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Cr (III) and Cr (VI) absorption and translocation of *Atriplex halimus* L.

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Abstract

Metal pollution has become, due to industrial and technological advances in recent decades, a major threat to human health and environment. It is thus important to have effective tools to assess the bioavailability of metallic element and their environmental effects in contaminated soils. The purpose of the present work was to evaluate the tolerance and capacity to accumulate chromium in its two valence states, Cr(III) and Cr(VI) of *Atriplex halimus* L., grazing species, one of the most abundant perennial halophytes which is found as hedges in agricultural soils near a discharge of a bolts, cutlery and fittings factory (BCR, located in Oued Rhiou, Algeria). The soil taken from the discharge of the BCR factory is used in the experiment. The obtained results show a variation of the accumulation of chromium according to the plant organs, the metal form and the rate of chromium. Chemical tests reveal an evolution of the chromium content in the aerial parts (leaves and stems) and the ground organs (roots) of *Atriplex halimus* L. This variation is related to the increase in dose and type of the used chromium. It was also found that Cr-III is more absorbed by *Atriplex halimus* L. than Cr-VI. The growth parameter results also show that *Atriplex halimus* L. is more tolerant to trivalent chromium than to hexavalent chromium. We finally found that this species present a large absorption roots capacity and a low translocation to the above ground organs.

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Introduction

The continued industrialization of countries has led to extensive environmental problems. A wide variety of chemicals (e.g. heavy metals, pesticides, chlorinated solvents, etc.) have been detected in different biota such soil, water, and air (Cheng, 2003; Turgut, 2003). Heavy metals are of major concern to environmental and human health due to their toxicity and interference in the absorption of nutrients. Heavy metals enter the environment through weathering and dissolution of minerals and through anthropogenic activities such as mining and smelting (Bradl, 2005). The most commonly used methods for dealing with heavy-metal pollution are still extremely costly (Memon *et al.,* 2001; Singh *et al.,* 2006). Several techniques have been employed to remediate soils, but most of them are expensive and often impractical (Cunningham and Berti, 1993; Vangronsveld *et al.,* 2009). Heavy metals cannot be biodegraded, and thus should be extracted from the contaminated sites. A recent technique using plants to clean contaminated areas, phytoremediation, is intensively studied and progressively applied to the field (Ghnaya *et al.,* 2005; Salt *et al.,* 1998).

The use of plants capable of extracting and storing heavy metals from the environment is an important, non-invasive and more cost effective alternative for remediation of inorganic pollutants, so that phytoremediation has been successfully used as a way to mitigate the impacts of heavy metals in the environment (Pilon-Smits, 2005; Almeida *et al.,* 2007). Indeed, some plants have a natural ability to absorb and hyperaccumulate trace element in their tissues (Zayed *et al.,* 1998; Qian *et al.,* 1999; Gao *et al.,* 2000).

The ideal plant species for remediating a metal-contaminated soil should be fast growing, deep rooted, easily propagated and capable of tolerate and accumulate the contaminants of interest (Ebbs and Kochian, 1997; Ghosh and Singh, 2005). Species belonging to the genus *Atriplex* are especially interesting because of their high biomass production associated with a deep root system that is able to cope with the poor structure and xeric characteristics of several polluted substrates (Lefèvre *et al.,* 2009; Lutts *et al.,* 2004).

Atriplex halimus (Chenopodiaceae) is a xerohalophyte which is perennial and native to arid and semi-arid Mediterranean regions. This species tolerates harsh conditions such as salinity (Bajji *et al.,* 1998), light stress (Streb *et al.,* 1997) and drought (Martinez *et al.,* 2005). Previous work with *Atriplex halimus*, with plants grown in pots of soil (Manousaki and Kalogerakis, 2009 ; Pérez-Esteban *et al.,* 2011), in “spiked” compost substrate (Tapia *et al.,* 2011) or in hydroponic culture (Lutts, 2004 ; Lefèvre *et al.,* 2009), showed that it is relatively tolerant of high concentrations of Cd, Cu, Pb and Zn in the external medium, in terms of growth. In the studies of Lutts *et al.* (2004) and Tapia *et al.* (2011). The metal accumulation in order of mean metal weight in the halophytes studied is Fe > Zn > Mn > Cu > Ti > Pb > As > Ni > Cr (Luque *et al.,* 1999). Plants absorb and accumulate heavy metals in their organs, with larger amounts stored in roots, and smaller fractions translocated to shoots (Pilon-Smits, 2005), with Cr not being an exception (Shanker and Pathmanabhan, 2004; Choo *et al.,* 2006; Barbosa *et al.,* 2007).

The degree of toxicity differs according to the oxidation state of Cr with Cr (VI) being more toxic than Cr (III) (Shanker *et al.,* 2005). There are various procedures commonly employed for the decontamination of Cr from water and soil. Some of these involve the reduction of Cr6+ to Cr3+ by chemical and electrochemical processes. Through bioremediation (Castilhos *et al.,* 2001),

Cr interacts with plants at a cellular level mainly by producing reactive oxygen species such as superoxide radicals, hydroxyl radicals and hydrogen peroxide either by direct electron transfer involving metal cations, or as a consequence of metal-mediated inhibition of metabolic reactions (Shanker and Pathmanabhan, 2004). Once absorbed, Cr causes multiple direct and indirect effects on growth and metabolism (Panda and Choudhury, 2005). Cr affects plant growth by reducing transpiration, photosynthesis, stomatal conductance, size, number and diffusive resistance of stomata, and uptake and transport of mineral nutrients (Panda and Choudhury, 2005; Barbosa *et al.,* 2007).

To prevent the negative impact of heavy metals on an organism, plants developed detoxification system based on phytochelatins, metalothioneins and other sulphurrich compounds. This system also helps to control the concentration of heavy metals in the cells (Cobbett and Goldsbrough, 2002).

The aim of this study was to investigate the *Atriplex halimus* capacity to remediate polluted soil by Cr, in both forms and the effects of chromium in its two valence states, Cr(III) and Cr(VI) on the metal concentrations in plants and bioavailability of metals in contaminated soils. The experiment was carried out in plastic pots for evaluate the tolerance, metal accumulation and translocation to aerial biomass by *Atriplex halimus* L. in relation to the chemical forms of chromium and soil conditions.

Materials and methods

Plant material, growth conditions and Application of Chrome

The experiment was conducted in a greenhouse conditions. Fruits of *A. halimus* were collected during November, 2010 from wild plants in Oued-Rhiou, which is located to the Northwest of Algeria (35°57'N longitudes, 00°55'E latitudes). Seeds were removed from the bracts by hand and stored in darkness at 4°C for one month. After the storing period, seeds were germinated in a soil sample collected under field conditions at 0–30cm depth in a area in agricultural soils near a discharge of a bolts, cutlery and fittings factory (BCR, located in Oued Rhiou). The main properties of this soil are shown in Table 1. Both samples were slightly basic, Sandy-silt loam, and poor in organic matter; they also contained low concentrations of Cu, Pb and Cr and presented low salinity and cation exchange capacity (CEC). that was placed into plastic trays (01 seed per tray) with capacity of 01L, irrigated with distilled water every two or three days and with nutrient solution at 1/1000 ionic strength, prepared according to Hoagland and Arnon (1938). Renewal of the nutrient solution was made every fortnight. Insolation was also controlled in the greenhouse. For acclimation, the seedlings remained in these conditions for eight months.

Once this period was completed, the treatments were applied as increasing concentrations of Cr^{3+} (0, 250, 500 and 750 ppm) and Cr^{6+} (0, 50,100 and 150ppm) in the forms of $CrCl_3 6H_2O$ and K_2CrO_4, respectively diluted in distilled H_2O; the metal solution was made once.

Table 1. Characteristics of the soils used in this study/Selected physico-chemical properties of the studied soil.

Paramètres	Study site
Texture	Clay-loam
Clay (%)	25,71
Silt (%)	35,25
Sand (%)	39,04
Total Calcaire (%)	9,33
Organic carbon (%)	5,12
Organique Matter (%)	2,59
Total-N (%)	0,09
pH	7,73
CEC (cmol+kg^{-1})	4
EC (ms. Cm^{-1})	0,344
Cl (meq/l)	14,925
CO_3^{-2} (meq/l)	0
HCO_3^{-1} (meq/l)	3
SO_4^{-2} (meq/l)	29,78
Total concentrations	
Copper (ppm)	1,149
Lead (ppm)	3,36
Chromium (ppm)	1,09

CEC: cation exchange capacity, EC: electrical conductivity.

Determination of heavy metals in plants and metal fractionation in soils

Saltbush plants (*Atriplex halimus* L.) were harvested four weeks after metals application and separated into three parts: roots, stems and leaves. The plants were thoroughly washed in tap water, rinsed three times with distilled water and oven-dried at 105°C to a constant weight. Dry weights were recorded and plant material was prepared for acid digestion, samples (1g aerial parts 'leaves and stems' and 0.3g for the roots) were then digested in 10cm^3 concentrated nitric acid (HNO_3) in a warm (60°C) sand bath for 2 h, filtered through a Whatman 540 filter paper, made up to volume and then analyzed.

Soil samples collected from the pots after the harvest of the plants were homogenised, air-dried and analyzed for metal fractionation. The amount of chromium which had been adsorbed or absorbed to soil was examined by digesting a sample of soil (50 g) in 50cm^3 of 1 M HNO_3 acid in a warm (60°C) sand bath for 2 h. The acid was then filtered, made up to volume and analyzed (Mant *et al.,* 2005). Metal concentrations in the soil and plant extracts were determined by atomic absorption spectrophotometry (AAS) at 540 nm.

For each experimental treatment, data obtained were the means of the measurements from thirty five plants each and were expressed as mg element kg^{-1} dry weight.

Translocation index is used to work out the ability of plants to translocate heavy metal from roots to harvestable aerial plant parts (Zu *et al.,* 2005). High translocation factor is always favourable for phytoremediation. It is calculated by the following formula:

Translocation Index

$$= \frac{\text{Cr contnet in the leaves (mg kg}^{-1}\text{ DW)}}{\text{Cr content in the root (mg kg}^{-1}\text{ DW)}} \times 100$$

Growth parameters

At the end of the experimental period, the plants of *A. halimus* were collected from the different treatments, the aerial parts (leaves and stems) and the ground organs (roots) were rinsed in distilled water to remove ions from the free space and gently blotted dry. Stems, leaves and roots were separated; the root lengths and the shoot lengths were recorded. Tissues were then incubated during 24 h in an oven at 105°C and the dried root weight and shoot weight were measured (Sauvant, 1988).

Statistics

All data presented in this study are the mean values of five replicates. Statistical analysis was performed using STATBOX v6.4 statistical software. The experiment was performed on a completely randomized design with two factors (metal and dose) and seven treatments (three Cr^{3+} and three Cr^{6+} concentrations, and the control).

The chromium contents in roots, stems and leaves and Cr concentrations in soil results were subjected to analysis of variance (ANOVA); means of the several studied parameters were compared by the NEWMAN- KEULS test ($p < 0.05$).

Results and discussion

The effects of Cr were assessed on growth parameters, both doses of Cr^{6+} and Cr^{3+}caused a significant increase in the dry weight of roots, stem and leaves, with a more pronounced effect of the 750ppm of Cr^{3+} and 150ppm of Cr^{6+} concentrations. We noted stronger effects caused by the hexavalent form (Fig.1).

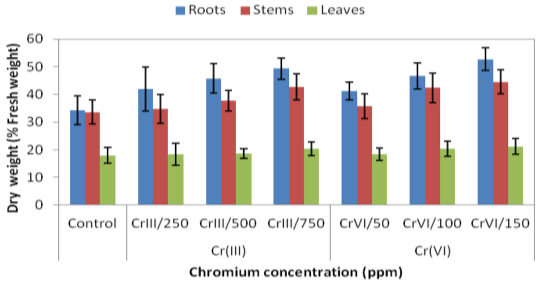

Fig. 1. Roots, stems and leaves dry weight of *Atriplex halimus* seedlings exposed for 30 days to varying concentrations of Cr (III) and Cr (VI).

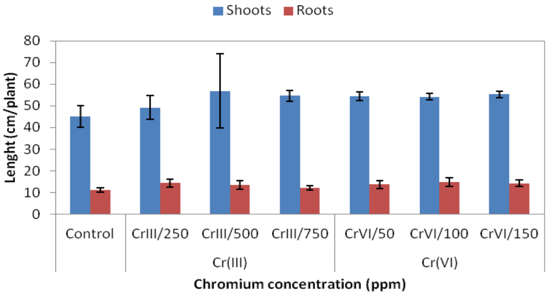

Fig. 2. Shoot and root length of *Atriplex halimus* seedlings exposed for 30 days to varying concentrations of Cr (III) and Cr (VI).

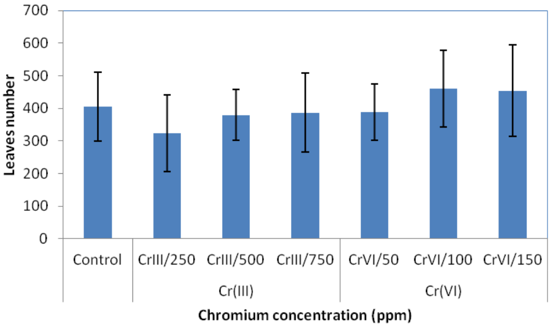

Fig. 3. Leaves number of *Atriplex halimus* seedlings exposed for 30 days to varying concentrations of Cr (III) and Cr (VI).

Also, the root lengths and the shoot lengths of *A. halimus* were clearly affected by increasing concentrations of Cr in both oxidation states (Fig. 2). Whereas, the number of leaves (NL) did not present significant differences (Fig. 3). A significant relationship was found between the metal concentrations in plants and plant growth. Roots, stems and leaves dry weight and length shoot and root; in Cr treatment was significantly higher than control for *A. halimus*. While no significant increase was observed on number leaf parameter. *Atriplex halimus* L. was able to grow in Cr treatments. Despite its toxicity, Cr, in two forms and at various concentrations, seemed to have a stimulating effect on *A. halimus*. The ability of the plants to stay healthy and therefore continue to grow is an important factor in the choice of plants for phytoremediation. A plant will only take up the metal to any great extent if it is growing, and it will only grow if it can tolerate the concentration of metal in the media in which it is growing (Mant *et al.,* 2005).

The total dry weight of root and shoot, Shoot and root length and leaf number of *Atriplex halimus* increased gradually with the increase in chromium concentrations in both oxidation states. Cr (VI) stimulated elongation of root hairs and biomass production in *A. thaliana* (Castro *et al.,* 2007). Earlier, Peralta *et al.* (2001) also observed an increase in root growth of *M. sativa* in Cr (VI) stress. Barcelo *et al.* (1993) observed increase in root and leaf dry weight in *P. vulgaris* and *Z. mays* plants exposed to Cr (III). Arnon (1938) found that *L. sativa* and *Asparagus spp*. grown in nutrient solution containing Cr(III) have improved growth.

The dry weight and length of shoot and root and leaves number of *Atriplex halimus* L. are mainly based on their growth performance of a particular plant. Early growth stages of seedling are very important indicators in determining toxicity impacts of heavy metals like chromium in plants (Sharma *et al.,* 1995; Pandey and Pandey, 2008). Compared to any other heavy metal, Cr supra affects the root length. Cr in the roots makes them a metal excluder (Raskin *et al.,* 1994). Low doses of Cr can stimulate vegetative growth for certain plant species (Samantaray *et al.,* 1998).

However, high levels of Cr (mainly Cr^{6+}, due to its greater toxicity) tend to promote biomass decreases (Shanker *et al.,* 2005a), exert a severe effect on root growth and function, resulting in root damage, reduction in fresh and dry weight, and a diminished uptake of water and nutrients (Terry, 1981).

The solubility of heavy metals can be increased or decreased, depending upon the presence of other mineral elements in the soil–plant system (Samantaray *et al.,* 1998). Qian *et al.* (1999) found that variation in biomass accumulation in plants subjected to metal treatments seems to be a species-specific effect and not simply caused by differences in plant size. Due to its structural similarity with some of these essential elements, Cr affects the mineral nutrition of plants in a complex way (Kaline, 2012).

The increase in growth parameters promoted by both doses of Cr^{6+} and Cr^{3+} in *A. halimus* contradicts the results from other studies, since Cr tends to inhibit the synthesis of chlorophyll and disorganize the chloroplast ultrastructure, leading to chlorosis and necrosis of leaves (Barcelo *et al.,* 1985). In general, the decrease in root growth may be due to inhibition of cell division (Shanker *et al.,* 2005), or to a collapse induced by the direct contact of the seedlings with Cr in nutrient solution (Barcelo *et al.,* 1985). Buendia-Gonzalez *et al.* (2010) observed a decrease in number of secondary roots in Prosopis laevigata under Cr(VI) stress. However, Barcelo *et al.* (1993) observed increase in root and leaf dry weight in *P. vulgaris* and *Z. mays* plants exposed to 1µM Cr (III).

The positive effect of Cr (III) on plant growth was suggested to be related to an influence on the levels of cytokinin or other plant growth hormones, interaction with nucleic acids, competitive inhibition by Cr on the binding of spermine to DNA, or Cr-induced increase in the levels of the polyamine spermine (Poschenrieder *et al.,* 1991). Using highly purified cultures and sensitive analytical techniques, Huffman and Allaway (1973) clearly and conclusively demonstrated the non-essentiality of Cr to plants.

Their results showed that if Cr is required for normal plant growth, the required concentrations in plant tissues ought to be much lower than the levels of any known essential nutrient. This is because they could not reduce the Cr concentration in their nutrient solution below 0.38 × 10-6 mM as well as the entry of trace amounts of atmospheric Cr to their experiment. The stimulation of plant growth in response to Cr addition may simply be due to a limited substitution of Cr (VI) for molybdate (Warington, 1946).

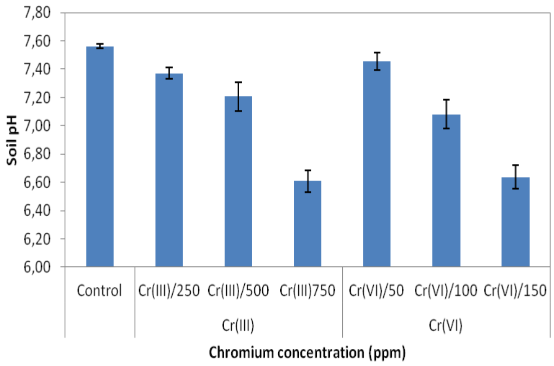

Fig. 4. pH rate from the soil eight months after the beginning of the experiments.

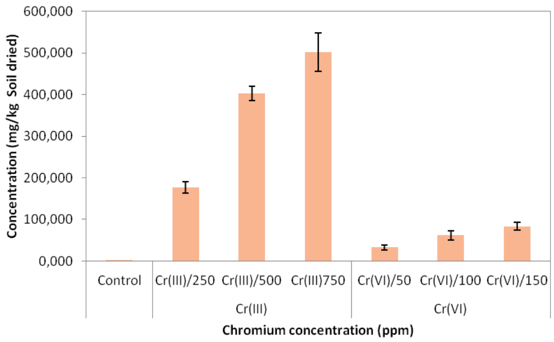

Fig. 5. Chromium concentration in the soils at the end of the experiments.

Selected properties of the soil samples are presented in Fig.4 and Fig. 5. Soil pH ranges from 7.5 to 6.6 with a tendency to decrease with increasing concentration of chromium as expected since it is well known that an increase of metals such as $CrCl_3 6H_2O$ and K_2CrO_4 in soil results in a progressive decrease of soil pH. A decrease in pH after the addition of metal, because the precipitation of chromium hydroxide increases with a decrease in pH, within a certain pH range (Alves *et al.,* 1993).

The pH value of the nutrient substrate solution decreased with Cr (III) and Cr (VI) application. This indicates a high buffering capacity of this metal. However, the effect of pH cannot be separated from the chelating effect of chromium due to the pH is the main factor that controls the chemical behavior of metals. Alkorta *et al.* (2004) have concluded that soil pH does play a key role in influencing the availability of toxic metals for root uptake.

Although pH is indirectly the main factor that significantly controls the chemical behavior of metals (Merrington *et al.,* 2003), increasing their mobility in acidic conditions (Alloway 1995). Mobility of heavy metals in soil depends greatly on soil pH. Fuller (1977) considered that in acidic soils (pH 4.2–6.6) Cr is moderately mobile, and in neutral to alkaline soils (pH 6.7–7.8), Cr is highly mobile. Furthermore, soil pH constitute important factors affecting metal bioavailability in the soil since the transfer of metals between the readily available and less-available phases of the soil is significantly influenced by the competition for surface exchange sites by other cations (especially H^+) and by the presence of binding surfaces such as the organic matter (Martin and Kaplan, 1998; Naidu *et al.,* 2003; Fitzgerald *et al.,* 2003; Rieuwerts *et al.,* 2006).

It is evidenced that, in acidic environments, the more soluble Cr(VI) species showed higher bioavailability as compared to Cr(III) (Bartlett and Kimble 1976; Bartlett and James 1979). It is known that solubility of Cr(III) compounds is strongly influenced by pH, thus decreasing drastically at pH>4.5 and increasing at pH>8.5, where highly stable organic complexes are formed. These latter compounds show higher affinity toward plant roots (Palmer and Wittbrodt, 1991). Clemente *et al.* (2005). It was considered the amount of metals to be extracted from the soil as the product of the soil dry weight in the pots and the difference between the total metal soil concentrations.

Fig. 5 shows Cr concentration in soil in each treatment. In the present context, the soil Cr concentration was relatively normal because the Cr concentration of natural soil ranges from 5–3,000 mg kg^{-1} dry soil (Zayed and Terry, 2003).

The levels chromium content of the collected soils eight months after the beginning of the experiments showed a high degree of variation, Fig.5 also shows that a high Cr concentration in soil (501,56mg/kg Dry Weight), was obtained in treatment with Cr^{3+} at concentration (750ppm). Whereas, a low Cr concentration in soil (32,55mg/kg Dry weight) was obtained in the less concentration of Cr^{6+} (250ppm).

Cr is generally mobile in soils and plant tissues, is known to be extremely insoluble in the normal range of soil pH and moreover its translocation from roots to aerial shoots is limited due to binding at root surfaces and cell walls (Raskin *et al.* 1997; Balsberg Påhlsson, 1989; Lasat 2002; Butcher 2009; Saifullah *et al.,* 2009); the possible mechanism is that $CrCl_3 6H_2O$ and K_2CrO_4 addition changes the pH value of the substrate and promotes plant growth.

Alkorta *et al.* (2004) have concluded that soil pH does play a key role in influencing the availability of toxic metals for root uptake.

Table 2. Cr concentration (milligrams per kilogram of dry weight) and TI in different parts of *A. halimus* after 30 days of irrigation treatments.

Treatment	Total Chrome (mg/kg Dry Weight)				TI (%)
	Root	Stem	Leaf	Soil	
Control	0,003±0,002f	0,001±0,000b	0,0011±0,000e	0,49±0,20f	20,249
CrIII/250	0,603±0,158cd	0,098±0,022a	0,192±0,043d	176,57±13,85c	31,805
CrIII/500	1,174±0,296b	0,091±0,029a	0,460±0,028b	402,61±17,07b	39,203
CrIII/750	1,759±0,329a	0,087±0,038a	0,617±0,054a	501,56±46,14a	35,100
CrVI/50	0,227±0,025ef	0,005±0,005b	0,053±0,021e	32,55±5,56^{e}	23,288
CrVI/100	0,419±0,088de	0,011±0,003b	0,160±0,037d	61,76±11,27d	38,106
CrVI/150	0,704±0,073c	0,022±0,008b	0,253±0,056c	83,59±9,40d	36,017

TI: Translocation Index.

In this study, the amount of *Atriplex halimus* L. samples cultivated in the nutrient solution containing different Cr concentration was collected. The total chromium content of different *Atriplex halimus* L. parts showed a high degree of variation and it is listed in Table 2. The concentrations of Cr and TI in roots, stems, and leaves for Cr (III) and Cr (VI) treated plants are shown in Table 2. As can be seen, in both doses of Cr (III) and Cr (VI) concentration Cr in tissues increased as the external Cr increased, Najeeb *et al.* (2009) found that plant uptake is positively correlated with the metal concentration in the growth media. A great bioaccumulation capacity for Cr was observed in the parts of *A. halimus*.

The maximum Cr(III) concentrations in the roots, stems and leaves were 1,759 mg/kg DW, 0,098 mg/kg DW and 0,617mg/kg DW respectively. As reported for other plants, most of the absorbed Cr was kept in the roots (Lytle *et al.,* 1998; Montes-Holguin *et al.,* 2006; Parsons *et al.,* 2002). The low translocation of chromium from the roots to the leaves has been linked to the precipitation of Cr as Cr (III) hydroxide in roots (Howe *et al.,* 2003).

A high concentration of an element on the roots with poor translocation to the stems and leaves is indicative of non-active transport. A further examination of Cr absorption data shows that *A. halimus* absorbed Cr (III) more efficiently.

However, the Cr concentrations in the stems and leaves treated with two forms of Cr were much lower than those in the root (Table 2). Several studies have reported Cr bioaccumulation of macrophytes in the root being higher than that in the shoot (Zayed and Terry, 2003; Maine *et al.,* 2004; Shanker *et al.,* 2005; Paiva *et al.,* 2009). The reason for the poor translocation of Cr from root to shoot is that plants have no specific transport system for Cr^{3+}; plant Cr uptake occurs only through passive transport (Zayed and Terry, 2003).

Table 2 also shows that a high roots and leaves Cr concentration (1,759 mg/kg Dry Weight, 0,617mg/kg Dry Weight) respectively, was obtained in treatment with Cr^{3+} at concentration (750ppm).

Whereas, a high stems Cr concentration (0,098 mg/kg Dry Weight) was obtained in the less concentration of Cr^3 (250ppm). The absorption of Cr in *A. halimus* is variable from the two form of this metal, the results show that the accumulation of Cr followed this order: $Cr^{3+} > Cr^{6+}$, indicating that the metal release in the soils correlates with their absorption by the plants. However, the results of the present study clearly suggest that absorption and/or translocation of Cr to aerial parts were much higher in *A. halimus* when trivalent Cr was applied into nutrient solution.

In this study, higher Cr values were found in each part of *A. halimus* for Cr^{3+}, implying that Cr^{3+} was more easily taken up and accumulated than Cr^{6+} by *A. halimus* through the root systems from soil. Although *A. halimus* reached a high biomass and a significant amount of metals accumulated in its tissues, the metal uptake was very low compared to the total metal content in the soils.

Atriplex halimus L. especially suitable to phytoremediation of areas in which the more toxic Cr form is present, by phytostabilizing and retaining it as the less toxic Cr^{3+} form. The absorption of Cr in *A. halimus* is variable from the two form of this metal, the results show that the accumulation of Cr followed this order: $Cr^{3+} > Cr^{6+}$, indicating that the metal release in the soils correlates with their absorption by the plants. All of studies have shown that the Cr reduction occurs at the root level and only Cr (III) is found within the plants (Lytle *et al.,* 1998; Hiram *et al.,* 2006).

Also, the Translocation index of *A. halimus* was clearly affected by increasing concentrations of Cr in both oxidation states (Table 2). When compared among the treatments, the maximum translocation index was obtained with 500ppm of Cr^{3+} and 100ppm of Cr^{6+} concentrations. The phytoremediation performance of a plant is determined not only by its capacity to extract high metal concentration, but also by its ability to translocate the metal to aerial parts and simultaneously produce a high biomass (Ximenez-Embun *et al.,* 2001).

The Cr content was higher in the root than other plant parts. In order to continue absorption of Cr from the substrate, plants must be capable to translocate Cr from roots to the leaf, or to compartmentalize it. Our test plant qualifies this criterion as is evident from the elevated translocation index. High translocation is advantageous to phytoextraction, as it can reduce Cr saturation, and the consequent toxicity potential in any given part of the root. Similar results were obtained by Ghosh and Singh (2005) from Cr-treated *Phragmites karka*.

Conclusion

From the results of the present study, it is concluded that *A. halimus* demonstrated a clear potential for phytoremediation strategies of chromium trivalent (Cr^{+3}) and hexavalent (Cr^{+6}), which can be possible in two ways: not only by rhizofiltration of Cr^{+3} and Cr^{+6}, as the seedlings showed capability to absorb and concentrate them on the root system. However, to be able to accumulate high level of the metal concerned in its harvestable tissues, to develop a high biomass production without being affected by metal toxicity and managed to accumulate a significant amount of metals in roots and shoots. Consequently, *A. halimus* has the ability to tolerate difficult soil conditions and was found to be a chromium-tolerant plant.

The current findings confirm the ability of *A. halimus* to minimize Cr and accumulate both oxidation states of this metal in its aerial parts. Based on these criteria, *A. halimus* could be a good candidate for phytostabilization in moderately contaminated soils. Mediterranean saltbush behaved as a metal indicator for Cr, indicating that it can be used for testing changes in metal availability in soils.

The concentrations of metals in this plant exceeded the limits established for humans and grazing an animal, which implies a health risk linked with the spread of the pollution from polluted sites to agricultural areas.

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