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Effects of Heavy Metals on Growth and Bioaccumulation of the Annual Halophytes *Atriplex Hortensis* and *A. Rosea.*

[1]S. Sai Kachout, [2]J.C. Leclerc, [3]A. Ben Mansoura, [3]M.N. Rejeb, [1]Z. Ouerghi

[1]Laboratoire de physiologie végétale, faculté des sciences de Tunis, campus universitaire, Tunisie
[2]Equipe d'Ecophysiologie Appliquée Faculté de Sciences et Techniques Saint Etienne, France
[3]Institut National de Recherche en Génie Rural, Eaux et Forêts (INRGREF), Tunisie

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Abstract: Heavy metals such Zn, Pb, Cu and Cd can cause a non-degradable pollution in numerous sites in France as well as in Tunisia, or elsewhere. This pollution resulting from various human polluting activities, related to industry or mining, is often diffuse in soils. Vegetation can play an important role in decontaminating these soils, their rehabilitation, and making their environment safer. For a better understanding of metal reactivity, a review of general knowledge concerning this kind of polluting metals and plant tolerance mechanisms is presented. A study was also conducted on the accumulation of the following metals: Cd, Cu, Zn, Pb and Ni, in their localisation in plant tissues and their induced toxic effects. The most general visible, but nonspecific symptom of heavy metal stress is growth inhibition, which has been investigated in many plants, including *Atriplex*. A cultivation of annual *Atriplex* plants was conducted according to hydroponic experimental design. The experimental approach consisted of hydroponic cultures using simplified medium represented by a nutritive solution. Results showed that plant final biomass, leaf area and metal accumulation, all varied with the metals level of toxicity and the plant species considered. Hence, the plants of the three annual arroach species or varieties used, all showed an intermediate level of tolerance according to the imposed treatments. Metal induces a number of physiological changes, such as growth inhibition, a significant reduction in biomass production was observed in metal treated plants compared with the control plants. The bioaccumulation factor decreased at the highest metal level, the low transfer of metal from solution to above-ground organs at higher solution metal concentrations indicates an exclusion mechanism. Trace element accumulation in shoots and the bioconcentration factors were proportional to the initial concentration of individual metals in the growth medium and the duration of exposure. Annual orach : *A. hortensis* seem to have a good capability for tolerance and phytostabilisation areas containing heavy metals.

Key words: Metals, hydroponic, *Atriplex*, accumulation, bioaccumulation factor growth..

INTRODUCTION

Heavy metal contamination affects the biosphere in many places worldwide[18,47,55]. These metals tend to accumulate in the environment causing various diseases and disorders in living organisms. Excess concentrations of some heavy metals in soils such as Cd, Cr, Cu, Ni, and Zn have caused the disruption of natural aquatic and terrestrial ecosystems[32,47]. Some heavy metals at low doses are essential micronutrients for plants, but in higher doses, they may cause metabolic disorders and growth inhibition for most of the plants species[17,28]. Phytoremediation, an approach that uses plants to remediate contaminated soil through degradation, stabilization or accumulation, may provide an efficient solution to some contamination problems. Researchers have observed that some plants species are endemic to metalliferous soils and can tolerate greater, than usual, amounts of heavy metals or other toxic compounds[6,19,13,55]. The ideal plant species to remediate a heavy metal contaminated site would be a rapidly growing, high biomass crop with an extensive root system that can both tolerate and accumulate the contaminants of interest.

Several studies have been conducted in order to evaluate the effects of different heavy metal concentrations on live plants[68,56,55]. Most of these studies have been conducted using seedlings or adult plants[29,16,33,49,51]. According to Baker[4], there are three basic types of tolerance strategy to heavy metals (accumulation, exclusion and indication), which describe the relationship between the total soil and plant metal concentration, and excluder as accumulator plants could grow together in the same environment. In phytoremediation, i.e. the use of plants to remove degrade or inactivate contaminants in soil, the root

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Corresponding Author: S. Sai Kachout, Laboratoire de physiologie végétale, faculté des sciences de Tunis, campus universitaire, Tunisie.
E-mail: salmasey@yahoo.fr

zone is of special interest. Here, contaminants can be absorbed by the root to be subsequently stored or metabolised by the plant, processes known as phytoextraction and phytodegradation[69]. The ideal plant species to remediate a heavy metal contaminated site would be a rapidly growing, high biomass crop with an extensive root system that can both tolerate and accumulate the contaminants of interest. Several halophytes are also heavy metal tolerant.

Among Chenopodiaceae the genus *Atriplex* is probably the most studied, probably because many species are used for rehabilitation of saline soils[52].

These plants could be promising, since *Atriplex* species have special bladders in the leaves that act as salt sinks for the removal of the excess of salt[40]. Plants in the genus *Atriplex* (Chenopodiaceae) have been proposed as possible candidates for phytoremediation of Se, these plants could improve grower participation in phytoremediation[71]. Additionally, recent studies have shown that *A. hortensis* (red orach), a salad green, also has a high salt tolerance as compared to other vegetables[73]. Because Na_2SO^{4-}dominant salts can reduce the uptake of Se due to competitive inhibition. *Atriplex spp.* is often grown as fodder plant in drier areas because of its great resistance to drought and salt tolerance[1].

In the Mediterranean region, native species adapted to water stress are particularly required for a successful remediation because plants have to cope with the long dry summer season in addition to unfertile soil conditions. In Tunisia, the national strategy for rangeland rehabilitation started in 1990 and is based on fencing, reseeding and shrub establishment fodder[10]. *Atriplex* is known to be tolerant to drought[43]. It is a halophyte species able to grow under conditions unfavourable for other species. It is not a leguminous species, but its foliage is high in crude protein[41,9].EINPRE.

Since *Atriplex* species are commonly used for revegetation of degraded rangelands countries, it is important to understand the impact of *Atriplex* browse on animal production[2]. In the arid zones and other dry lands, halophytic plants often dominate because of their tolerance to drought and salinity. *Atriplex spp* are not affected by heavy textured and high salinity soils and water. Their frost resistance is high[26] and *Atriplex* is the dominant native invader of bentonite mine spoil[62].

It is suggested that *Atriplex spp.* may be more suitable for revegetating very saline soils and also be a good source of productive feed[36,50]. But specially in dry countries, many soils are both rich in sodium salts and heavy metal.

The present manuscript reports data regarding the ability of annual *Atriplex* to accumulate and grow in media containing Cd, Cu, Pb, Ni, and Zn ions

MATERIALS AND METHODS

2.1. Plants: Seeds of *Atriplex hortensis* were taken from a botanic garden: Denmark House, Pymoor, Ely, Cambridgeshire (CN seeds). The seeds of *Atriplex rosea* were collected from the site of Usinor and from that, plants were grown furtherly in sand cultures at the "Conservatoire Botanique" Laboratory of the Tête d'Or, in Lyon.

2.2. Hydroponic Experiment: Metals (Cd, Cu, Ni, Pb and Zn) Accumulation: Atriplex seeds were germinated in a Petri dish on wet vermiculite. After 10 days, the seedlings were placed in the vessel of the hydroponic units, allowing the roots to pass through the mesh into the nutrient solution. Uniform plants were selected and transplanted to vessel (32 cm length × 17.5 cm height × 14 cm width) containing 4 L of modified Hoagland's solution at pH 6,1. They were then transferred to modified Hoagland's solution which contained one of the following heavy metals: Cd, Cu, Zn, Pb and Ni. The hydroponic medium was changed once a week. Each vessel contained three plants which represented one replicate. There were five replicates (fifteen plants for each treatment). A total of 45 plants were used for each metal. Plants grown in nutrient solution without metals served as controls.

At the end of the experiment the plant samples were collected, washed with tap water twice and rinsed with distilled water before being separated into leaf, stem and root and oven-dried (50° C) for 3 days to a constant weight.

The composition of all hydroponic solutions[35] was as follows: NH_4NO_3 2.0 mM, KH_2PO_4 750 µM, KNO_3 3.0 mM, $MgSO_4$ 750 µM, NaCl 200 µM, K_2HPO_4 30 µM, $Ca(NO_3)_2$ 2.5 mM, $MnSO_4$ 5 µM, $ZnSO_4$1µM, $CuSO_4$0.25 µM, Na_2MoO_4 0.25 µM, NiCl2 0.25 µM, Fe-EDTA 30µM, H3BO3 30 µM.

In all treatments, Zn was added at the concentrations of 300, 600, 1000 µM/l, Cu and Pb were added at the concentrations of 150, 400, 1000 µM/l, Cd was added at the concentrations of 50, 150, 400 µM/l and Ni was added at the concentrations of 25, 50, 75µM/l.

Plants were grown in a growth chamber at a thermoperiod and a photoperiod of 22 °C/16 h the day, and 20 °C/8 h the night (150 µmol photons m^{-2} s^{-1}).

Hydroponic experiments perhaps are favoured probably because it is very easy to control the conditions so that the data are inherently more reproducible than when soil mixtures are used. We believe however, that experiments such as ours, using soils rather than solutions, approximate more closely to field and natural conditions where the effect of soil buffering capacity influences nutrient availability to plants.

2.3. Analyses: Harvested shoots were washed and dried at 50°C to constant weight. The dry biomass was digested in concentrated HNO_3 65% for 2 h at 90°C under atmosphoric pressure in a block heater. Metal concentrations were measured using Inductively Coupled Plasma – Atomic Emission Spectroscopy (ICP-AES, JY36).

2.4. Statistical Analysis: The hydroponic experiment was set up in randomized complete block design replicated five times. ANOVA (SAS version 10.0) was employed for statistical analysis of data. Statistical significance was defined as $P < 0.05$.

RESULTS AND DISCUSSION

Results:

Hydroponic Experiment: Metals (Cd, Pb, Zn, Cu and Ni) Accumulation, Bioconcentration Factor and Growth: Hydroponic cultures constitute a soil-less culture technique, which can be very useful for this purpose. Table 1 reports the concentrations of Cd, Cu, Ni, Pb and Zn in the leaves of *Atriplex* plant grown in contaminated solution.

This study showed a significant difference in heavy metals (Pb, Cd, Zn, Cu, Ni) accumulation and transport from the roots to shoots between the three taxon of *Atriplex*.

The results showed that in the two week of growth, the shoots (stems + leaves) of *Atriplex rosea* extracted 680 ppm of cadmium in Cd 400. Cadmium has been recognized to be a highly toxic element but it is only recently that more concern has been expressed about its possible effects on human health after the long term exposure to low concentrations of the Cd element[39]. The shoot Cd concentrations of the three taxon of *Atriplex* increased with an increase in solution Cd concentration.

The toxic effect of Cd on plants was extensively reviewed[53,61,74]. The visual symptoms of Cd toxicity include growth retardation, chlorosis, and necrosis of leaves. In the present study, the maximum Cd concentration in the shoots of *Atriplex* (680 $\mu g\ g^{-1}$) is lower than those in *T. caerulenscens*, *A. halleri*[46], *Viola baoshanensis*, and *Salsola kali*.

In the treatment Ni 75, the shoot concentration of red *Atriplex* increased up to 770 ppm. With increasing levels of Ni, the shoot yield decreased, perhaps due to concentration effect which hindered the shoot growth. For zinc, the removal by the shoots of all *Atriplex* reached 1570 ppm and 1356 ppm, respectively. In Zn 600, moreover, a total removal of 771 ppm was established by *Atriplex hortensis* (green).

Adversely, the copper (Cu1000) removal was not influenced by the high levels of metal in hydroponic solution. In fact in all treatments, the Cu removal by the shoots did not exceed 500 ppm. So, aerial parts of the plants are only few contaminated.

The higher concentration of Pb in shoots of *Atriplex* under the solution culture condition was almost certainly due to the far higher Pb availability in the nutrient solution[75].

The accumulation patterns of Pb, Cd, Ni, Cu and Zn in whole plants of *Atriplex* during the hydroponic experiments of the present study increased in the order of Nickel>Cuivre>Zinc>Plomb>Cadmium (Table 1). Kim *et al.*[38] reported a similar translocation pattern in *Polygonum thunbergii* but a different accumulation pattern (Cd < Pb < Zn < Cu). Several studies reported different results on accumulation and translocation patterns even in the same plant species. For example, in *B. juncea*, Dushenkov *et al.*[22] reported the accumulation pattern in roots of plants grown under hydroponics increased in the order of Cd < Pb < Cu < Zn. Kim *et al.*[28] suggested such discrepancies arise due to variation in heavy metal concentration, form of metal present, and plant species.

Among the heavy metals, cadmium is of special concern due to its potential toxicity to biota at low concentrations[20]. Nickel, although essential for plants at low concentrations, is, however, toxic at higher concentrations, and suggesting that *Atriplex* plant might be used for phytoremediation only of low levels of Ni. Nickel has been classified among essential micronutrients and it remains associated with some metallo-enzymes, however, it is toxic at supraoptimal concentrations to plants. Table 1 also gives the shoot metal concentrations of the two *Atriplex*. With an increase in metal concentration in the hydroponic solution from 25 to 1000 ppm, the shoot metal concentration increased in almost a linear relationship. Based on these criteria, *A. hortensi* (red) could be regarded as good stabilizer of most of the trace metals studied. It is a plant hence, could be leaves and stems totally harvested. Its well developed root system and fast rate of growth are quite advantageous.

The bioaccumulation coefficient (BC), or phytoextraction rate, was described as the heavy metal concentration in plant divided by heavy metal concentration in the solution[48].

The BC of five metals in annual *Atriplex* increased from Ni < Pb < Cd < Cu < Zn (Table 2). The highest BC for each metal were 4.6, 2.9, 8.4, 5.8 and 1.6 for 50ppm Cd, 150ppm Cu, 25ppm Ni, 50ppm Pb and 300ppm Zn, respectively. The results showed that these trace elements were differentially accumulated in the tissues.

Shoot height was significantly ($P < 0.05$) inhibited by the metals. The level of inhibition depended on (i) metal type, and (ii) metal concentration. The mean value of 19,2 cm was observed for the control plant of

Table. 1: Cadmium, Cu, Ni, Pb and Zn concentrations in the shoots of *Atriplex hortensis* (green and red) and *A. rosea* growing in hydroponics solution.

Metal	Concentration of solution (ppm)	*Atriplex hortensis* Green	Red	*A. rosea*	$\text{PPDS}_{0.05}$
			<- - - concentration in the shoots (µg/g d.w.) - - ->		
	50	230 a	210 a	220 a	50
Cadmium (Cd)	150	290 b	270 b	430 a	70
	400	320 b	340 b	680 a	100
	150	430 a	340 b	160 c	90
Copper (Cu)	400	490 a	390 b	370 b	70
	1000	500 a	400 b	390 b	80
	25	140 b	210 a	90 c	40
Nickel (Ni)	50	260 b	290 a	210 c	30
	75	530 b	770 a	460 c	60
	150	871 a	773 b	126 c	52
Lead (Pb)	400	1319 a	1220 b	1088 c	49
	1000	2885 a	2276 b	1341 c	207
	300	476 a	351 b	157 c	106
Zinc (Zn)	600	771 a	709 b	416 c	46
	1000	1356 a	1257 b	1184 c	61

Different letters indicate significant differences at $P \leq 0.05$ (LSD test).

Table. 2: Influence of heavy metals: Cd, Cu, Ni, Pb and Zn on the Bioconcentration factor of *A. hortensis,* green and red, and *A. rosea* in hydroponics solution.

Metal	Concentration of solution(ppm)	Specie: *Atriplex hortensis* Green	Specie: *Atriplex hortensis* Red	Specie: *Atriplex rosea*
			<- - - - - - -Bioconcentration factor- - - - - - ->	
Cadmium	50	4,6	4,2	4,4
	150	1,9	1,8	2,9
	400	0,8	0,9	1,7
Copper	150	2,9	2,3	1,1
	400	1,2	1,0	0,9
	1000	0,5	0,4	0,4
Nickel	25	5,6	8,4	3,6
	75	5,2	5,8	4,2
	150	3,5	5,1	3,1
Lead	50	5,8	5,2	0,8
	400	3,3	3,1	2,7
	1000	2,9	2,3	1,3
Zinc	300	1,6	1,2	0,5
	600	1,3	1,2	0,7
	1000	1,4	1,3	1,2

A. hortensis (green) at the end of the experimental period of 3 weeks compared to 11.5, 8.9 and 8.6 cm observed for plants treated with 400 ppm Cd, Cu and Pb respectively. There were no significant differences among the three varieties at each particular Cd concentration. With an increase in metal concentration the average shoot height decreased significantly accordingly.

This plant presented differential tolerance for the various metals under study. The order of tolerance being Cd > Pb > Cu > Zn > Ni. A 3-week exposure of *A. rosea* to 1000 ppm of Cu, Pb and Zn gave a respective mean values of height 4.0, 2.7 and 2.8 cm. These values were significantly ($p < 0.05$) lower than the 10.4 cm observed for the control (Table 3).

The total fresh matter yields of *A. rosea* exposed to various concentrations of heavy metals are shown in Table 3. A significant reduction in biomass production was observed in metal treated plants compared with the control plants. While such effect is typical for all the metals under study, the toxic effect of Ni on biomass production was generally considered to be the most dramatic. A mean value of 0.18 g was observed for the control plant compared to inhibition plants treated with Ni 25, Cu150, Pb150, Zn400 and Cd400 which respectively had 0.09, 0.08, 0.08, 0.07 and 0.11 g. The plant presented differential tolerance for the various metals under study. Decrease of fresh biomass and height was observed with the increase of metal concentration when compared to controls in plants from both contaminated and non-contaminated solution (Table 3). Ni and Cu were more toxic to *Atriplex* than others metals.

Generally, *Atriplex* plant showed gradual decrease in leaf area following metal treatments (Fig.1). The severity of this effect was dependent on the type of metal and the concentration to which the plant was exposed. A 3-week exposure of *A. hortensis* (green) to 400 ppm of Cd, Cu and Pb gave a respective mean values of 4,98, 3,55 and 2,79 cm^2. These values were significantly ($p \leq 0.05$) lower than the 19,10 cm^2 observed for the control.

4. Discussion: *Atriplex* is a annual chenopod, it occurs on clayey, saline lands to which few species are adapted[31] and is the dominant native invader of bentonite mine spoil[62]. Morphology and apparent vigor of the species vary considerably from site to site, and studies have shown that growth and vigor of the species are greatly improved by organic amendments[64,72]. Phytoextraction of contaminants depends on shoot biomass production and metal concentration in the shoots[24,23]. Ideally, metallicolous plants should also be native to the local flora of the mining area in question[57], grow quickly and have dense root and shoot systems[12].

Heavy metals are able to interact with essential macro- and microelements, thus exerting a significant influence on plant nutrient uptake. The nature of this interaction depends on the ion concentrations, the pH, the presence of chelates, *etc.*, so the results of such experiments are heterogeneous and difficult to compare. Heavy metals have an influence on plant–water relationships, causing a direct reduction in the absorption surface by inhibiting the formation of root hairs. They reduce membrane permeability, and the number and diameter of vascular bundles[8].

Heavy metals are transported from roots to shoots in terrestrial plants to different extents. Different metals are differently mobile and, within a plant, Cd and Zn are more mobile than Cu and Pb[34]. Zn may be translocated extensively as it is essential to the plant metalloenzymes[21,70] and photosynthesis[37], while Pb and Cd are toxic to plants.

The chemical similarity of Cd and Zn has been considered to be the main reason for Cd toxicity in higher plants, because Cd interferes with the normal functions of Zn in bio-metabolism.

When metal enters plant cells, it influences metabolic processes by interacting with organic compounds in the cytosol and cell organelles. It may also interact with lipids and proteins, thus affecting membrane fluidity and enzyme activities and causing oxidative stress by inducing the formation of free radicals. As the result of heavy-metal stress, changes occur in the lipid composition, and the membranes become rigid, thus resulting in changes in the activity of enzymes bound to membranes[58,30].

The most important consideration in phytoremediation is that the plant should translocate metals from the soil to the aerial parts allowing a significant quantity of metal to be removed from the soil with each crop.

Zayed *et al.*[76] mentioned that bio-concentration factor (BCF) was a better indicator to classify a particular plant as a hyper accumulator. This was so because BCF take into account the trace element concentration in the solution. He stated that a good metal accumulator must have the ability to bio-concentrate the element in its tissue to a BCF of ≥ 1000. Results obtained in the present study agreed with the finding of Zayed *et al.*,[76] that Lemna minor was a good accumulator of Hg[44] Cyperus alternifolius for Cr[54]. Previous studies showed that most wetland plants accumulate very little Cu in their tissues[67,45,65].

The criterion for defining Ni hyperaccumulation is 1000 μg Ni g^{-1} on a dry leaf basis[15], whereas for Zn and Mn the threshold is 10,000 $\mu g\ g^{-1}$ and for Cd 100 μg Cd g^{-1}. Finally, the criterion for Co, Cu, Pb and Se hyperaccumulation is also 1000 $\mu g\ g^{-1}$ in shoot dry matter[14,5,46].

Table. 3: Influence of heavy metals: Cd, Cu, Ni, Pb and Zn on the height and fresh biomass (FB) of *A. hortensis,* green and red, and *A. rosea* in hydroponics solution.

Metal	Concentration of solution (ppm)	*Atriplex hortensis*					
		Green		Red		*A. rosea*	
		Height. (cm)	F.B. (g)	Height (cm)	F.B.(g)	Height (cm)	F.B. (g)
Control	0	19,2 a	3,04 a	14,3 a	0,90 a	10,4 a	0,18 a
	50	15,9 a	1,60 b	12,2 a	0,75 a	8,3 b	0,21 a
Cadmium	150	11,6 b	1,34 b	7,8 b	0,48 b	6,7 c	0,16 b
(Cd)	400	11,5 b	1,02 b	8,5 b	0,35 b	7,1 c	0,11 c
	$\mathrm{PPDS}_{0,05}$	3,7	1,01	3,4	0,18	0,8	0,04
	150	11,2 b	0,23 b	9,1 b	0,14 b	7,0 b	0,08 b
Copper	400	8,9b	0,49b	8,7 b	0,24 b	6,7 b	0,07 b
(Cu)	1000	5,9 c	0,22 b	5,4 c	0,13 b	4,0 c	0,04 c
	$\mathrm{PPDS}_{0,05}$	2,8	1,76	2,9	0,47	1,4	0,03
	25	9,7 b	0,43 b	9,4 b	0,29 b	6,0 b	0,09 b
Nickel	50	10,2 b	0,33 b	8,8 b	0,15 b	4,7 c	0,05 c
(Ni)	75	7,1 b	0,21 b	8,7 b	0,12 b	3,9 c	0,04 c
	$\mathrm{PPDS}_{0,05}$	5,4	0,93	3,8	0,33	1,6	0,03
	150	10,0 b	1,22 b	8,0 b	0,68 b	5,0 b	0,08 b
Lead	400	8,6bc	1,11 b	7,2 b	0,52 b	3,8 c	0,03 c
(Pb)	1000	6,0 c	0,80 b	4,8 c	0,28 c	2,7 d	0,02 c
	$\mathrm{PPDS}_{0,05}$	3,1	1,17	2,0	0,20	0,9	0,04
	300	10,6 b	0,55 b	8,7 b	0,31 b	5,2 b	0,07 b
Zinc	600	7,5 c	0,22 c	4,7 c	0,12 bc	3,7 c	0,05 c
(Zn)	1000	6,4 c	0,08 c	3,7 c	0,05 c	2,8 d	0,04 c
	$\mathrm{PPDS}_{0,05}$	2,4	0,31	2,9	0,13	0,7	0,02

Different letters indicate significant differences at $P \leq 0.05$ (LSD test).

An interaction of heavy metals with salinity factors in soils and plants is present under field conditions and a stronger soil salinity might increase the contents of heavy metals and specific metabolites in plant products considerably[11,25,64]. Since the phytoextraction of contaminants depends on shoot biomass production, also agronomic practices need to be developed to optimize growth. Furthermore, because absorption by roots could possibly be limited by reduced bioavailability, amendment strategies may need to be employed to increase metal bioavailability in the soil[24]. On the other hand, the buffer capacity of the crop against the contaminated soil, makes feasible the use of *Atriplex rosea and A. hortensis* for phytostabilization and revegetation of the spill polluted soils.

However, in highly polluted areas, where the removal of metals by phytoextraction using hyperaccumulating plants is not efficient due to the slowness of the process[27], the most suitable method is phytostabilization[50,3], leading also to crops for cattle use.

5. Conclusion: This study showed a significant difference in heavy metals (Cd, Cu, Ni, Pb, Zn) concentration and transport from the roots to shoots between the three populations of *Atriplex*. These annual herbs with great ecological amplitude possesses great potential for use in the remediation of contaminated soils. These plants could be used to treat soil containing low concentrations of these elements. This study indicated that *Atriplex* accumulated metal in roots and translocated few of these elements in the harvestable parts of the plant. The data obtained in this study suggest that *Atriplex* may be effective in the phytoremediation of soils with high cadmium, lead and zinc concentrations. Adversely, it looks to be unreliable

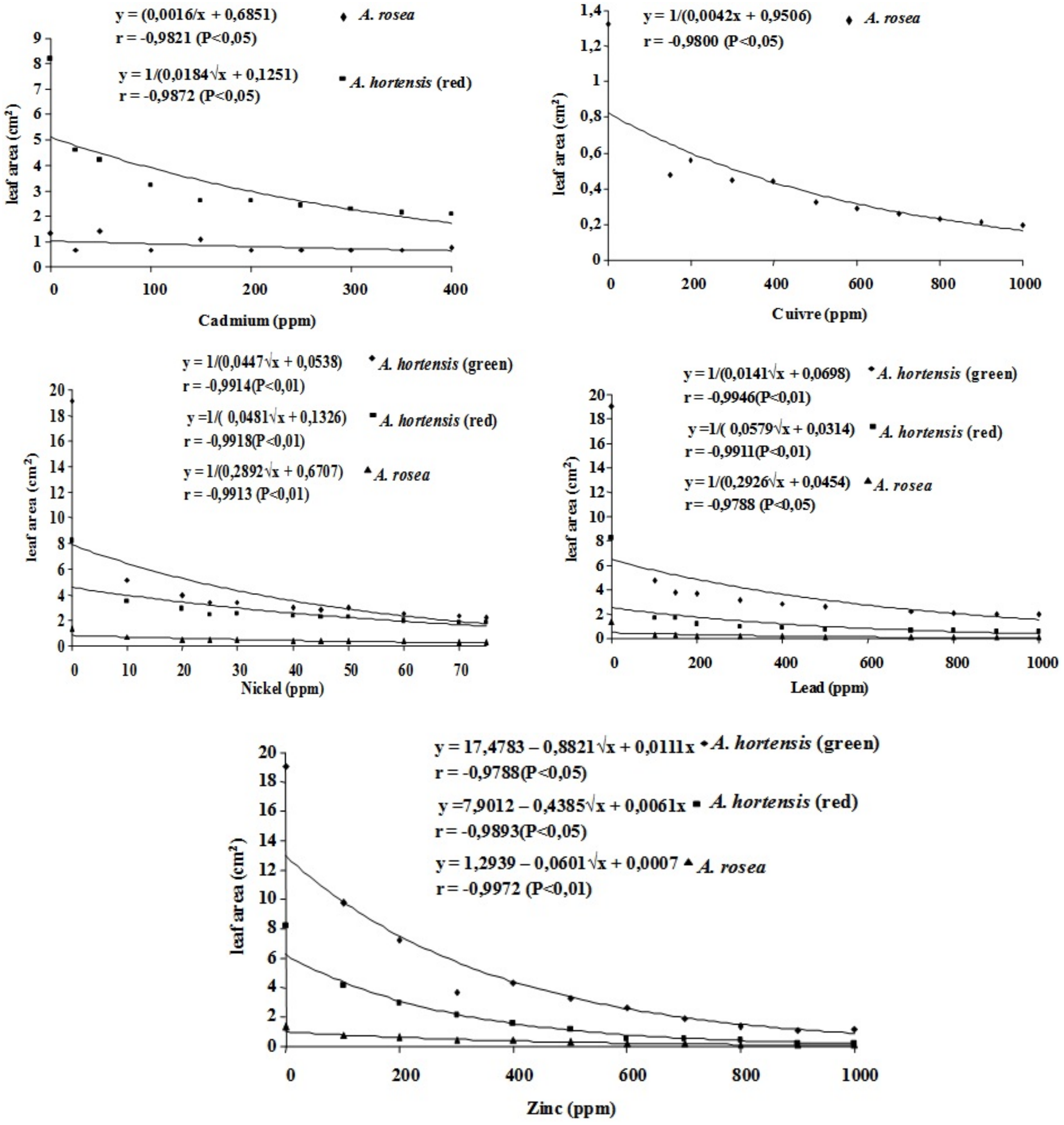

Fig. 1: Effect of exposure to Cadmuim, Copper, Nickel, Lead and Zinc during 3 weeks on leaf area of *Atriplex hortensis* (green and red) and *A. rosea*.

where high copper and nickel concentrations occur. In conclusion, between the two species tested, *A. hortensis* plants grew much more rapidly and were able to yield higher biomass in comparison with *A. rosea*. The specie *A. rosea* was also more tolerant to Ni than *A. hortensis*.

From the phytoremediation perspective a good metal accumulator should meet the following criteria: (i) it should be able to accumulate high level of the metal concerned in its harvestable tissues, (ii) it should be a fast growing species, and (iii) it should possess well developed root system (Qian et al., 1999). Based on these criteria, *Atriplex* might have higher potentiel for use in the remediation of most of the trace metals studied, but in phytostabilisation and not in extraction. An important field for further research would be the tolerance mechanism of plants exhibiting metal accumulation in roots but not in leaves. The knowledge gained in such investigations could facilitate both selection and the breeding of heavy metal–tolerant plants. These results are quite encouraging for phytostabilization deployment, since they represent good conditions for plant growth even on contaminated soil.

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