

Adsorption of Mercury and Zinc in Agricultural Soils by *Sphagneticola trilobata*

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ABSTRACT

Given the imminent deterioration of environmental quality, the accumulation of heavy metals in agricultural soil is one of the main concerns worldwide. Therefore, this research aimed to evaluate the adsorption potential of mercury and zinc by *Sphagneticola trilobata*. After 60 days, the distribution of heavy metals in the roots and the leaves of the plants was determined. As a result, the plant adsorbed mercury between 43.49 and 59.22%, and zinc between 32.68 and 64.37%. According to the bioconcentration and translocation factors of *Sphagneticola trilobata* obtained in the present work, the phytostabilizing capacity of mercury and zinc is like *Eichhornia crassipes* and *Sorghum bicolor*.

Keywords: phytoremediation, *Sphagneticola trilobata*, mercury, zinc, soil, wetland.

INTRODUCTION

The intensification of industrial processes and agricultural activities has led to a notable deterioration in environmental quality (Yan et al., 2020). One of the worldwide concerns is the accumulation of heavy metals in the soil since these compounds are not degradable but persist in the environment, representing a threat to biota when biomagnified (Furini et al., 2015; Khalid et al., 2018). These heavy metals come from natural or anthropogenic sources, such as water generated in the oil and gas industries, phosphate fertilizers in agriculture, sewage sludge, mining, metal smelting, pesticide application, and burning of fossil fuels (Yan et al., 2020). Mercury (Hg) is one of the most dangerous environmental pollutants with carcinogenic, teratogenic, neurotoxic, genotoxic, and bioaccumulation effects, which cause damage to the human body and ecosystem; exposure to soils contaminated with Hg has caused devastating neurological damage, kidney damage, and even death, is a threat to human health (Liu et al., 2020; Tiodar et al., 2021). Zinc (Zn) is

an essential heavy metal because it is indispensable for physiological and biochemical processes during the life cycle of plants; however, it can become toxic in excess (Yan et al., 2020). Both Hg and Zn cause environmental pollution and severely affect various physiological and biochemical processes in crop plants and reduce agricultural productivity (Furini et al., 2015).

Given the above problems, phytoremediation is a cost-effective ecological technique that takes advantage of the ability of some plant species to extract and adsorb heavy metals or reduce their bioavailability in the soil (Vimal and Singh, 2020). The main advantages of phytoremediation are: (i) reduced cost of installation and maintenance, (ii) reduction of the exposure of pollutants to the environment and ecosystems, (iii) prevention of erosion and leaching of metals, reducing the risk of contamination, (v) can also improve soil fertility by releasing various organic matter into it (Yan et al., 2020; Vimal and Singh, 2020; Furini et al., 2015).

In recent decades, numerous studies are aimed to determine the molecular mechanisms about the tolerance of heavy metals and how to develop

techniques to enhance phytoremediation efficiency. In this sense, this research aims to evaluate the potential of phytoadsorption of mercury and zinc in agricultural soils by *Sphagneticola trilobata*.

METHODOLOGY

The soil and plant samples used in this research were collected from a community known as Balsa-En-Medio with coordinates 617373 E; 9890506 N, belonging to the Bolívar canton, Manabí-Ecuador (Figure 1). This study area has characteristics of tropical climate, influenced by the changes that occur in the Pacific Ocean and by the movement of the Intertropical Convergence Zone; according to the bioclimatic map of Ecuador, this region is classified as Tropical Sub-humid, located in an ecological region of tropical dry forest type.

Soil collection and planting of *Sphagneticola trilobata* in microcosmos

Sphagneticola trilobata was chosen considering adaptability, physiological characteristics, and wide distribution in tropical and subtropical areas (Sun et al., 2019). The microcosmos test was

performed in a greenhouse (8×12 meters) from the City of Agricultural Research, Innovation, and Development (CIIDEA) at the ESPAM MFL, at approx. 25 °C avoiding significant variations in light and temperature for which the area was covered with cadi leaves (*Phytelphas*). The following procedure was performed:

Individuals of *Sphagneticola trilobata* from 20 to 25 cm in height were considered. The initial content of Hg and Zn in roots and the plant-air zone was evaluated by inductively coupled plasma – optical emission spectrometry (ICP-OES) method. At a depth of 0 to 30 cm, 15 kg of soil were taken from the greenhouse. This soil was contaminated with solutions of $Hg(NO_3)_2$ and $Zn(NO_3)_2$ (Ortega et al., 2011), to achieve final concentrations of 27 µg/g of Hg and 180 µg/g of Zn. Contaminated soil was distributed in pots of 6 kg. In each pot, individuals of *Sphagneticola trilobata* were planted and watering was applied every three days (200 ml of water per pot).

At the end of the trial period (60 days), the concentrations of Hg and Zn in soil and *Sphagneticola trilobata* were quantified by the ICP-OES method.

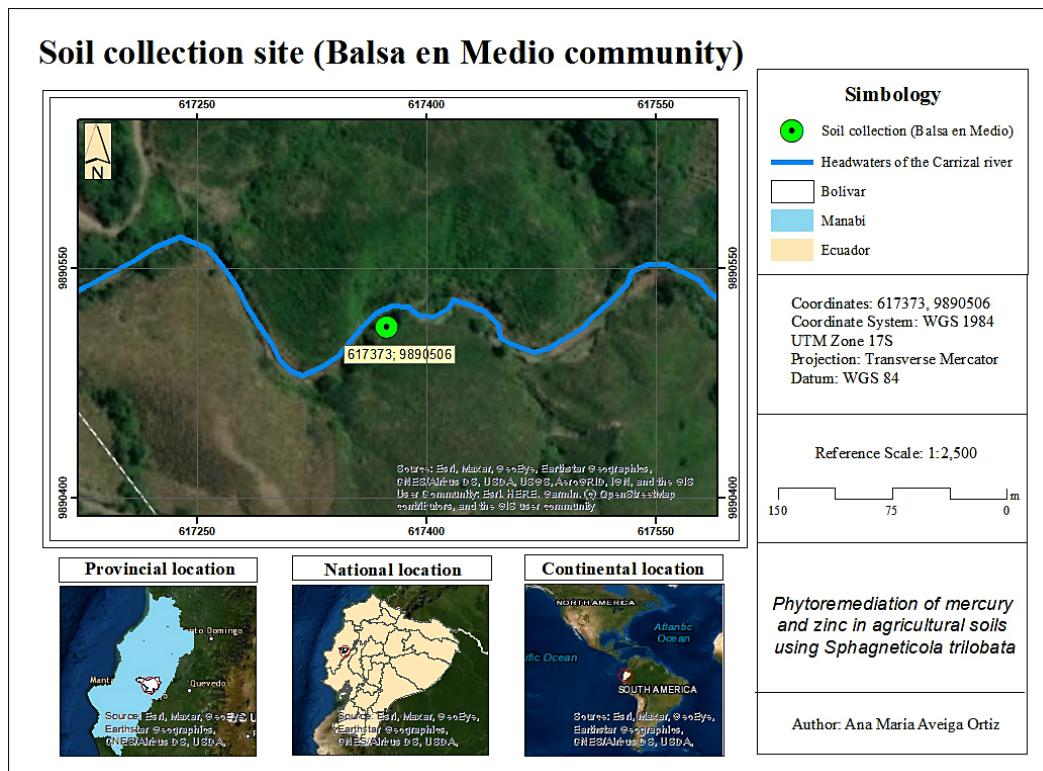


Figure 1. Location of the soil collection site (Balsa-En-Medio, Ecuador)

Application of *Sphagneticola trilobata* in situ phytoremediation

The phytoadsorption test *in situ* on the banks of the river of the Balsa-En-Medio community, a place selected for the constant development of agricultural activities in which contamination of Hg and Zn was previously detected. The following procedure was performed:

The initial concentrations of Hg and Zn were determined. *Sphagneticola trilobata* was sowed in two plots of 40 m² each one (Length = 10 m; Width = 4 m). After 90 days, the final concentrations of Hg and Zn in the soil were determined.

Comparison of the phytoremediation potential of *Sphagneticola trilobata* with other plant species

A systematized literature review was carried out in research databases like Scopus and Web of Sciences to identify quantitative references on the phytoremediation potential of Hg and Zn that other plant species possess. The selection criteria were based on the following: publications with quantitative data of the initial and final concentrations of Hg and Zn content in plants and soil; publications with high solidity in their results; and selected research over the last ten years.

RESULTS AND DISCUSSION

Adsorption effects in microcosmos

At the start of the experiment, the seedlings of *S. trilobata* revealed a Hg content <0.001 µg/g in roots

and leaves. The concentration of Zn in roots was 2.79 µg/g and 2.32 µg/g at the leaves, indicating that the seedlings did not contain higher concentrations of heavy metals. Regarding the phytoadsorption test in microcosmos pots, it was found that the Hg soil content was reduced from 26.53 µg/g to 10.83 µg/g, obtaining the removal of 59.22%. A concentration of 12.57 µg/g was determined in the roots, while 0.09 µg/g was in the leaves (Figure 1). These findings agreed with Ranieri et al. (2019), who obtained a reduction of 52.30% using *H. annuus* (sunflower) for phytoadsorption of soils contaminated with Hg.

Regarding the Zn content, this was reduced from 186.69 µg/g to 66.51 µg/g, meaning a 64.37% of removal; in this case, 70.15 µg/g of Zn were found at the roots and 24.39 µg/g of Zn in the leaves of *S. trilobata* respectively (Figure 2). The high absorption capacity of Zn by *S. trilobata* could be attributed to the large amount of parenchyma in its tissues. In addition, Zn is mostly concentrated in the roots of plants belonging to the Asteraceae family in relation to its leaves.

Adsorption effects in soil

In soil, the level of Hg was reduced from 24.88 µg/g to 14.06, representing a decrease of 43.49%; results that agree with the reports of Hg reduction with *Eichhornia crassipes* (Rusnam and Efrizal 2016). Similarly, soil Zn levels went from 101.24 µg/g to 68.15 µg/g, reflecting a reduction of 32.68%; in agreement with the reduction of Zn in soil by *Eichhornia crassipes* (Bassey et al., 2018).

According to Marrugo et al. (2015), the Bio-concentration Factor (BCF) records the metal uptake from soil to roots, while the Translocation

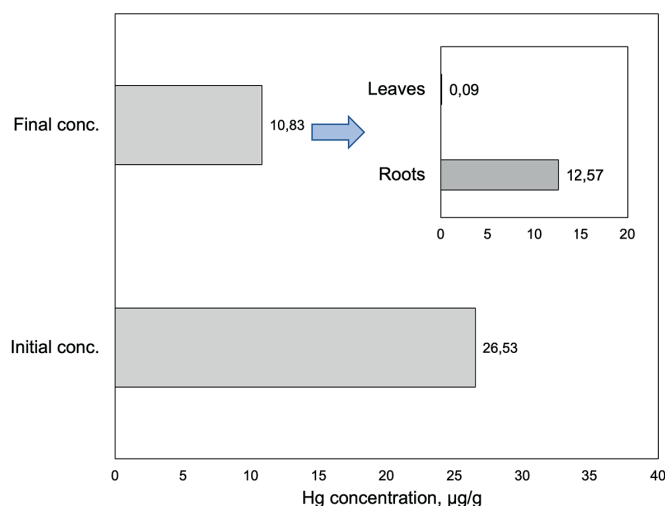


Figure 2. Hg concentration in the microcosmos phytoadsorption assay

Table 1. Distribution of Hg and Zn in soil, roots and shoot of *Sphagneticola trilobata*

Heavy metals	Initial concentration in soil	Final concentration in soil	Concentration in roots	Concentration in leaves	*BCF	**TF
Hg ($\mu\text{g/g}$)	26.53	10.83	12.57	0.09	1.16	0.01
Zn ($\mu\text{g/g}$)	186.69	66.51	70.15	24.40	1.06	0.35

*BCF – bioconcentration factor, **TF – translocation factor.

Factor (TF) is the metal uptake from roots to shoot (Tripti & Vimal, 2019). Table 1 shows the results of the analysis of Hg and Zn in the soil, roots and leaves of *Sphagneticola trilobata*, finding that the BCF of Hg is 1.160, with a TF of 0.006. Therefore, the plant is considered a phytostabilizing system, where Hg is highly transferable during early periods of exposure. In addition, it has been shown that the greatest translocation of Hg occurs when the roots are exposed to a greater volume of soil, promoting better absorption of the metal (Smolinska and Szczodrowska, 2016). On the other hand, a low TF represents low plant adsorption to the contaminant to avoid its toxic effects.

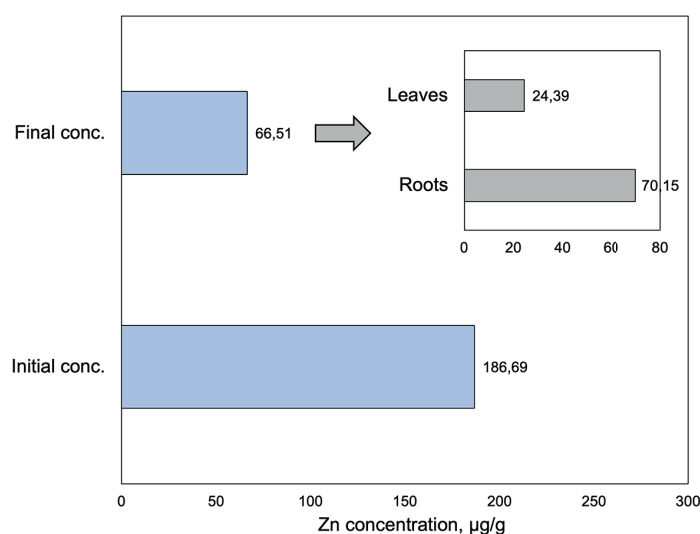
The BCF of Zn in *Sphagneticola trilobata* was 1.055, and the TF of 0.348, showing also a phytostabilizer effect for Zn. Similar results were obtained for *Helianthus annuus* in soils contaminated with Zn, with an BCF of 0.973 and a TF of 0.464 (Arunakumara et al., 2015). In general, the amount of Hg that accumulates in the roots and aerial parts of the species analyzed in this research is directly proportional to the concentration of Hg in the soil and the time of exposure; in addition, normally the concentration of Hg in the roots is higher than in the leaves, because the absorption of metals by the roots is rapid compared to transport to other tissues

(Marrugo et al., 2015; Lominchar et al., 2015; Chattopadhyay et al., 2012).

Comparison with other species

Regarding the efficiency of other plant species in Hg adsorption (Figure 3), *Jatropha curcas* represented a removal up to 2 $\mu\text{g/g}$ in decreasing order: roots > leaves > stems (Marrugo et al., 2015). The species *Oxalis comiculata* shows a smaller distribution in the removal of Hg, reaching up to 0.5 $\mu\text{g/g}$, pointing out that the amount of Hg in all parts of this species and especially in the shoots, can be increased using enhancers such as $\text{Na}_2\text{S}_2\text{O}_3$ (Liu et al., 2018). *Sorghum bicolor* showed the largest distribution in terms of Hg removal, with a maximum of 2.6 $\mu\text{g/g}$, suggesting that this species can survive and grow well in soils contaminated with Hg (Kokyo et al., 2016).

Typha domingensis is the species with the lowest distribution for Hg adsorption, reaching a maximum limit of 0.3 $\mu\text{g/g}$; although, the accumulation of Hg in the organs of this species depends on the concentration of Hg in the environment (Lominchar et al., 2015). *Eichhornia crassipes* describe a remarkable distribution, with an upper limit of 1.91 $\mu\text{g/g}$, emphasizing that this species

**Figure 3.** Zn concentration in the microcosmos phytoadsorption assay

can adsorb both Hg and methylmercury (MeHg) in significant amounts even under extremely high levels of pollution (Chattopadhyay et al., 2012).

As shown in Figure 4, *Arundo donax* represents the largest distribution in terms of Zn removal in contaminated soils, with an upper limit of up to 10.45 µg/g, reporting that the biomass and root length of this species are directly proportional to the concentration of Zn (Li et al., 2014). On the other hand, *Helianthus annuus L.* showed a maximum of up to 7.84 µg/g with a narrower distribution; in addition, this species accumulates up to 45.46 µg/g of Zn (Mani et al., 2015).

Besides, *Salix pedicellata* achieves a removal of up to 9.71 µg/g of Zn; in this species, high concentrations of Zn cause immediate wilting and the appearance of chlorosis (Amdoun et al., 2020). *Miscanthus sacchariflorus* shows a remarkable distribution with a limit of decrease of 5.77

µg/g of Zn with levels of two to seven times higher in the roots than in the shoots, and, correlating significantly in a positive way with the concentration of Zn (Li et al., 2014) (Figure 5).

CONCLUSIONS

In conclusion, processes such as phytoadsorption in agricultural soils reduce the content of heavy metals. After 60 days, regarding the phytoadsorption test in microcosmos pots, it was found that the Hg soil content was reduced up to 59.22%, and Zn was reduced up to 64.37%. In soil, the level of Hg was reduced up to 43.49% meanwhile Zn concentrations were reduced up to 32.68%. According to the factors of bioconcentration and translocation, *Sphagneticola trilobata* is phytostabilizing for both metals. Like other species, the adsorption time

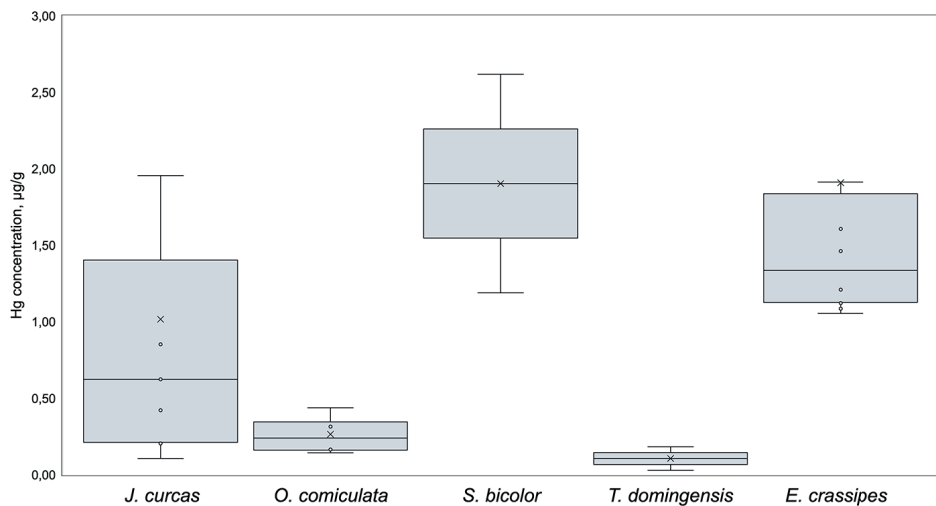


Figure 4. Bibliographic review of various species used in the phytoremediation of soils contaminated with Hg

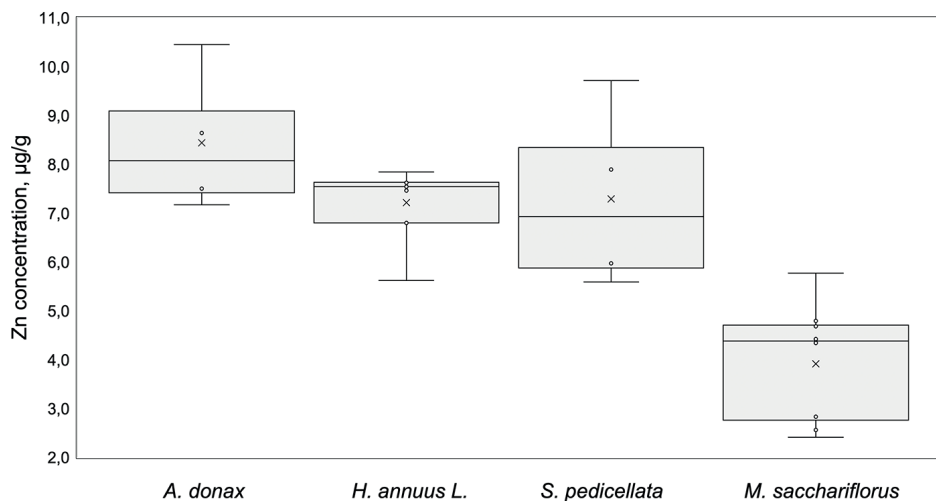


Figure 5. Bibliographic review of various species used in the phytoremediation of soils contaminated with Zn

of this plant species is directly proportional to the extraction of the heavy metal.

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