the plants.

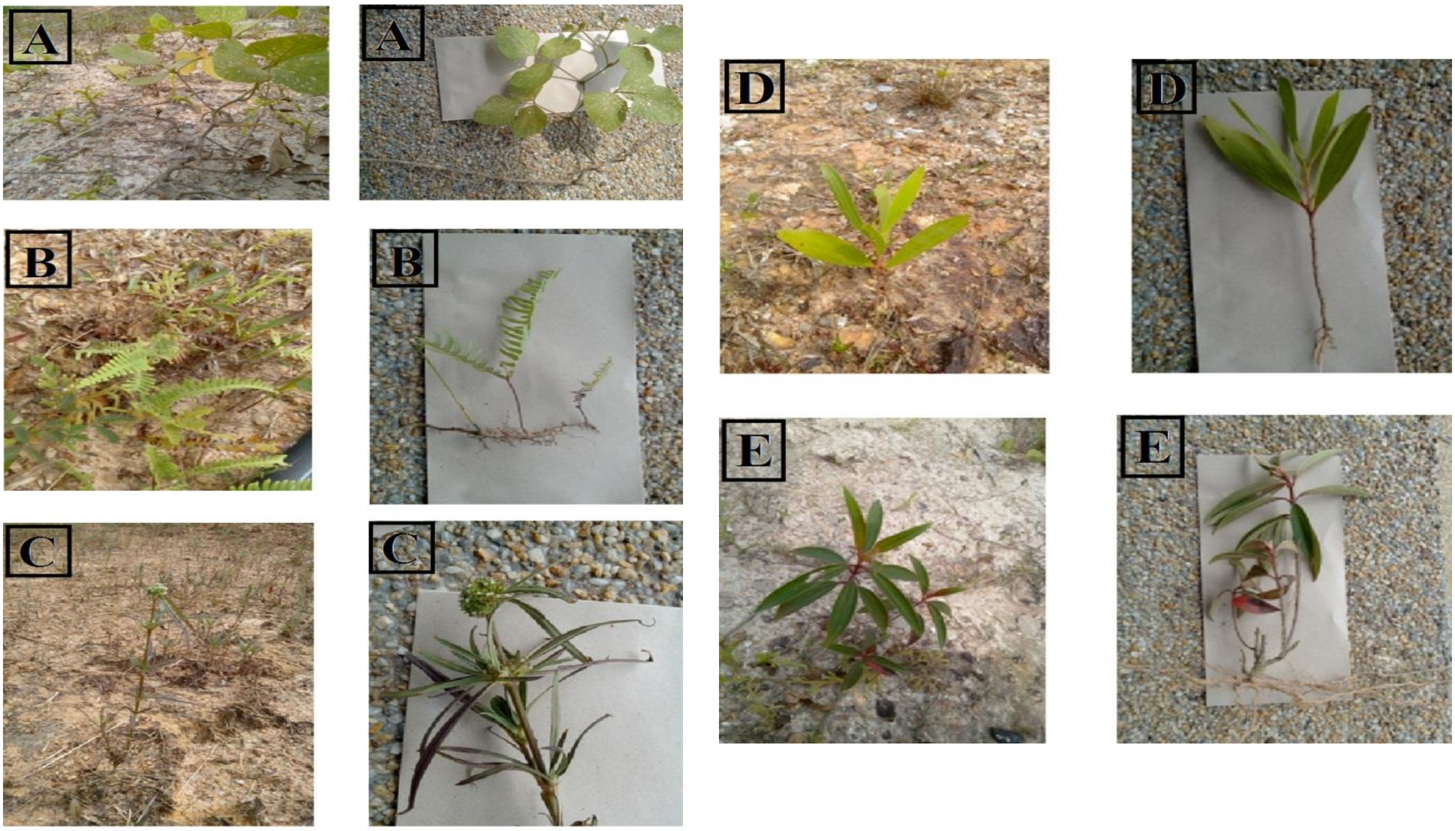

Figure 2: *Pueraria phaseoloides* (A), *Dicranopteris linearis* (B), *Cyperus rotundus* (C), *Acacia spp.* (D) and *Melastoma malabathricum* (E) samples.

Heavy metal concentration in plant parts

The heavy metal concentrations in the plant samples were divided according to different plant parts, which are the stem, leaves and roots. The combined values of these heavy metal concentrations represent the total heavy metal concentration of the plants.

Cadmium concentrations in plant parts

As shown in Figure 3, Cd concentrations were highest in the leaves for three plant species, which are *Pueraria phaseoloides* (0.022 ppm), *Cyperus rotundus* (0.019 ppm) and *Melastoma malabathricum* (0.018 ppm). For *Dicranopteris linearis*, the highest concentration of Cd was recorded in the roots (0.019 ppm) while *Acacia* spp. exhibited the highest Cd concentration in the stem (0.018 ppm). The highest total Cd concentration was recorded by *Pueraria phaseoloides* (0.056 ppm). For four of the plant species (*Pueraria phaseoloides, Cyperus rotundus, Acacia* spp. and *Melastoma malabathricum*), the highest Cd concentration was found in the aerial parts of the plant (Leaves and stem). This is because Cadmium is a mobile heavy metal, easily transported from the root of the plant to the stem and leaves (Gregor *et al.* 2004).

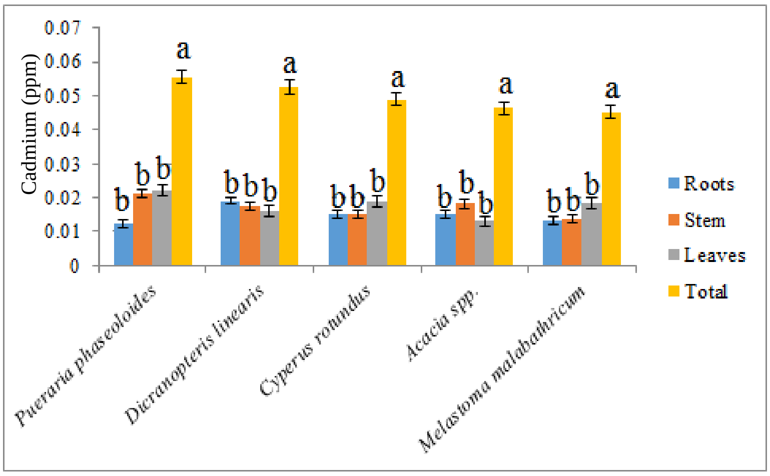

Figure 3: Cd concentrations in different plant parts.
Mean values followed by same letter are not significantly different at P ≤0.05 by Tukey HSD test.

Iron concentrations in plant parts

As shown in Figure 4, Iron concentrations were highest in the roots for all plant species, which are *Pueraria phaseoloides* (16.34 ppm), *Dicranopteris linearis* (18.36 ppm),*Cyperus rotundus* (13.31 ppm), *Acacia* spp. (9.77 ppm) and *Melastoma malabathricum* (13.34 ppm). The highest total Cd concentration was recorded by *Cyperus rotundus* (26.28 ppm). High metal concentrations are commonly found in the roots of most plants due to its direct contact with the metal in the soil (Rajoo *et al.* 2013). Previous studies have shown that the presence of Fe for phytoremediation purposes is beneficial as it assists in the uptake of other heavy metals (He *et al*. 2015).

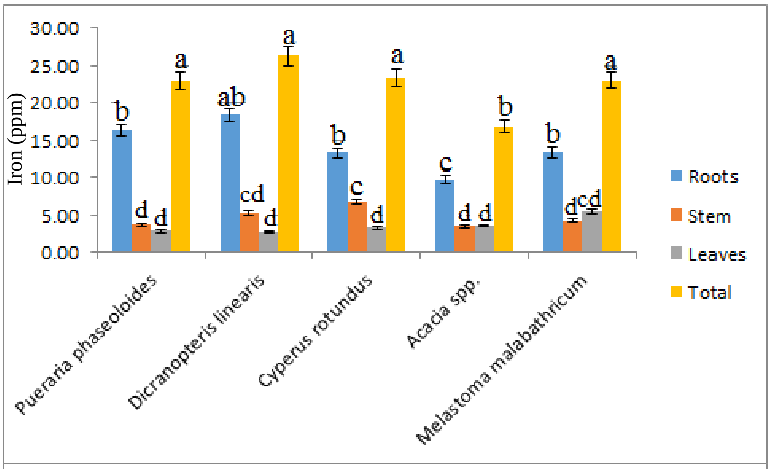

Figure 4: Fe concentrations in different plant parts.
Mean values followed by same letter are not significantly different at P ≤0.05 by Tukey HSD test.

Zinc concentrations in plant parts

As seen in Figure 5, Zinc concentrations were highest in the roots for all plant species, which are *Pueraria phaseoloides* (10.72 ppm), *Dicranopteris linearis* (17.98 ppm), *Cyperus rotundus* (13.63 ppm), *Acacia* spp. (8.73 ppm) and *Melastoma malabathricum* (12.15 ppm). The highest total Zn concentration was recorded by *Dicranopteris linearis* (31.55 ppm). The availability of

Zn is very dependent on the soil pH; as pH decreases, the availability of Zn increases (Ripin *et al*., 2014). All the plants studied mostly stored Zn in its roots, which is common in most plants (Rajoo *et al*. 2013).

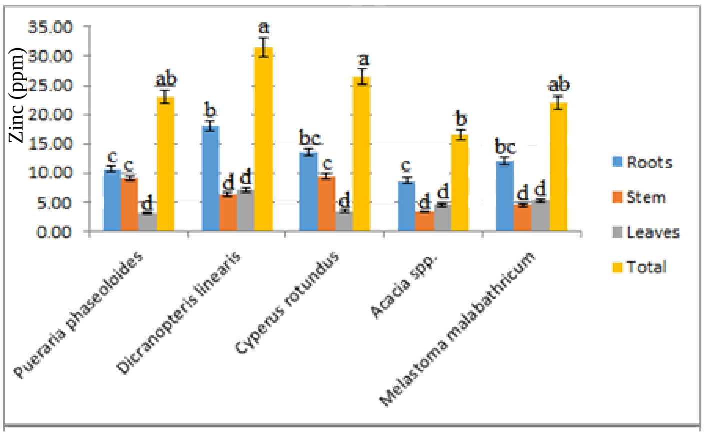

Figure 5: Zn concentrations in different plant parts. Mean values followed by same letter are not significantly different at P ≤0.05 by Tukey HSD test.

The Translocation Factor (TF) and Bioconcentration Factor (BCF) of plant samples

A plant's potential as a phytoremediator can be determined by calculating the plant's BCF (metal concentration ratio of plant roots to the soil) and TF (metal concentration ratio of plant shoots to roots) values. If both the BCF and TF value is above 1, the species has the potential to be a hyperaccumulator while a BCF value of above 1 and a TF value below 1 was a potential phytostabilizer species.

TF and BCF of Cadmium

The Cadmium BCF values for all plant species was below 1 (Figure 6). The BCF values for all respective species were *Pueraria phaseoloides* (0.59), *Dicranopteris linearis* (0.90),*Cyperus rotundus* (0.71), *Acacia* spp. (0.71) and *Melastoma malabathricum* (0.63). Four plant species had TF values of above 1, which are *Pueraria phaseoloides* (1.70), *Cyperus rotundus* (1.02), *Acacia* spp. (1.20) and *Melastoma malabathricum* (1.04). The results show that none of these species were potential phytoremediators of Cd. However, the four plant species that had TF values of above 1 could be potentially used as bioindicators for Cd.

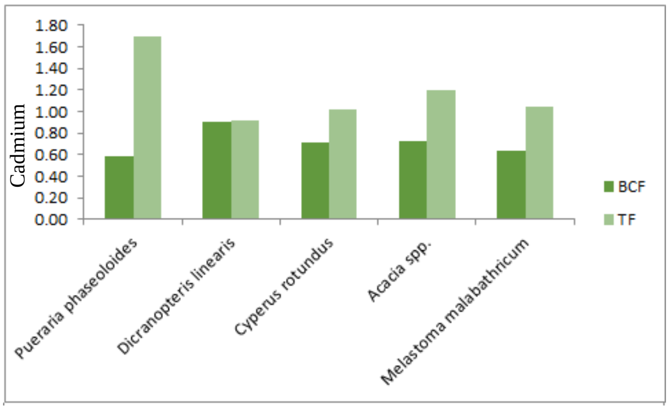

Figure 6: BCF and TF values of Cd in different plant species
(Note: BCF = Bioconcentration Factor and TF = Translocation Factor)

The TF and BCF of Iron

Similar to Cd, the Iron BCF values for all plant species was below 1 (Figure 7). The BCF values for all respective species were *Pueraria phaseoloides* (0.80), *Dicranopteris linearis* (0.90), *Cyperus rotundus* (0.65), *Acacia* spp. (0.48) and *Melastoma malabathricum* (0.65). All the plant species also had Fe TF values of lower than 1, the respective values being *Pueraria phaseoloides* (0.23),*Dicranopteris linearis* (0.29), *Cyperus rotundus* (0.51) *Acacia* spp. (0.36) and *Melastoma malabathricum* (0.31). The results show that none of these species were potential phytoremediators of Fe.

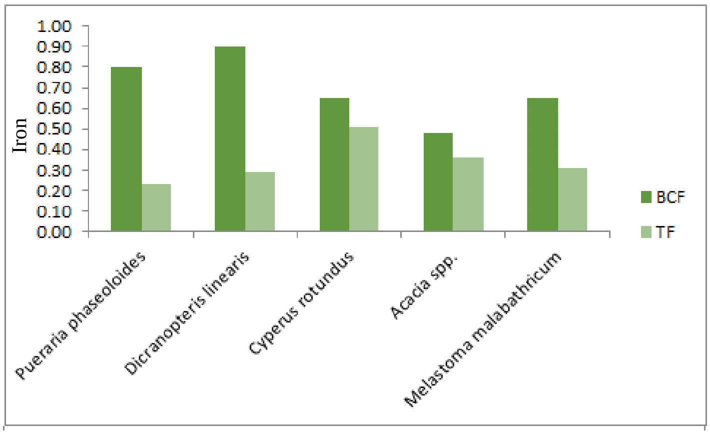

Figure 7: BCF and TF values of Fe in different plant species
(Note: BCF = Bioconcentration Factor and TF = Translocation Factor)

The TF and BCF of Zinc

The Zinc TF and BCF values for all plant species was below 1 (Figure 8). The BCF values for all respective species were *Pueraria phaseoloides* (0.21), *Dicranopteris linearis* (0.36), *Cyperus rotundus* (0.34), Acaciaspp. (0.17) and *Melastoma malabathricum* (0.24). The Zn TF values of the plant species were *Pueraria phaseoloides* (0.85), *Dicranopteris linearis* (0.35), *Cyperus rotundus* (0.69) *Acacia* spp. (0.39) and *Melastoma malabathricum* (0.38). The results show that none of these species were potential phytoremediators of Zn. This is unlike numerous other species which have been found to be suitable phytoremediators of Zn, most notably phytoextractors such as running grass and desert broom.

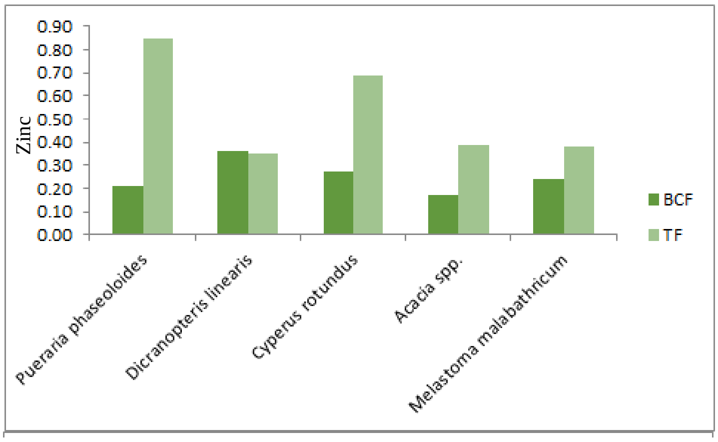

Figure 8: BCF and TF values of Zn in different plant species
(Note: BCF = Bioconcentration Factor and TF = Translocation Factor)

CONCLUSION

Based on the TF and BCF values of all the plants studied, none of the plant species were potential phytoremediators. However, four plant species had Cd TF values of above 1, which were *Pueraria phaseoloides*, *Cyperus rotundus*, *Acacia* spp. and *Melastoma malabathricum*. Hence, these four plant species could be potentially used as bioindicators for Cd. It is advisable that identified phytoremediator plant species be planted at sites that could cause ecosystem contamination, such as landfills.

ACKNOWLEDGEMENTS

The authors would like to thank Worldwide Environment for allowing us to conduct this study at Air Hitam Sanitary Landfill. The authors would also to thank Universiti Putra Malaysia for funding this research and the APC, under Geran Putra Berimpak (Vot: 9725800).

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