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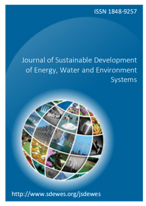

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Potential Phytoremediator of Native Species in Soils Contaminated by Heavy Metals in the Garbage Dump Quitasol-Imponeda Abancay

Carolina Soto Carrión*[*1], Wilber Jiménez Mendoza[2]

[1]Technological University of the Andes, Apurimac, Perú Avenue 700, Abancay, Peru
e-mail: caro7001@hotmail.com

[2]National University Micaela Bastides of Apurímac, Garcilaso Avenue W/N, Abancay, Peru
e-mail: wjimenezmendoza@yahoo.es

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ABSTRACT

Discarding waste in open spaces, commonly called dumps, is highly damaging to the environment. High concentrations of heavy metals are observed, which creates the need to carry out restoration processes in such places. The use of plants for the remediation of soils contaminated by heavy metals in the garbage dump, is a strategy. The work was carried out in the garbage dump of Quitasol-Imponeda de Abancay, with three native plant species. The objective was to evaluate the levels of contamination by the heavy metals: lead, cadmium, nickel, chromium and zinc in the waste matrix in root, stem and leaves. A complete factorial design was applied: three species and five treatments with heavy metals, each with two repetitions applied and in three selected plots (A, B, C). The results show that the highest accumulation of zinc, lead and cadmium was obtained in *Amaranthus hybridus*, with 23.03 parts per million in the root, 5.87 parts per million in the stem and 8.83 parts per million in the leaves, in plots two and three. In *Brassica rapa*, the highest values of accumulation were recorded for zinc, lead and cadmium in the roots, and showed a decrease in leaf growth and stem thickness. *Amaranthus spinosus* obtained higher values of zinc accumulation of 24.28 parts per million in the roots and in leaves, zinc 11.63 parts per million, lead 1.74 parts per million and cadmium 0.55 parts per million. It is concluded that the three native species present rapid growth, do not require chemical controls, with absorption of high levels of heavy metals, becoming an alternative for the restoration of the garbage dump, due to its high phytoremediation potential.

KEYWORDS

Garbage dump, Heavy metals contamination, Phytoremediation potential, Native plant species, Amaranthus spinosus, Brassica rapa, Amaranthus hybridus.

INTRODUCTION

One of the problems that affects the city of Abancay is the final disposal of solid waste in the garbage dump of Quitasol-Imponeda, located only six kilometers from the city. There is an average garbage accumulation of fifty tons per day for the entire city and the district of Tamburco involving large concentration of heavy metals, with the

[*] Corresponding author

inhabitants of this area being the most affected as well as the flora, fauna and the environment.

Heavy metals are one of the groups of environmental pollutants subject to further investigation and concern, mainly due to their persistence and the low concentrations at which they can manifest their toxic effects [1].

Regarding its toxic effects, the most problematic heavy metals are mercury (Hg), cadmium (Cd), lead (Pb), arsenic (As), copper (Cu), zinc (Zn), tin (Sn) and chromium (Cr) [2]. Faced with the problem described, it is necessary to find alternatives that allow the recovery and remediation of contamination by heavy metals produced by solid waste in the dump.

Currently, for the recovery of soils contaminated with heavy metals there are several technologies [3], which often resort to the use of metal-phytate plants that can be used in the processes of phytorestoration and phytoremediation to recover sediments and waters contaminated by heavy metals, eliminating pollutants from the environment or making them harmless [4]. Phytoremediation is often considered as an alternative for conventional remediation technologies because it is an economically sustainable, efficient and environmentally friendly activity [5].

Phytoremediation is an emerging technology for the remediation of contaminated sites due to its profitability, aesthetic advantages and long-term applicability.

Conventional remediation technologies are based on biological, physical and chemical methods, which can be used together to reduce pollution to a safe and acceptable level [6]. Despite being efficient, these methods are expensive, timeconsuming and environmentally destructive [7, 8]. At the same time, they are often detrimental to the natural environment of the soil and generate large amounts of waste [9]. Phytoremediation is an emerging technology for the remediation of contaminated sites due to its profitability, aesthetic advantages and long-term applicability [10, 11].

The phytoextraction or phytoaccumulation consists of the absorption of polluting metals by the roots of the plants and their accumulation in stems and leaves. The first step for the application of this technique is the selection of the most suitable plant species for the metals present and the characteristics of the site. Once the vegetative development of the plant is complete, the next step is to cut them and proceed to their incineration and transfer of the ashes to a sanitary landfill. Phytoaccumulation can be repeated indefinitely until the remaining concentration of metals in the soil is within the limits considered acceptable [12]. Phytoremediation is based on the use of plants and their associated microbiota to eliminate, retain or reduce contaminants present in the environment and can operate through various mechanisms that involve different parts of plants [13, 14]. A wide diversity of species that are used for this purpose has been identified. Some of them, due to their great capacity to accumulate heavy metals, are called hyperaccumulators.

Phytoremediation is attractive to improve soil due to its low cost, and because it is aesthetically pleasing and respectful with the environment [15, 16]. Conventional methods are often expensive and can irreversibly affect the properties of soil, water and the living beings that inhabit them [17].

There are so-called metallofilic plants, which have developed physiological mechanisms to resist, tolerate and survive in soils degraded by mining activities [18]. The use of autochthonous plant species is generally favored because they show tolerance to imposed stress conditions, require less maintenance and present less environmental and human risks than non-native or genetically altered species [19].

Phytoremediation processes are most effective when contaminants are present at low to medium levels, since high levels of contaminants can inhibit the growth and activity of plants and microbes [20].

For the phytoremediation of heavy metals (and phytoextraction in particular), the bioavailability of metals in contaminated soils is a crucial factor that regulates the absorption of heavy metals by the roots of plants [21, 22].

Species of plant differ widely in their ability to accumulate heavy metals. Many authors [23, 24] concluded that the concentrations of metals in plants that grow in the same soil vary between species and even between genotypes of a species. Three native plant species from the Abancay area with phytoremediation capacity were selected.

In general, metals with greater bioavailability for absorption by storage plants are: Cd, nickel (Ni), Zn, As, selenium (Se) and Cu. With moderate behavior are cobalt (Co), manganese (Mn) and iron (Fe), while Pb, Chrome (Cr) and uranium (U) are practically not bioavailable [25].

Some trace elements are essential for the nutrition and growth of plants [boron (B), Cu, Fe, Mn, molybdenum (Mo) and Zn] and animals [As, Cu, Co, Fe, Mn, Mo, Zn, Cr, fluorine (F), Ni, Sn, Se and vanadium (V)]. The toxicity of these elements depends on the concentration, the chemical form and its persistence [26].

The purpose of the work is to evaluate the phytoremediating potential of three native plant species: *Amaranthus spinosus*, *Amaranthus hybridus* and *Brassica rapa* in soils contaminated with heavy metals, having selected five heavy metals: Zn, Cd, Pb, Cr and Ni in the garbage dump of Quitasol-Imposed as an alternative to recover the contaminated area.

The experimental part of the work was carried out under field conditions measuring plant growth, dry matter production and the absorption of heavy metals in roots, stems and leaves of the three native plant species. These results show the phytoremediation potential of these species that have rapid growth, resistance, and do not require chemical controls because they are native to the area, being an alternative to the recovery of soils contaminated by heavy metals in the garbage dump.

General purpose

The general purpose of the present research is to determine the phytoremediation potential of *Amaranthus spinosus*, *Brassica rapa* and *Amaranthus hybridus* in soils contaminated by heavy metals in the garbage dump of Quitasol-Imponeda, Abancay.

Specific objectives

The specific objectives of the present study are as follows: determine the concentration of Heavy Metals (HM): Pb, Cd, Ni, Cr and Zn in the waste matrix, in the samples of roots, stems, leaves of three native species (*Amaranthus hybridus*, *Amaranthus spinosus*, *Brassica rapa*) in the garbage dump of Quitasol-Imponeda Abancay, evaluate the phytoremediation potential in three native species (*Brassica rapa*, *Amaranthus hybridus* and *Amaranthus spinosus*) as heavy metals extractors in the garbage dump of the sector of Quitasol-Imponeda Abancay.

MATERIALS AND METHODS

Phytoremediation involves the use of plants to eliminate or reduce the toxicity of environmental pollutants. The main technologies for the phytoremediation of metals are: phytoextraction – the use of plants to extract metals from the soil, transport them and accumulate them in the organs of the aerial part, and phytostabilization – the use of plants to minimize the mobility of metals through their accumulation in the root or their precipitation in the rhizosphere [26].

The experimental unit was the garbage dump of Quitasol-Imponeda located 6 km from the city of Abancay, with an area of land with heavy metals of all the waste accumulated by the residents of the city of Abancay and the district of Tamburco.

Three parcels were selected and identified: plot A (1, 2, 3), plot B (1, 2, 3) and plot C (1, 2, 3) in three different places within the garbage dump of Quitasol-Imponeda. Three native species were planted. The soil of the selected plots were removed, prepared and demarcated, each measuring two meters by four meters each. The plots were protected with screens to prevent the entry of foreign objects.

The seeds of the native species were collected from the zone of the Yanaca district as well as the buffer zone of the national Santuary Ampay especially clean of metals. All of them were planted in the garbage dump of Quitasol-Imponeda whose characteristics are summarized in Table 1-3 (Figure 1-3).

Table 1. Physical characteristics chemical water evaluated in the area of the experiment

Water analysis				
	Place 1*		Place 2**	
	Samples			
Source No.	1.1	1.2	2.1	2.2
Water temperatura [°C]	6.1	5.6	5.2	6.0
Potential of hydrogen ions [pH]	8.1	7.92	8.27	8.28
Electrical conductivity [microsiemens]	467	487	211.6	229.4

Source: Laboratories of agroindustrial analysis of the UNAMBA.2017

* Piped water, which reaches a brick warehouse, covered with cement and distributed through ducts for human consumption

** Upper part of the dump, approximately five hundred water that moves through irrigation canal, used for irrigation of agricultural land adjoining the municipal dump

Table 2. Physical-chemical characteristics of the soil

Characteristics	Value	Assignment
Ph	7.49	Slightly alkaline
O.M.%	1.48	
Texture		
Clay%		Sandy loam soil
Plot A	18	
Plot B	14	
Plot C	14	
Silt%		Sandy loam soil
Plot A	18	
Plot B	18	
Plot C	20	
Sand%		Sandy loam soil
Plot A	64	
Plot B	68	
Plot C	66	

Source: Data evaluated by SAG Lima laboratories 2017

Table 3. Characteristics of CEC of the soil

Characteristics	Value	Assignment
CEC		mEq/100 g
Plot A	18.6	
Plot B	16.8	
Plot C	16.1	

Source: Data evaluated by SAG Lima laboratories 2017

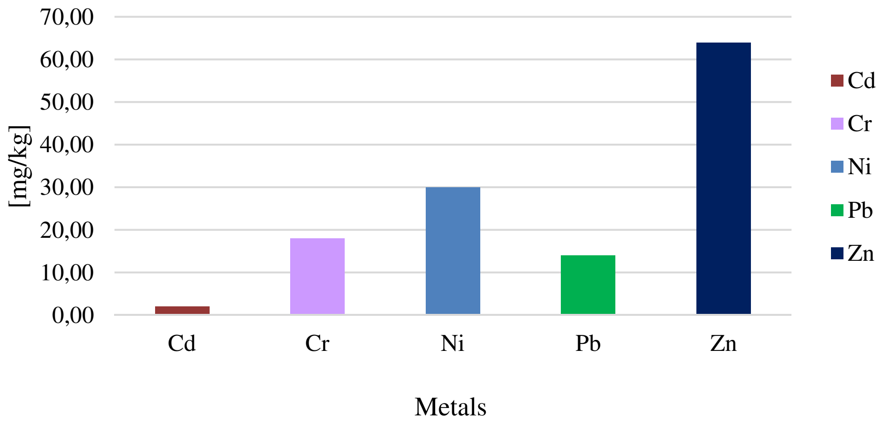

Figure 1. Heavy metals in soil

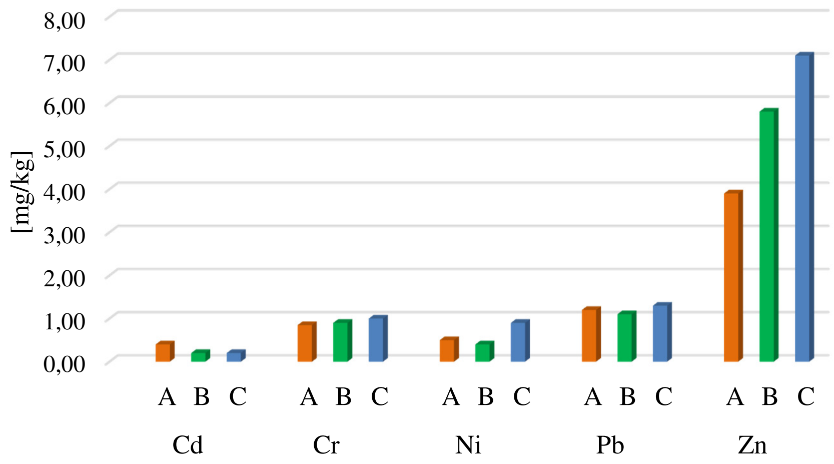

Figure 2. Heavy metals in soil by plots

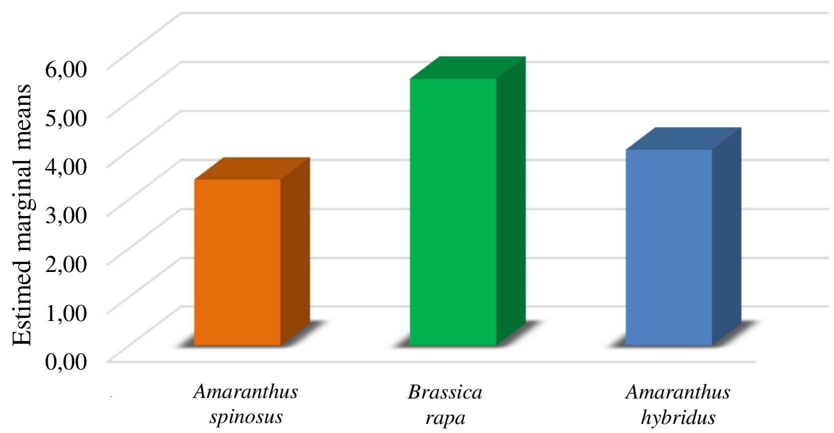

Figure 3. Heavy metals in the roots of species *Amaranthus hybridus*, *Brassica rapa* and *Amaranthus spinosus*

SOIL CHEMICAL CHARACTERISTICS

The pH, organic matter, texture, Cation Exchange Capacity (CEC) as shown in Table 2-3 and amount of heavy metals from the dump soil were determined in the three selected plots, two meters wide and four meters long. The heavy metals of the soil were evaluated by atomic absorption spectrometry at the National University Micaela Bastidas

Abancay and SAG Laboratories of Lima, using the method EPA [27]. The graphite furnace technique and official methods of analysis were also applied expressed in ppm. After ten months of sowing of the native species, the samples were harvested to determine the accumulation of heavy metals: Pb, Cd, Ni, Cr and Zn, in roots, stems and leaves of each native species are represented in Tables 4 and 5 (Figures 4 and 5). Two replications were applied in each case. The samples were dried in an oven at 105 degrees centigrade to obtain a constant weight. They were dehydrated taking into account the anatomical components of absorption in roots, stems and leaves. The retention of heavy metals in the plant tissue (roots, stems and leaves) of the three native species (*Amaranthus hybridus*, *Brassica rapa* and *Amaranthus spinosus*) was determined are summarized in Figures 3-14.

Table 4. Characteristics of heavy metals from the soil of the Quitasol-Imponeda garbage dump

Characteristics	Value [mg/kg]	Assignment [mg/kg DLM]
Cd		0.04
Plot A	1.48	
Plot B	1.48	
Plot C	3.11	
Cr		0.04
Plot A	22.64	
Plot B	13.07	
Plot C	19.74	
Ni		0.06
Plot A	39.39	
Plot B	23.16	
Plot C	27.52	
Pb		0.06
Plot A	9.94	
Plot B	10.38	
Plot C	20.45	
Zn		0.2
Plot A	50.01	
Plot B	46.03	
Plot C	97.20	

Source: Data evaluated by SAG Lima laboratories 2017

Table 5. Characteristics of retention of heavy metals in vegetable tissue in the three species

		Amaranthus hybridus	*Brassica rapa*	*Amaranthus spinosus*	Detection limit of the method [mg/kg]
Ni	A	1.77	1.30	1.50	0.06
	B	1.79	4.10	1.42	
	C	4.98	3.70	3.90	
Zn	A	19.2	50.5	21.4	0.20
	B	54.1	48.3	60.1	
	C	168.6	94.8	138.6	
Cd	A	0.24	0.44	0.25	0.40
	B	0.13	0.39	0.16	
	C	0.66	0.42	0.70	
Pb	A	1.11	0.68	1.2	0.06
	B	0.90	1.29	0.97	
	C	5.30	2.77	4.90	
Cr	A	2.49	1.91	1.80	0.04
	B	1.58	4.22	1.60	
	C	8.48	5.24	8.80	

A, B, C = Plots

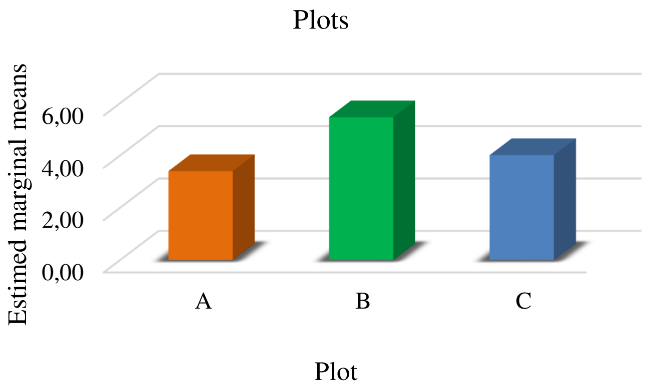

Figure 4. Heavy metals in the roots by plots

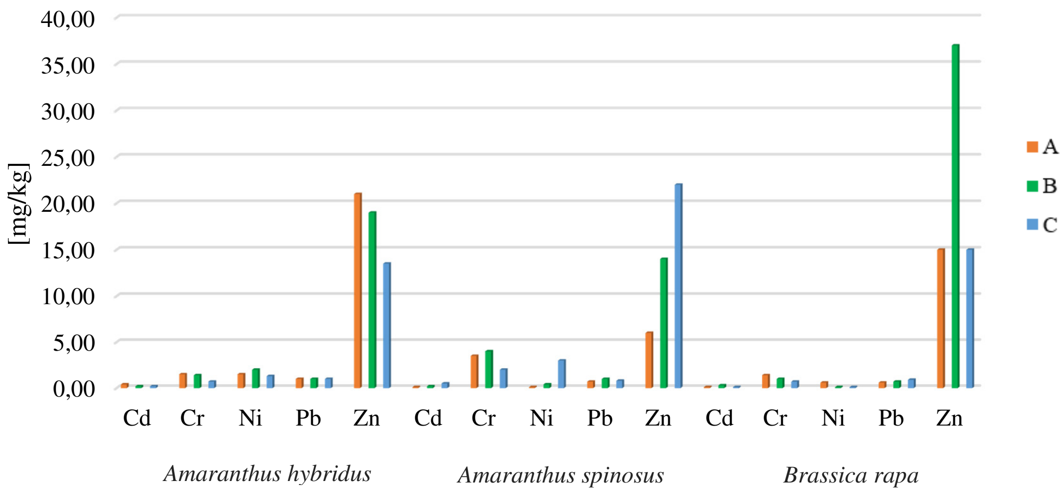

Figure 5. Heavy metals in the roots of *Amaranthus hybridus*, *Amaranthus spinosus* and *Brassica rapa* by plots

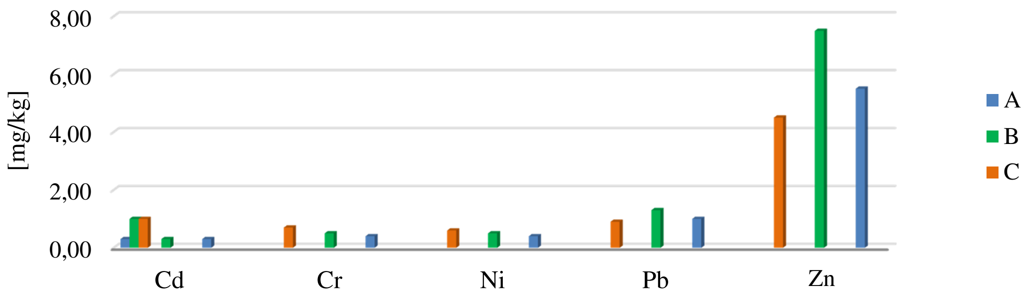

Figure 6. Heavy metals in stems by species

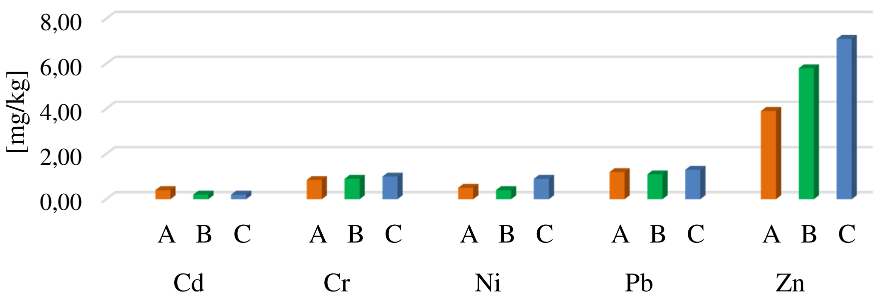

Figure 7. Heavy metals in stems by plots

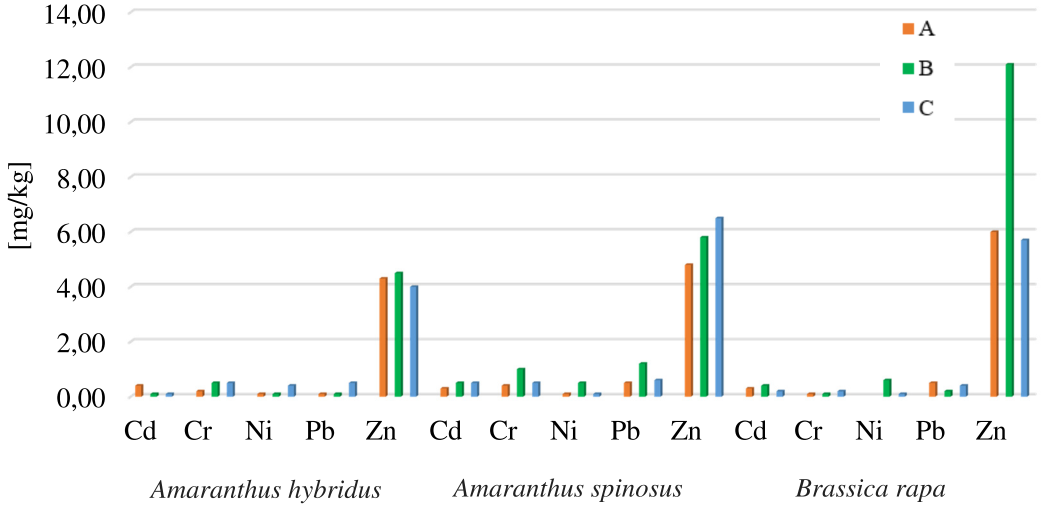

Figure 8. Heavy metals in *Amaranthus hybridus*, *Amaranthus spinosus*, *Brassica rapa* by plots in stems

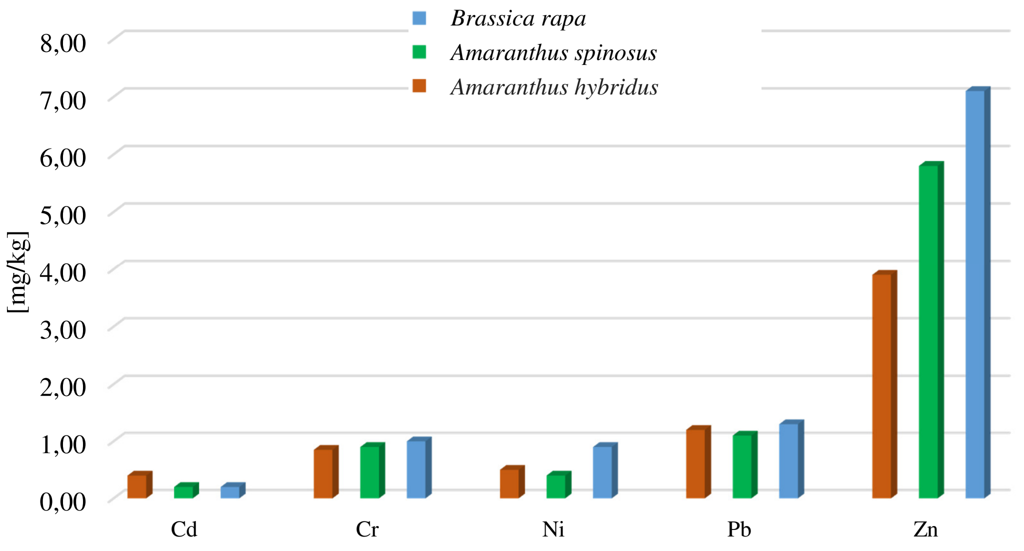

Figure 9. Heavy metals in leaves by species

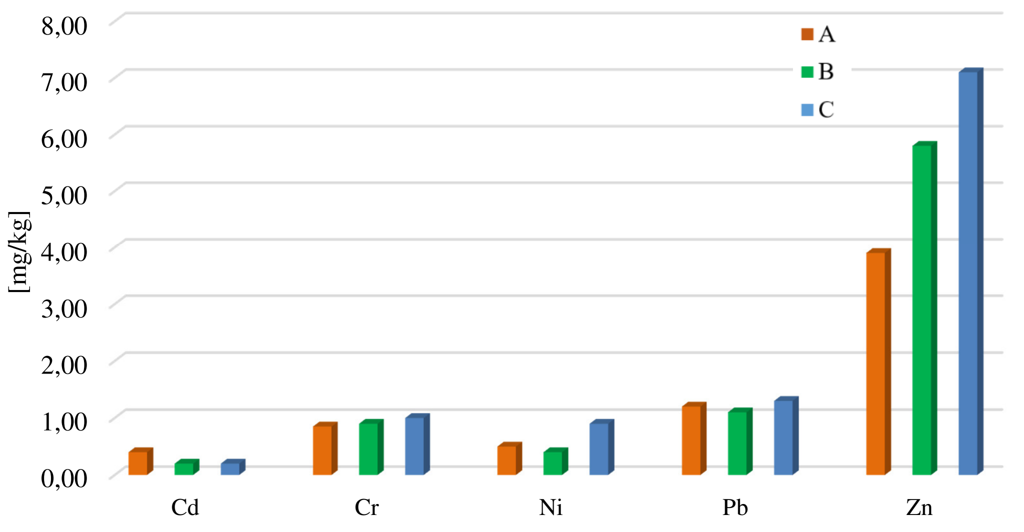

Figure 10. Heavy metals in leaves by plots

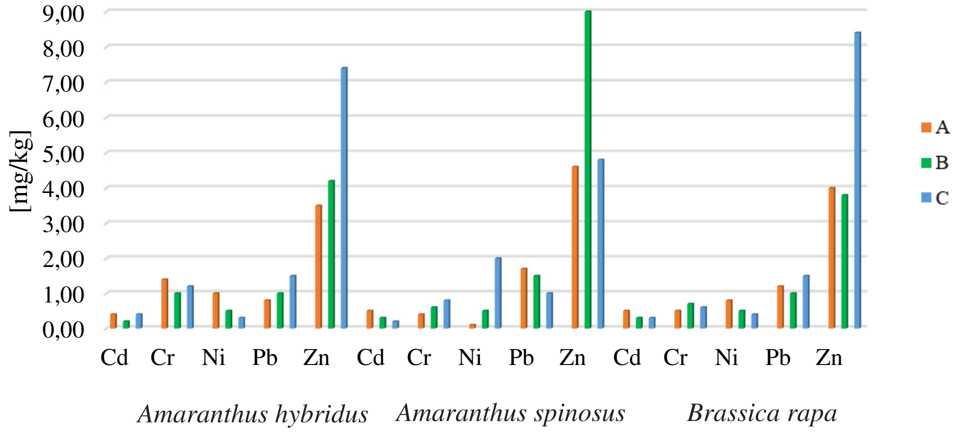

Figure 11. Heavy metals in species by plots in leaves

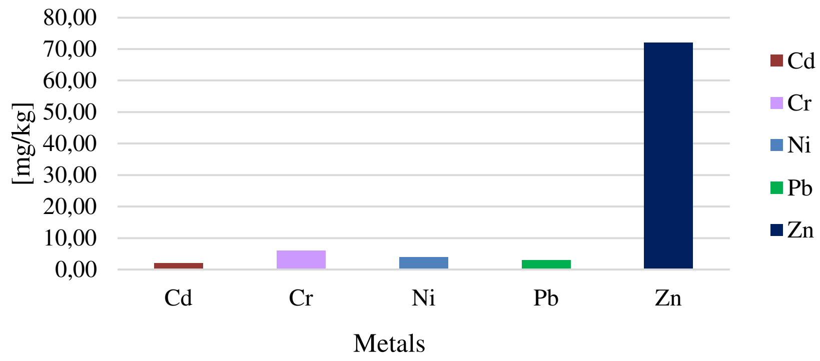

Figure 12. Heavy metals in tissue

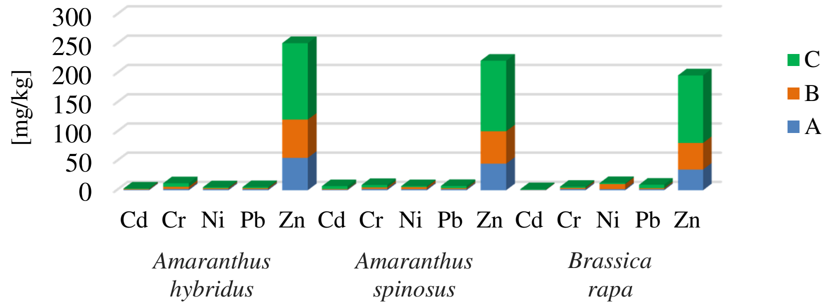

Figure 13. Heavy metals in tissues in species by plots

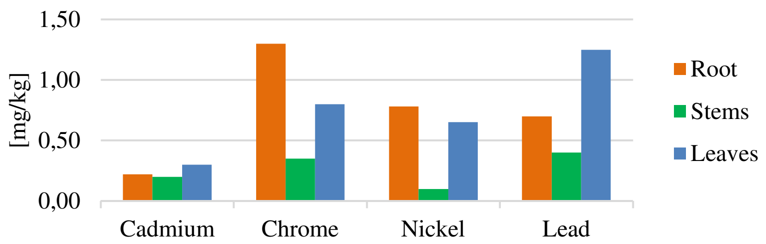

Figure 14. Heavy metals in root, stem, leaves (tissues)

SITUATION AND CHARACTERISTICS OF THE ZONE OF STUDY

The garbage dump of Abancay is in the community of Juan Velasco Alvarado, Abancay, in the place called Quitasol-Imponeda, six kilometers from Abancay, which has access by the Pan-American highway and the detour of a carriageway trail, and located at an altitude of 2,205 m above sea level. The climate in Abancay is 16.7 °C annual average temperature and 685 millimeters annual average rainfall.

During the experimental development of the phytoremediation potential of contaminated soils in the Quitasol-Imponneda dump in the city of Abancay, the temperature of the environment was recorded every fifteen days with an environmental thermometer. The records showed temperature fluctuations between the maximum of 25.0 °C and a minimum of 18.0 °C.

Samples of water have been taken from the Imponeda-Quitasol area, in sterile bottles, for the determination of the physical-chemical characteristics of the water resource (Table 1).

Characteristics of the soil

The pH is one of the main parameters that conditions the process of absorption of metals in the soil. Its activity and availability affect the processes of metal entry to the roots of plants [28]. The soil pH is at 7.49, and this slightly alkaline condition would be directly favoring the absorption of heavy metals by the plant as shown in Table 1.

When the content of heavy metals in the soil reaches levels that exceed the maximum allowed limits, they cause immediate effects such as inhibition of normal growth and development of the plants, and a functional disturbance in other components of the soil as well as a decrease in microbial populations for which the term "soil pollution" is used [29].

As shown in Table 2, the granulometry analysis indicates that the soil has a sandy loam texture, 1.48% organic matter, considered by many researchers as a positive complex in the aggregation of soil and a nutrient contributor that favors the absorption [30], likewise, consists of compounds aliphatic and aromatic that contain a large number of functional groups (amino, carboxyl, carbonyl, alcohol, phenols) capable of binding with heavy metals or other components of soil [31]. Approximately 70-90% of heavy metals are distributed in the particles of size smaller than PM10.

The concentration of metals increases with decreasing particle size [32]. Potentially toxic metals, e.g., Ni, Pb and Cd are accumulated in the urban environment mainly in the particles of aerodynamic diameter < 1 μm [33] aspects that probably contributed to the metals being bioavailable and are absorbed by the plant in the amounts indicated in Table 2.

A complete factorial design was used in three plots, three native species (*Amaranthus hybridus*, *Brassica rapa*, *Amaranthus spinosus*) and five treatments evaluated with heavy metals (Zn, Cd, Ni, Cr, Pb), two repetitions each as shown in Tables 6-8.

Table 6. Retention characteristics of heavy metals in roots

		Amaranthus spinosus	*Amaranthus spinosus*	*Brassica rapa*	*Brassica rapa*	*Amaranthus hybridus*	*Amaranthus hybridus*
		Repetition 1	Repetition 2	Repetition 1	Repetition 2	Repetition 1	Repetition 2
Ni	A	0.097	0.04	0.35	0.46	1.73	0.89
	B	0.50	MLD*	0.34	MLD*	3.08	0.84
	C	MLD*	3.77	0.04	0.18	1.68	0.39
Zn	A	1.96	9.05	22.56	7.98	18.52	23.03
	B	10.75	12.88	39.97	34.53	20.69	18.39
	C	18.73	24.28	22.46	8.06	15.49	12.15
Cd	A	0. 17	0.18	0.14	0.14	0.27	0.22
	B	0.33	0.31	0.33	0.42	0.28	0.09
	C	0.55	0.58	0.190	0.08	0.18	0.24
Pb	A	0.21	1.05	0.709	0.27	0.93	0.88
	B	0.13	1.74	0.451	0.92	0.65	1.37
	C	1.03	0.59	0.709	1.29	0.98	0.93
Cr	A	0.74	3.23	1.905	0.59	1.91	0.59
	B	0.52	3.66	0.699	1.48	0.69	1.48
	C	2.38	0.55	0.735	0.43	0.74	0.43

Graphite oven [Official Methods of Analysis (A.O.A.C.)] (15th ed. 1990) in ppm
* Lower than Detection Limits (LDL)
A, B, C = Plots

Table 7. Retention characteristics of heavy metals in stems

		Amaranthus spinosus Repetition 1	*Amaranthus spinosus* Repetition 2	*Brassica rapa* Repetition 1	*Brassica rapa* Repetition 2	*Amaranthus hybridus* Repetition 1	*Amaranthus hybridus* Repetition 2
Ni	A	MLD	0.10	MLD*	MLD*	0.03	MLD*
	B	0.67	MLD*	0.67	0.14	0.01	0.06
	C	0.09	MLD	0.08	0.01	0.37	0.08
Zn	A	2.13	7.58	5.80	3.11	2.29	5.87
	B	7.16	4.28	13.97	10.61	3.21	5.79
	C	8.89	4.04	10.81	0.73	5.07	2.68
Cd	A	0.02	0.44	0.08	0.18	0.16	0.09
	B	0.60	0.17	0.30	0.35	0.01	0.05
	C	0.45	0.27	0.31	0.001	0.12	0.09
Pb	A	0.33	0.51	0.56	0.13	0.14	0.09
	B	1.97	0.01	0.14	0.24	0.07	0.15
	C	0.95	0.68	0.38	0.12	0.54	0.22
Cr	A	0.38	0.17	0.05	MLD*	0.25	MLD*
	B	1.43	0.14	0.05	0.18	0.72	0.06
	C	0.70	0.08	0.28	0.05	0.60	0.08

Graphite oven [Official Methods of Analysis (A.O.A.C.)] (15^{th} ed. 1990), in ppm
* Lower than Detection Limits (LDL)
A, B, C = Plots

Table 8. Retention characteristics of heavy metals in leaves

		Amaranthus spinosus Repetition 1	*Amaranthus spinosus* Repetition 2	*Brassica rapa* Repetition 1	*Brassica rapa* Repetition 2	*Amaranthus hybridus* Repetition 1	*Amaranthus hybridus* Repetition 2
Ni	A	0.09	0.038	0.42	1.08	1.55	0.56
	B	0.49	MLD*	MLD*	0.92	1.34	0.34
	C	MLD*	3.77	0.13	0.53	0.73	0.47
Zn	A	4.69	4.77	3.53	4.26	2.71	3.81
	B	6.68	11.63	4.71	2.41	4.57	4.34
	C	4.17	5.63	10.32	7.35	6.05	8.83
Cd	A	0.089	0.86	0.24	0.59	0.24	0.59
	B	0.37	0.21	0.21	0.30	0.21	0.13
	C	0.19	0.27	0.37	0.21	0.48	0.22
Pb	A	0.99	2.12	0.57	1.81	1.21	0.65
	B	1.15	1.65	0.35	1.59	1.51	0.74
	C	1.76	0.53	1.14	1.76	2.07	0.76
Cr	A	0.80	0.29	0.45	0.68	2.01	0.59
	B	0.85	0.65	0.61	0.81	0.99	1.14
	C	0.64	1.41	0.58	0.70	1.56	0.91

Graphite oven [Official Methods of Analysis (A.O.A.C.)] (15^{th} ed. 1990), in ppm
* Lower than Detection Limits (LDL)
A, B, C = Plots

Certain factors are proposed for the phytoremediation of metal ion decontamination and various aspects of plant metabolism during metal decontamination [34].

ANALYSIS OF RESULTS

Results obtained from the retention of heavy metals in three native species, *Amaranthus spinosus*, *Brassica rapa*, *Amaranthus hybridus* are described in the Figures 1-13 and Tables 1-5. In the garbage dump of Quitasol-Imponeda, in roots, stems and leaves as well as results in total tissues of each plant species. These have been analyzed in dry matter and the retention of heavy metals by atomic absorption was determined.

The waste dump of Quitasol-Imponeda, presents higher concentrations of accumulation of heavy metals with Zn, Ni, Cr and in smaller quantities, Pb and Cd are represented in Table 4 (Figure 1).

Plot C presents better conditions of accumulation of Zn, the plot A has better conditions of accumulation of Ni and Cr.

Plot C presents high values of metal accumulation, with 97.20 mg/kg of Zn and 20.45 mg/kg of Pb.

Plot A presents accumulation values of metals with 39.39 mg/kg of Ni and 22.64 mg/kg of Cr, are shown in Table 4 and Figure 2.

Roots

Brassica rapa produces greater metal retention, then *Amaranthus hybridus*, and *Amaranthus spinosus*.

Brassica rapa shows better Zn retention conditions in plot B. *Amaranthus spinosus* has better Zn retention conditions in plot C.

Amaranthus hybridus has better Zn accumulation conditions in plot A.

Stems

Brassica rapa has better conditions of accumulation of Zn, *Amaranthus spinosus* has better conditions of accumulation of Pb, Cr, Cd and Ni. *Amaranthus spinosus* after *Brassica rapa* has better conditions of accumulation of Zn, Pb, Cr, Cd and Ni.

Plot B presents better accumulation conditions of Zn, Cr, Pb and Ni in stems.

Plot C presents better conditions of accumulation of Zn, Pb, Cr in stems.

Plot A has better conditions of accumulation in Zn, Pb, Cd, Cr and Ni in stems.

The three species have better conditions of accumulation in Zn, Pb, Cr, Ni and Cd in stems.

Plot B has better conditions of accumulation of Zn in the stems in the three species. *Amaranthus spinosus* has better conditions of accumulation of Zn, Pb, Cr, Ni and Cd in plot C and B.

Brassica rapa has higher retention values in Zn in stems in plot B.

Leaves

Amaranthus spinosus presents better conditions of accumulation of Zn, Pb, Ni, and Cr in leaves.

Brassica rapa has better accumulation conditions in Zn, Pb, Cr and Ni.

Amaranthus hybridus has better conditions of accumulation of metals in Zn, Cr, Pb and Ni.

Plot C presents better conditions for the accumulation of metals in Zn, Pb, Cr, Ni and Cd. Plot B has accumulation of Zn, Pb, Cr, Ni and Cd. Plot A has better accumulation of metals in Zn, Pb, Cr, Ni and Cd.

Amaranthus spinosus has better conditions of accumulation of Zn in plot B in leaves.

Brassica rapa presents better conditions of Zn accumulation in plot C in leaves.

Amaranthus hybridus has better conditions of Zn accumulation in plot C in leaves.

The three species show conditions for Pb retention being *Amaranthus spinosus* with better conditions in plot A.

Brassica rapa and *Amaranthus hybridus* have better conditions for Ni and Cr retention.

Brassica rapa and *Amaranthus hybridus* have better conditions for retention of Ni, Cr and Cd in plot A.

Amaranthus spinosus has better conditions of accumulation of Zn in plot B in leaves.

Brassica rapa presents better conditions of Zn accumulation in plot C in leaves.

Amaranthus hybridus has better conditions of Zn accumulation in plot C in leaves.

The three species show conditions for Pb retention being *Amaranthus spinosus* with better conditions in plot A.

Brassica rapa and *Amaranthus hybridus* have better conditions for retention of Ni, Cr and Cd in plot A.

Tissues

The order of the accumulation of heavy metals in tissue of the species *Amaranthus hybridus*, *Amaranthus spinosus* and *Brassica rapa* is Zn, Cr, Ni, Pb and Cd.

Amaranthus hybridus has better conditions of accumulation of Zn in plot C, B and A.

Amaranthus spinosus has better conditions of Zn accumulation in plot C.

Brassica rapa has better Zn retention conditions in plot C. The three species have high values of metal retention such as Zn, Cr, Ni, and Pb being species with phytoremediation capacity.

Zn, Cr and Pb are the metals with the best retention conditions, then the Ni and Cd in tissues roots. Zn, Pb, Cr, Cd, Ni are the metals with the best retention conditions in stems.

The species and varieties of plants vary in their capacity for the accumulation of heavy metals [35] showed that uptake and accumulation of Zn by shoots and roots varied with Zn levels in growth media and plant types.

Cd also has a significant influence on the yield of dry matter in roots, leaves and stems [36] (Table 5).

DISCUSSION

The waste dump of Quitasol-Imponeda has slightly alkaline soils (7.9 pH), sandy loam, room temperature up to 25.0 °C, 1.48% of organic matter, with values of heavy metals that exceed the limits of the applied method, Zn with 50.01 mg/kg, Pb with 20.45 mg/kg and 3.11 mg/kg of Cd. Plot C presented better conditions of accumulation of heavy metals before sowing, with 97.20 mg/kg of Zn and 27.52 mg/kg of Ni. Plot A presented 22.64 mg/kg of Cr and 39.39 mg/kg of Ni, plot B presented 23.16 mg/kg of Ni and 13.07 mg/kg of Cr [37] identified that some heavy metals are directly related to specific sources such as: fertilizers (Cd, Cr, Mo, Pb, Zn), pesticides (Cu, As, Hg, Pb, Mn, Zn), compost derived from conventional solid waste (Cd, Cu, Ni, Pb, Zn) and manure (Cu, As, Zn). The highest amount of metals on average in the soil is Zn, Ni and Cr. These species have the strategy of accumulating metals in the roots, regardless of the level of contamination of the substrate, this strategy is carried out for those plants called phytostabilizers [38]. The other metals such as Pb and Cd are statistically similar, in smaller quantities and very variable (coefficients of variability greater than 40%), which means that the quantities of these metals are not homogeneous in each plot. Metals tend to accumulate on the surface of the soil, being accessible for the consumption of the roots of the crops [39].

Plants grown in contaminated soils generally absorb more trace elements and the concentration of these in plant tissues is often directly related to their abundance in soils, and especially in the humid solution [30].

Plot B has better accumulation conditions of heavy metals in root (5.46 ppm), and in *Brassica rapa*, plot C with 4.01 ppm and in *Amaranthus spinosus*, and plot A with 3.40 ppm in *Amaranthus hybridus*.

In comparison with other *Brassica* species such as *Brassica juncea*, *Brassica rapa* and *Brassica napus*, the toxicity of Zn and Cu significantly reduced root growth and dry weight [39] the extraction of phytoremediation from *Brassica juncea*, *Brassica napus*, *Brassica rapa*, *Thlaspicaerulescens*, *Agrostiscapillaris* and *Festucarubra*, finding better results in *Brassica* species.

Brassica rapa has better accumulation conditions of Zn, Cr, Pb, Ni, Cd in stem and in plot B, *Amaranthus spinosus* has better accumulation conditions in Zn, Pb, Cr, Cd and Ni and in plot C, *Amaranthus hybridus* has better conditions to accumulate Zn, Cr, Pb, Ni and Cd in plot B. The identification of new fast-growing pioneer species to grow in poor contaminated soils, such as those originating in mining waste, and the study of their behavior in relationship with metals, continues to be of great importance in the development of phytoremediation [40].

Amaranthus spinosus presents better conditions of accumulation of Zn, Ni, Pb, Cr, Cd in leaves in plot (B, C, A). It is known that species of other bronchogenic phytoextract genus store many heavy metals in the leaves, for example *Thlaspi caerulescens* is a specie hyperaccumulative of Zn which managed to accumulate up to 14,000 $mgkg^{-1}$ of Dry Matter (DM) [18]. *Brassica rapa* has better accumulation conditions in Zn, Pb, Cr, Ni and Cd in plot C, A, B. Likewise, when the selected accessions of *Brassica juncea*, *Brassica napus* and *Brassica rapa* were cultivated in soils contaminated with Zn and Cd, these were the most efficient in eliminating Zn fundamentally, achieving 10 times more biomass of stems and leaves than *Thlaspi caerulescens* [37]. *Amaranthus hybridus* has better conditions of accumulation of metals in Zn, Cr, Pb and Ni in plot C, B and A. These species have the ability to reduce the transport of contaminants to stems and leaves, and minimize the mobility of heavy metals through precipitation and accumulation in the roots [26]. The order of the accumulation of heavy metals in tissue of the species *Amaranthus hybridus*, *Amaranthus spinosus* and *Brassica rapa* is Zn, Cr, Ni, Pb and Cd. *Amaranthus hybridus* has better Zn accumulation conditions in plot C, B and A. *Amaranthus spinosus* has better conditions of Zn accumulation in plot C. *Brassica rapa* has better Zn retention conditions in plot C. Zn, Cr, Pb are the metals with the best retention conditions, then Ni and Cd in the roots of the tissue.

Zn, Pb, Cr, Cd and Ni are the metals with the best retention conditions in the stems.

Zn, Cr, Pb, Ni and Cd is the order of the metals with accumulation conditions in leaves.

The number of confirmed hyperaccumulatory species is expanding rapidly, and includes about 300 plants that hyperacumulate Ni, 26 Co, 24 Cu, 16 Zn and 11 Mn. Hyperaccumulators of Se, thallium (TI), Cd, Pb and U have also been reported [40].

The metals accumulated by the plants were distributed mainly in the tissues of the roots, which suggests that there is an exclusion strategy for tolerance to metals widely present among them.

The species mentioned could accumulate relatively high concentrations of metals well above the toxic concentration in the shoots of the plant. With a high translocation factor, the metal concentration ratio of the shoots of the plant to the roots indicates an internal mechanism of tolerance to detoxification of the metal [41].

There are also transgenic plants with improved phytoremediation capacities and their potential use in environmental cleanup [42].

CONCLUSIONS

The soil of the garbage dump of Quitasol-Imponeda presented the largest amount of heavy metals in Zn, Ni, Cr, Pb and Cd at the time of planting.

In *Brassica rapa*, the highest accumulation values of Zn, Pb, Cr and Ni were added in the roots and in plot B. In *Amaranthus spinosus* the best accumulation of metals was in Zn, Pb, Cr, Ni and Cd on stems and in the plot C.

Amaranthus hybridus has the highest accumulation of Zn, Pb, Cr, Ni and Cd in leaves and in plot C.

Amaranthus hybridus in tissue, it has better phytoremediation capacity in Zn and in the plot C.

In the tissues of root, stem and leaves the Zn, have better retention conditions in the species *Amaranthus spinosus*, *Amaranthus hybridus* and *Brassica rapa*.

The garbage dump contains the highest levels of Zn and the species evaluated have the capacity of phytoremediation with high values in Zn, values in Pb, Cr and Ni which means that they are species with big phytoremediation capacity.

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