ORIGINAL WORKS[1]

PHYTOREMEDIATION EFFECT OF FIVE NATIVE TREE SPECIES FROM SOILS CONTAMINATED WITH HEAVY METALS, IN THE COLOMBIAN AMAZON.

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ABSTRACT

Phytoremediation consists of the use of plants to remedy in situ soils, sediments, water and air contaminated by organic waste, nutrients or heavy metals, eliminating pollutants from the environment or rendering them harmless.
This work was carried out in natural conditions in the department of the Amazon, in Colombia, from October 2015 to October 2020. Twenty treatments were evaluated with a full factorial design 5 x 4: 5 native Amazonian tree species, in four soils contaminated by metals heavy products of illegal artisanal mining in the Amazon river basin, with polluting loads of 10%, 20%, 30% of mine tailings (RM) and soil without RM. The tree species chosen were: **Yarumo (Cecropia peltata), Coctinu (Miconia amazonica), Monteverde (Monteverdia macrocarpa), Caimito (Pouteria caimito) and Amazonian Sauco (Salix humboldtiana).**

The highest accumulation efficiency of Mercury, lead and zinc was obtained in the roots of Yarumo (Cecropia peltata) with the treatment of 30% of mine tailings, obtaining 2213.2 mg of mercury kg-1 DM; 2015.1 mg of lead kg-1 DM and 1024.2 mg of cadmium kg-1 DM. The highest accumulation of cadmium was obtained in the roots of Caimito (Pouteria caimito), with a concentration of 1287.3 mg kg-1 DM with the treatment of 30% of mine tailings. Amazonian sauco (Salix humboldtiana) presented the highest tolerance index (IT) to the treatment of 30% mine tailings, with an IT of 41.5%, but Coctinu (Miconia amazonica), Monteverde (Monteverdia macrocarpa) presented the highest IT at the treatment of 20% of mine tailings with IT of 68.5% and 67.9; concluding that these species can be used for the recovery of soils contaminated with heavy metals such as mercury, lead and cadmium, by-products of mining.

Keywords: phytorrestoration; Amazon trees; ecosystems ecosystems of the Amazon; phytostabilization; mine tailings.

INTRODUCTION

In the Amazon ecosystems located below 3300 m of altitude, the headwaters of the basins of the Western and Eastern Slopes of the Andes are formed, here we can find grassland meadows, forest patches, scrublands and wetlands (Young et al. 1997), many of them threatened by mining and associated activities. Mining activities deposit their residues with heavy metals on the surface of the mining environment, causing soil contamination, and representing an environmental problem of great global concern (Alkorta et al. 2010).

In general, the original soils of the mines are irreversibly degraded or lost, generating new modified soils made up of materials not suitable for the development of biological processes (Becerril et al. 2007). The direct consequences of this soil contamination are the disappearance of vegetation, loss of its productivity and a decrease in biodiversity; indirectly, air, surface and groundwater pollution is mentioned (Wong 2003).

However, there are so-called metalophyte plants, which have developed the physiological mechanisms to resist, tolerate and survive in soils degraded by mining activities (Becerril et al. 2007). These species can restrict the absorption of metals or translocate them to the leaves or actively absorb and accumulate them in their aerial biomass (Baker & Proctor 1990). Some plants modify the conditions of the rhizosphere producing root exudates or altering the pH (Adriano 2001, Wenzel et al. 2003). The degrees of metallic accumulation range from traces to more than 1% of the dry matter of the plant (Diez 2008).

Currently for the recovery of soils contaminated with heavy metals there are several technologies (Diez 2008), these generally resort to the use of metalophytic plants that can be used in the phytorerestoration and phytoremediation processes to recover sediments and waters contaminated by heavy metals, eliminating environmental pollutants or making them harmless (Salt et al. 1998).

On the other hand, the so-called hyperaccumulator plants are being investigated, those capable of accumulating more than 1000 mg of Nickel per kilogram of dry matter, or more than 10000 mg kg-1 of Mn and Hg, more than 1000 mg kg-1 of Co , Cu, Ni and Pb and more than 100 mg kg-1 of Cd (Brooks et al. 1977, Baker et al. 2000), which could be used in the different phytoremediation techniques.

The present work reports the results of an experiment that evaluates the phytoremediation capacity of five Amazonian plants: Yarumo (Cecropia peltata), Coctinu (Miconia amazonica), Monteverde (Monteverdia macrocarpa), Caimito (Pouteria caimito) and Amazonian Sauco (Salix humboldtiana)., in soils contaminated with mercury, lead, mercury and cadmium.

Material and methods

The experiment was carried out under greenhouse conditions in the Leticia district located at an altitude of 3668 m (11 ° 33'11” S, 76 ° 37'32” W), Amazonas province, Amazonas region, in the period of October 2015 to October 2019. The mean monthly temperature and the mean monthly relative humidity were recorded using a digital hygro-thermograph, VWR brand model

62344-734, whose values are presented in Table 1.

The experimental unit was a pot of 19 cm in diameter and 5 kg in capacity. Soil free of heavy metals, whose physicochemical characteristics are indicated in Table 2, and polymetallic mine tailings (RM), which was obtained from a polymetallic concentrator, in the town of Yani, district of Huamantanga, Province of Amazonas and its chemical characteristics are indicated in Table 3. Subsequently, the substrates were added to the pots, according to the corresponding treatments.

Yarumo (Cecropia peltata), Coctinu (Miconia amazonica), Monteverde (Monteverdia macrocarpa), Caimito (Pouteria caimito) and Amazonian Sauco (Salix humboldtiana) seeds were collected in the district of Leticia.

The seeds of these five species were sown at the rate of 6 viable seeds of each species in each pot, and according to the corresponding treatments. The substrates were irrigated with potable water and were kept in their field capacity throughout the experiment. The seeds of the species began their germination between 21 and 30 days after sowing.

A completely randomized experimental design was used, 20 treatments were evaluated with 5 repetitions per treatment. Treatments were generated from a 5 x 4 full factorial, where 5 indicates the five high Amazonian species, and 4 indicates the four substrates (30% mine tailings, 60% and 100% mine tailings, and soil without tailings (The 30% mine tailings treatment consisted of a mixture of 1.5 kg of RM and 3.5 kg of soil (853.0 mg of lead per kilogram of soil, 1134.0 mg of Mercury per kilogram of soil and 24.0 mg of cadmium per kilogram of soil) The 60% mine tailings treatment consisted of a mixture of 3.5 kg of RM and 1.5 kg of soil (1707.6 mg of lead per kilogram of soil and 2268.0 mg of Mercury per kilogram of soil and 48.1 mg cadmium per kilogram of soil).}

Table 1. Average monthly temperature and relative humidity registered in the greenhouse, from October 2015 to October 2019, in the Leticia district, Amazonas province, Amazonas region.

Meses	Tempertura media mensual (ºC)	Humedad Relativa media mensual (%)
Oct-2015	22.8	57.6
Nov-2015	24.8	56
Dic-2015	21.9	61.4
Ene-2019	16.4	72
Feb-2019	19.6	80.5
Mar-2019	18.9	81.5
Abr-2019	22.5	59.1
May-2019	28.7	47.5
Jun-2019	17.6	38
Jul-2019	13.7	31
Ago-2019	14.1	33

Sep-2019	24.7	39
Oct-2019	21.6	43

Table 2. Physical-chemical characteristics of the soil used in the experiment carried out in the district of Leticia, province of Amazonas, Amazon region.

Determinación		Valor	Metodología	Interpretación
Arcilla	(%)	60		
Limo	(%)	28	Hidrómetro de Bouyoucos	Franco arenoso
Arena	(%)	60		
Capacidad de campo	(%)	23.2	Olla de presión	—
pH (Relación agua 1:1)		6.72	Potenciometría	Ligeramente ácido
Conductividad Eléctrica	(dS m^{-1})	1.1	Potenciometría	No salino
Materia orgánica	(%)	5.6	Walkley y Black	Alto
Capacidad de Intercambio catiónico		26.4		
P disponible	(mg kg^{-1})	71.8	Olsen	Medio
K disponible	(mg kg^{-1})	1948		Alto
K intercambiable	($cmoles^+$ kg^{-1})	3.4		Medio
Ca intercambiable	($cmoles^+$ kg^{-1})	16.7	CH_3COONH_4 1N	Medio
Mg intercambiable	($cmoles^+$ kg^{-1})	3.0		Medio
Na intercambiable	($cmoles^+$ kg^{-1})	3.2		--
Hg	(mg kg^{-1})	287.5	DTPA	Alto
Cu	(mg kg^{-1})	39.5	DTPA	Medio

Fuente: Laboratorio de Suelos, Facultad de Agronomía. Universidad Nacional SAN MARCOS.

For the evaluation of the biomass (g) of the five species, complete plants harvested 12 months after the experiment was installed. Then the samples were dried in an oven at 70 oC and until constant weight, from there cooled in a desiccator and weighed in a precision balance.

Similarly, to determine the accumulation of lead, mercury and cadmium, the plant samples were harvested 12 months after starting the experiment and separated by organs. In the laboratory, these metals were determined in leaves and stems (Rascio & Navari-Izzo 2015), considering that hyper-accumulating plant species accumulate metals in these organs, and in roots (Barceló & Poschenrieder 2003) considering that phytostabilizing plants accumulate metals in this organ. Then the samples of each plant species were separated into leaves and stems, and roots. Subsequently, the samples were dried in an oven at 60 oC to constant weight, ground and then digested with HNO3 + HCl in a heat digester to obtain an extract (Allan 1971). The readings of the concentrations of these elements were determined in an Atomic Absorption Spectrophotometer, in the Laboratory of Suelos de la Facultad de Agronomía de la Universidad Nacional SAN MARCOS.

Tabla 3. Concentración de metales pesados del relave polime- tálico utilizado en el experimento, en el distrito de Leticia, provincia de Amazonas, región Amazonas.

Determinación		Valor	Metodología
Mercurio total	(mg kg^{-1})	3780.0	Digestión húmeda

Cobre total	(mg kg^{-1})	1440.0	Digestión húmeda
Plomo total	(mg kg^{-1})	2846.0	Digestión húmeda
Cadmio total	(mg kg^{-1})	48.1	Digestión húmeda

Fuente: Laboratorio de Suelos, Facultad de Agronomía. Universidad Nacional SAN MARCOS.

The tolerance index (IT) to lead, mercury and cadmium of the plant species was calculated by means of the relationship, in percentage, between the biomass of the aerial part (dry weight of leaves and stems) in a contaminated medium and the biomass aerial in an uncontaminated environment (Watson et al. 2003). Finally, specimens of the five evaluated species were collected in duplicate, the

Table 4. Biomass (grams) accumulated by the five high Amazonian species evaluated with mine tailings treatments (%) in the Leticia district, Amazonas province, Amazonas region.

Especies	**Tratamientos (relave de mina)**			
	100%	**60%**	**30%**	**Control**
Yarumo (Cecropia peltata)	§9.1 d	21.5 c	27.4 ab	31.3 a
Coctinu (Miconia amazonica)	2.5 c	3.2 bc	4.3 b	6.7 a
Monteverde (Monteverdia macrocarpa),	2.1 b	3.0 bc	4.1 ab	5.1 a
Caimito (Pouteria caimito)	1.2 b	1.8 b	2.1 bc	3.6 a
Amazonian Sauco (Salix humboldtiana).	2.8 d	4.7 c	6.3 b	8.7 a

Table 5. Analysis of variance of the accumulation of lead, cadmium and Mercury in leaves and stems, and in roots of five high Amazonian species evaluated with mine tailings treatments (%) in the District of Leticia, Province of Amazonas, Amazonas Region.

Acumulación de metales	**Tratamientos**											
	30% Relave de mina			**20% Relave de mina**			**10% Relave de mina**			**Control**		
	Grados de libertad	**F calculada**	**Significancia Pr>F**	**Grados de libertad**	**F calculada**	**Significancia Pr>F**	**Grados de libertad**	**F calculada**	**Significancia Pr>F**	**Grados de libertad**	**F calculada**	**Significancia Pr>F**
Plomo hojas y tallos	4	7108,9	***	4	2281,6	***	4	405	***	4	0,02	NS
Plomo raíces	4	2,5+05	***	4	93063,6	***	4	2094,5	***	4	4,5	**
Plomo total	4	1,9e+05	***	4	72252,5	***	4	2091,8	***	4	4,4	*
Mercurio hojas y tallos	4	1202,4	***	4	1275,9	***	4	160,3	***	4	34,4	***
Mercurio raíces	4	11050,3	***	4	31423,4	***	4	3867,1	***	4	11,2	***
Mercurio total	4	8177,6	***	4	24527,5	***	4	2154,7	***	4	15,9	***
Cadmio hojas y tallos	4	32,4	***	4	87,6	***	4	33,4	***	4	1,1	NS
Cadmio raíces	4	258,0	***	4	1180,4	***	4	175.7	***	4	8,4	***
Cadmio total	4	198,3	***	4	705,1	***	4	167.1	***	4	7,2	***

which have been deposited in the San Marcos Herbarium (USM), Museum of Natural History.

RESULTS

Biomass. - When performing the multiple comparison test of means, by the Tukey Test, it was shown that there are significant differences (P <0.050) between treatments and at least one of them is different from the others (Table 3). Of the five species evaluated, the highest biomass value was obtained with the control treatment. And comparing the biomass values between the evaluated species, Yarumo (Cecropia peltata) accumulated the highest biomass production (31.3 g).

It should be noted that Yarumo (Cecropia peltata) is a shrub species and the other species are herbaceous plants. On the other hand, the lowest biomass values in the 5 species evaluated were obtained with the treatment of 100% mine tailings (Table 4).

Accumulation and distribution of lead, Mercury and cadmium. - The analysis of variance showed that there are significant differences (P <0.05) between the treatments and indicated that at least one of them was different from the others compared to different concentrations of lead accumulation. Mercury and cadmium distributed both in the leaves and stems, as well as in the roots of the five species evaluated (Table 5).

In Yarumo (Cecropia peltata), the highest accumulation values of lead, mercury and cadmium were obtained in the roots with the treatment of 100% mine tailings. They accumulated 576 mg of lead per kg-1 of dry matter (DM), 431.4 mg of Mercury kg-1 DM (Fig. 1) and 8.7 mg of cadmium kg-1 DM (Fig. 2). A similar response was observed when analyzing as total lead, total mercury and total cadmium, the highest accumulation of these three elements occurred with the treatment of 100% mine tailings.

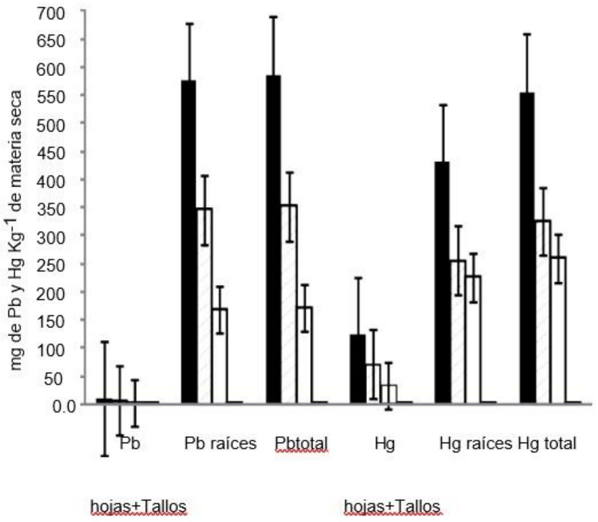
In Coctinu (Miconia amazonica), the highest accumulation values of lead, mercury and cadmium were obtained in the roots with the treatment 100% mine tailings disposal. The species accumulated 758.8 mg kg-1 DM of lead, 550 mg kg-1 DM of Mercury (Fig. 3) and 4.9 mg kg-1 DM of cadmium (Fig. 4). A similar trend was observed when total lead, total mercury and total cadmium were analyzed, where the highest accumulation of these three elements was generated with the treatment of 100% mine tailings.

In Monteverde (Monteverdia macrocarpa), the highest accumulation values of lead, mercury and cadmium were also obtained in the roots with the treatment of 100% mine tailings. They accumulated 2015.1 mg kg-1 DM of lead, 1024.2 mg kg-1 DM of Mercury (Fig. 5), and 11 mg kg-1 DM of cadmium (Fig. 6). A similar trend was observed when total lead, total mercury and total cadmium were analyzed, where the highest accumulation of these three elements was generated with the treatment of 100% mine tailings.

Of all the high Amazonian species evaluated, this species has the highest efficiency in extracting and accumulating lead and Mercury, these characteristics warrant considering it as a phytoremediate species of soils contaminated with these elements.

In Caimito (Pouteria caimito), the highest accumulation values of lead, mercury and cadmium were obtained in the roots with the treatment of 100% mine tailings. They accumulated 854.5 mg of lead kg-1 MS, 452.8 mg of Mercury kg-1 MS (Fig. 7) and 8.9 mg of cadmium kg-1 MS (Fig. 8). A similar trend was observed when total lead, total mercury and total cadmium were analyzed, where the highest accumulation of these three elements was generated with the treatment of 100% mine tailings.

In Amazonian Sauco (Salix humboldtiana) the highest accumulation values of lead and cadmium were obtained in the roots with the treatment of 100% mine tailings. They accumulated 992.8 mg of lead kg-1 DM (Fig. 9) and 287.3 mg of cadmium kg-1 DM (Fig. 10). A similar trend was observed when it was analyzed as total lead, total mercury and cadmium



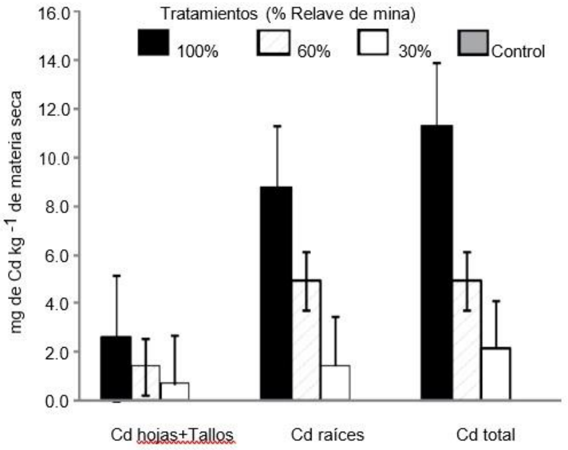


Figure 1. Accumulation of lead and Mercury in leaves and stems, roots and lead and total Mercury in Yarumo (Cecropia peltata) Ruiz & Pav.

Figure 2. Cadmium accumulation in leaves and stems, roots and total cadmium in Yarumo (Cecropia peltata) Ruiz & Pav.

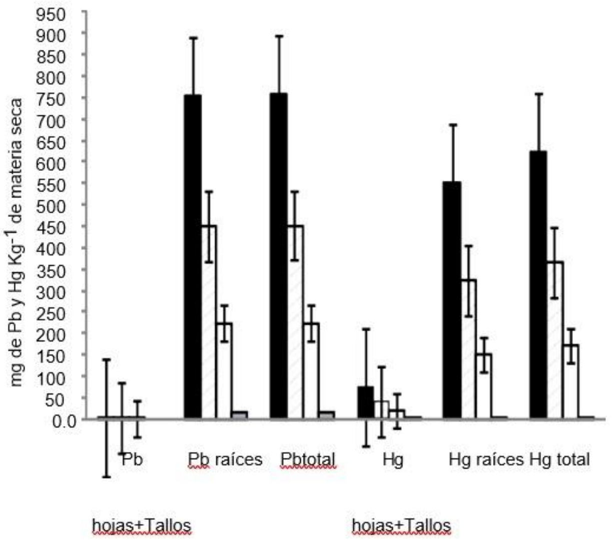


Figure 3. Accumulation of lead and Mercury in leaves and stems, roots and lead and total Mercury in Coctinu (Miconia amazonica) L.

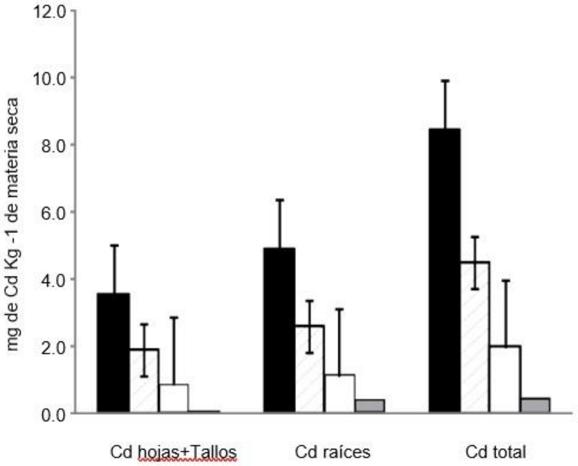


Figure 4. Cadmium accumulation in leaves and stems, roots and total cadmium in Coctinu (Miconia amazonica) L.

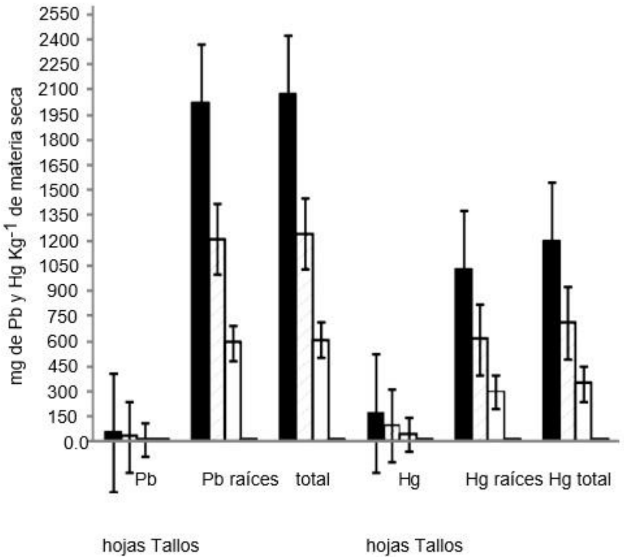


Figure 5. Accumulation of lead and Mercury in leaves and stems, roots and lead and total Mercury in Monteverde (Monteverdia macrocarpa) (C. Presl) Fryxell.

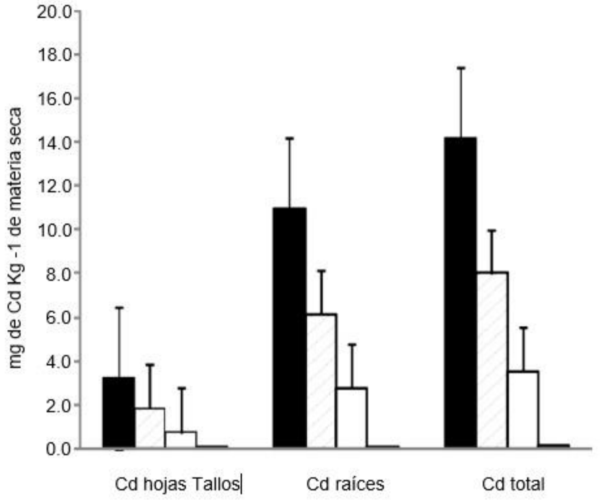
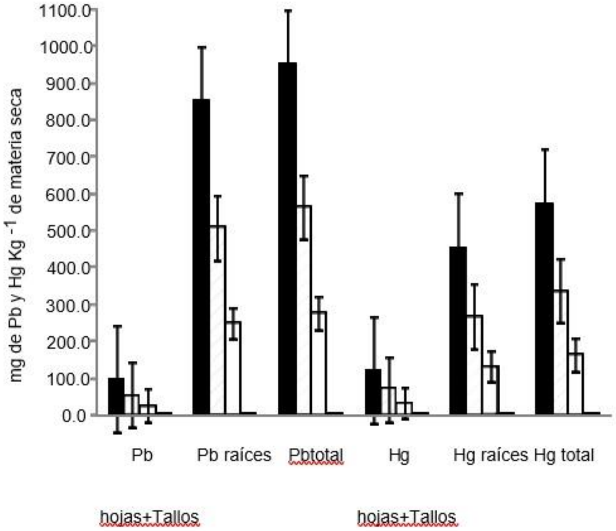


Figure 6. Cadmium accumulation in leaves and stems, roots and total cadmium in Monteverde (Monteverdia macrocarpa) (C. Presl) Fryxel.



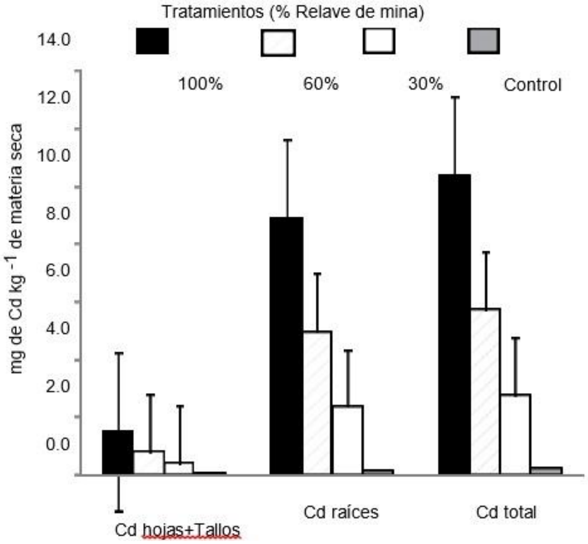


Figure 7. Accumulation of lead and Mercury in leaves and stems, roots and lead and total Mercury in Caimito (Pouteria caimito) L.

Figure 8. Cadmium accumulation in leaves and stems, roots and lead and total Mercury in Caimito (Pouteria caimito) L.

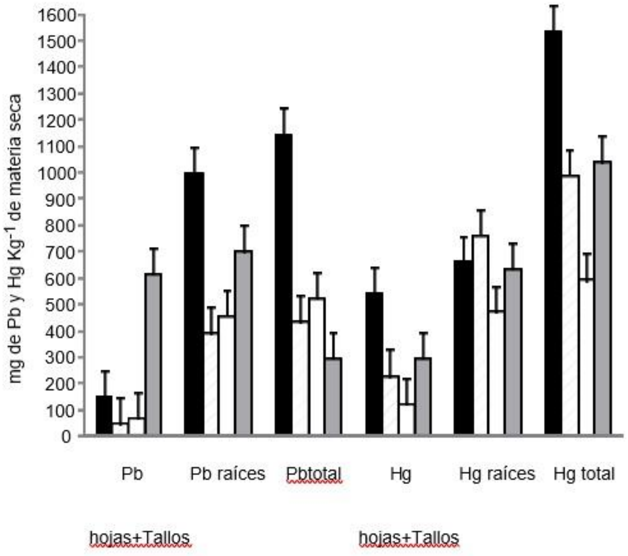


Figure 9. Accumulation of lead and Mercury in leaves and stems, roots and lead and total Mercury in Amazonian Sauco (Salix humboldtiana) C.P. Ye.

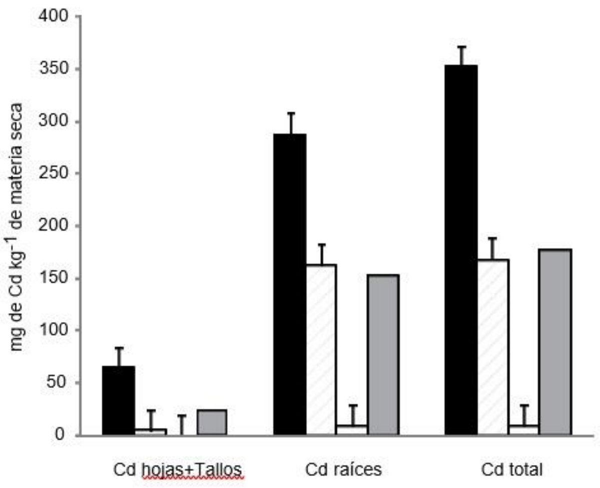


Figure 10. Cadmium accumulation in leaves and stems, roots and lead and total cadmium in Amazonian Sauco (Salix humboldtiana) C.P. Ye.

of these three elements was generated with the treatment of 100% mine tailings.

However, the highest accumulation of Mercury was obtained with the treatment of 60% mine tailings (763.6 mg kg-1. DM). A similar trend was observed when total lead, total mercury and total cadmium were analyzed, where the highest accumulation of these three elements was generated with the treatment of 60% of mine tailings.

Tolerance index of the species to lead, Mercury and cadmium. - The test of multiple comparison of Tukey means, showed that there are significant differences ($P < 0.05$) between the treatments for the TI to lead, Mercury and cadmium calculated for the five high Amazonian species (Table 6). The IT values show that Monteverde (Monteverdia macrocarpa) has the highest tolerance capacity to the treatment of 100% mine tailings, with an IT of 41.5%, but with a low biomass production (Table 6). Yarumo (Cecropia peltata) and Amazonian Sauco (Salix humboldtiana) presented medium TI to the treatment of 60% of mine tailings, achieving 68.5% and 67.9 TI, respectively.

Table 6. Tolerance Index (IT) of five high Amazonian species evaluated with mine tailings treatments (%) in the Leticia District, Amazonas Province, Amazonas Region.

Especies	Tratamientos (relave de mina)			
	100%	60%	30%	Control
Yarumo (Cecropia peltata) Ruiz &Pav.	§28.9 d	68.5 c	87.5 b	100 a

Coctinu (Miconia amazonica) L.	37.3 d	47.9 c	63.7 b	100 a
Monteverde (Monteverdia macrocarpa) (C.Presl) Fryxel	41.5 d	59.1 c	80.7 b	100 a
Caimito (Pouteria caimito) L.	32.5 d	50.1 c	58.4 b	100 a
Amazonian Sauco (Salix humboldtiana)C.P. Sm.	20.0 d	67.9 c	77.2 b	100 a

§ Valores con la misma letra en las columnas son estadísticamente iguales (Tukey, α=0.05).

for the five high Amazonian species (Table 6). The IT values show that Monteverde (Monteverdia macrocarpa) has the highest tolerance capacity to the treatment of 100% mine tailings, with an IT of 41.5%, but with a low biomass production (Table 6). Yarumo (Cecropia peltata) and Amazonian Sauco (Salix humboldtiana) presented medium TI to the treatment of 60% of mine tailings, achieving 68.5% and 67.9 TI, respectively.

DISCUSSION

Biomass.- Of the five species evaluated, the lowest biomass yield values were obtained with the treatment of 100% mine tailings. Consequently, the presence of high concentrations of lead, mercury, cadmium and other metals in the polymetallic tailings are associated with a low biomass production, compared to the control treatment.

Zornoza et al. (2002) indicate that the decrease in biomass can be attributed to the reduction of plant length and the loss of leaves, but it could also be due to the toxicity caused by the high concentration of cadmium available in the soil (Ehsan et al 2007).

Studies carried out in species of the genera Yarumo (Cecropia peltata), Coctinu (Miconia amazónica) and Caimito (Pouteria caimito) followed similar behaviors to those previously described, such was the case of Caimito (Pouteria caimito), which when evaluated with different concentrations of cadmium applied to the soil, showed growth inhibition in plant length and number of leaves; consequently, cadmium also significantly influenced the dry matter yield in roots, leaves and stems (Ehsan et al. 2009).

In Caimito (Pouteria caimito), the presence of lead in the substrate decreased the accumulation of total dry matter (Trejo et al. 2009). In other Yarumo species evaluated such as Caimito (Pouteria caimito), the toxicity of Mercury and copper significantly reduced root growth and dry weight (Stephen et al. 1997). Finally, Diez (2008) indicated that when evaluating the resistance and bioaccumulation of Mercury in different species of native plants of Spain, the biomass production in all the species studied decreased significantly due to the toxicity of this metal.

Accumulation and distribution of Lead, Mercury and Cadmium.- In Yarumo (Cecropia peltata), Coctinu (Miconia amazonica), Monteverde (Monteverdia macrocarpa) and Caimito (Pouteria caimito) the highest accumulation values of lead and cadmium were obtained with the treatment of 100 % of mine tailings. With the exception of Mercury, where the highest concentration of this element was obtained in Monteverde (Monteverdia macrocarpa), with the treatment of 60% of mine tailings.

The five high Amazonian species evaluated have the strategy of accumulating metals in the roots, regardless of the level of contamination of the substrate, this strategy is carried out by those plants called phytostabilizers (Hazrat et al. 2013). These species have the ability to reduce the transport of pollutants to the stem and leaves, and by minimizing the mobility of heavy metals through precipitation and accumulation in the roots (Alkorta et al. 2004). It has been proven that the roots produce changes in the speciation of metals, by producing variations in the redox potential, secretion of protons, and chelating agents, in addition, a large part of the metal ions are physically adsorbed to the external surfaces of the cell walls. negatively charged (Diez 2008).

In Yarumo (Cecropia peltata), with the 100% mine tailings treatment, the highest accumulation values of lead (576 mg kg-1 DM), Mercury (431.4 mg kg-1 DM) and cadmium (8.7 mg kg- 1 MS). The concentrations of mercury and cadmium obtained were very close to the concentrations obtained by Lerma (2006), in plant species with potential for accumulation of heavy metals, and where the roots of Monteverde (Monteverdia macrocarpa) accumulated 718.7 mg kg -1 MS of Mercury and 14.5 mg kg-1 of cadmium. However, Trejo et al. (2009) when evaluating the phytoextraction of this same species, obtained lead concentrations in the tissues between 3.8 and 6.9 mg kg-1 DM, and the cadmium concentration ranged from 0.2 to 0.3 mg kg-1 DM; in such a way that the lead concentration obtained in Yarumo (Cecropia peltata) was higher than that obtained by Monteverde (Monteverdia macrocarpa)

It is also important to mention that Peng et al. (2006) found that Monteverde (Monteverdia macrocarpa) accumulated 99 mg of cadmium kg-1 DM, so it is possible that Yarumo (Cecropia peltata) is a plant stabilizer of lead, Mercury and cadmium.

In Coctinu (Miconia amazonica), chemical analyzes indicated that the highest accumulation values of lead, mercury and cadmium were obtained in the roots with the treatment of 100% mine tailings. However, it is known that species of other genera of brassicaceae extract and store many heavy metals in the leaves, for example, Monteverde (Monteverdia macrocarpa) is a Mercury hyperaccumulating species, which managed to accumulate up to 14000 mg kg-1 DM (Becerril et al. 2007). Likewise, when selected Yarumo (Cecropia peltata) accessions were grown in soils contaminated with Mercury and cadmium, they were the most efficient in essentially removing Mercury, managing to produce 10 times more biomass of stems and leaves than Monteverde (Monteverdia macrocarpa), (Ebbs et al. 1997). Furthermore, in the work carried out by Turan and Esringü (2007) in the evaluation of the phytoremediation of Yarumo (Cecropia peltata) in soils contaminated with copper, cadmium, lead and Mercury, with the addition of the EDTA chelate, significant differences were obtained between species and by organs, Yarumo (Cecropia peltata) was the most efficient in the absorption of copper, cadmium, lead and Mercury; and in both species the highest accumulation of heavy metals was obtained in the roots.

In Monteverde (Monteverdia macrocarpa), the highest accumulation values of lead (2015.1 mg kg-1 DM), Mercury (1024.2 mg kg-1 DM) and cadmium (11 mg kg-1 DM) were obtained in the roots with 100% mine tailings treatment. This high Andean species presented the highest lead and cadmium phytostabilization capacity among the five evaluated.

Work carried out with other species of malvaceae corroborate these results, since for example in Yarumo (Cecropia peltata), the application of organic fertilizer promoted a greater capacity for accumulation of lead, and greater production of biomass. The roots accumulated more than 85% of the total lead, indicating that the root could be an important source of bioavailable lead (Ho et al. 2008). Yarumo (Cecropia peltata) were the most suitable for the phytostabilization of soils contaminated with lead and copper (Nassir et al. 2015).

Abe et al. (2008) when evaluating the accumulation of cadmium in stems and roots of 93 plant species, they found that Yarumo (Cecropia peltata) presented cadmium concentrations of 111.9 mg kg-1 DM in roots and 23.8 mg kg-1 DM in stems, Monteverde (Monteverdia macrocarpa), (46 mg kg-1 DM in roots and 8.7 mg kg-1 DM in stems), Monteverde (Monteverdia macrocarpa), (37.9 mg kg-1 DM in roots and 33.5 mg kg-1 DM in stems) and Yarumo (Cecropia peltata) (35.8 mg kg-1 DM in roots and 14.9 mg kg-1 DM in stems). The indicated cadmium concentrations were higher than those obtained. However, De Haro et al. (2000), when evaluating 96 species from the agricultural areas adjacent to the AHgalcóllar mine (Spain), indicated that Yarumo (Cecropia peltata) for example obtained the highest accumulation of cadmium, and they considered it as a promising species for phytoremediation purposes.

In Caimito (Pouteria caimito), the highest accumulation values of lead, Mercury and cadmium were obtained in the roots with the treatment of 100% mine tailings, accumulating 854.5 mg of lead kg-1 DM, 452.8 mg of Mercury kg- 1 DM and 8.9 mg kg-1 DM of cadmium. On the other hand, the work of Malizia et al. (2019) in Amazonian Sauco (Salix humboldtiana) pointed out that this species accumulated lead mainly in leaves, and could be used in the phytoremediation of lead-contaminated soils (Grubor 2008). However, in the work of Ziedler (2005), it was revealed that Amazonian Sauco (Salix humboldtiana) accumulated cadmium 2.5 mg kg-1 DM in roots, 2.8 mg kg-1 DM in stems and 2.1 mg kg-1 DM in leaves; lead 0.7 mg kg-1 DM in leaves, 0.6 mg kg-1 DM in roots and 1.9 mg kg-1 DM in stems; and Mercury, 0.4 mg kg-1 DM in leaves, 0.7 mg kg-1 DM in roots and 0.9 mg kg-1 DM in stems. In the present work, the accumulation of lead and cadmium obtained by Caimito (Pouteria caimito), very significantly exceed the results obtained by Ziedler (2005) in Amazonian Sauco (Salix humboldtiana).

In Amazonian Sauco (Salix humboldtiana), the highest accumulation values of lead and cadmium were obtained in the roots with the treatment of 100% mine tailings, accumulating 992.8 mg of lead kg-1 DM and 287.3 mg of cadmium kg -1 MS. Of the five species evaluated, Amazonian Sauco (Salix humboldtiana) obtained the highest efficiency of phytoextraction and accumulation of cadmium.

Ximénez-Embún et al. (2001) when evaluating the accumulation of heavy metals in Amazonian Sauco (Salix humboldtiana) and in L. hispanicus, mentioned that higher concentrations of Pb (II), Cr (III), and Cd (II) were also obtained in the roots than on the stems. Although the highest accumulation of Mercury (763.6 mg kg-1 DM) in Amazonian Sauco (Salix humboldtiana) was obtained with the treatment of 60% mine tailings, Pastor et al. (2003) report that in the evaluation of the accumulation of Mercury in Amazonian Sauco (Salix humboldtiana) in soils contaminated with this metal, the application of 300 parts per million of Mercury produced nutritional imbalances, for which a high accumulation of Mercury was obtained. in roots (4640 mg kg-1 DM) and in the aerial part (3605 mg kg-1 DM) and recommend their potential use in the phytoremediation of acidic or neutral soils contaminated with Mercury and in the revegetation of degraded areas. Mercury accumulation in Amazonian Sauco (Salix humboldtiana) was lower compared to the results obtained by Pastor et al. (2003). However, Martínez-Alcalá et al. (2009), indicated that in the stems of Amazonian Sauco (Salix humboldtiana) they observed a limited transfer of heavy metals, confirming the potential use of this species in the phyto-immobilization of heavy metals, and particularly in alkaline and neutral contaminated soils.

Vásquez et al. (2006) recommend the use of Amazonian Sauco (Salix humboldtiana) in the phytostabilization of soils contaminated with cadmium and arsenic, and in the revegetation of soils contaminated by metals. Dary et al. (2010) when evaluating the in situ phytostabilization of soils contaminated with heavy metals with the use of Amazonian Sauco (Salix humboldtiana), point out that this species managed to rapidly accumulate copper and cadmium mainly in the roots, and indicate its potential use in the phytostabilization of metals in the soil. In the work carried out with Amazonian Sauco (Salix humboldtiana), a high efficiency of cadmium accumulation in the roots was obtained, which has coincided with previous evaluations carried out on other species of the genus Amazonian Sauco (Salix humboldtiana).

Tolerance index of the species to lead, mercury and cadmium.- Monteverde (Monteverdia macrocarpa) was the species that obtained the highest tolerance index (IT) to the treatment of 100% mine tailings, with an IT of 41.5%, but obtained a low accumulation of biomass. However, Yarumo (Cecropia peltata) and Amazonian Sauco (Salix humboldtiana) presented median TI with indices of 68.5 and 67.9%, respectively, with the treatment of 60% of mine tailings. Ehsan et al. (2009) when evaluating the phytostabilization with Amazonian Sauco (Salix humboldtiana) of soils contaminated with cadmium, point out that when concentrations of 9 and 18 mg kg-1 of this metal are applied to the soil, the tolerance to metals was not considerably affected and they were obtained tolerance rates of 88 and 82%, respectively; While with the concentration of 27 mg kg-1 of cadmium, they observed a considerable decrease in tolerance, significantly affecting the height of the plant (decrease) and the number of leaves.

The values calculated for Amazonian Sauco (Salix humboldtiana) were close to the results of Ehsan et al. (2009). Although, Ximénez-Embún et al. (2002) pointed out that Amazonian Sauco (Salix humboldtiana) cultivated for 4 weeks in sand contaminated with 50 mg of cadmium L-1 obtained an index of tolerance to metals close to 100%. On the other hand, Diez (2008) obtained a tolerance index of 42% for Amazonian Sauco (Salix humboldtiana) with substrates strongly contaminated with Mercury and in treatments moderately contaminated with Mercury, it obtained an IT of 85%. Gisbert et al. (2006) when evaluating the accumulation and tolerance to heavy metals of species cultivated in contaminated soils.

In conclusion, the biomass production in the five species decreased significantly with the treatment of 100% mine tailings (RM). In Yarumo (Cecropia peltata), Coctinu (Miconia amazonica), Monteverde (Monteverdia macrocarpa), Caimito (Pouteria caimito), the highest accumulation values of lead and cadmium were obtained in the roots, with the 100% RM treatment due to the process of phytostabilization In Monteverde (Monteverdia macrocarpa) the highest accumulation of lead and Mercury was obtained in the roots, with 2015.1 mg kg-1 of dry matter (DM) and 1024.2 mg kg-1 DM, respectively with the 100% treatment. RM. In Amazonian Sauco (Salix humboldtiana) the highest accumulation of cadmium was obtained in roots with 287.3 mg kg-1 DM with the treatment of 100% RM. But the highest accumulation of Mercury was obtained with the treatment of 60% RM. Monteverde (Monteverdia macrocarpa) obtained the highest tolerance index (TI) to the 100% RM treatment, with a TI of 41.5%, Yarumo (Cecropia peltata) and Amazonian Sauco (Salix humboldtiana) presented a median TI with indices of 68.5 and 67.9% , respectively.

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