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Original Article

Phytoaccumulation of Heavy Metals by Two Coastal Halophytes

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Abstract

The capacity of halophytes to influence the concentration and speciation of metals in the sediment is well documented. Two halophytic species were studied for heavy metals phytoremediation. A total of 16 plant samples (9 samples of *Senecio glaucus*, and 7 samples from *Cakile maritima*) were collected from 12 sites from the Mediterranean coastal area and analyzed for metal concentrations by using the Inductively Coupled Plasma-Mass Spectrometry (ICP-OES). The concentrations of metals in the root and shoot of the studied species were found to be in variably higher than the corresponding sediments. Enrichment Coefficient (EC) and Translocation Factor (TF) are important factors when considering the phytoremediation. Results showed that the both investigated species can much better accumulate Al, Fe, Cu, Mn, As, Ba, and Zn in roots than shoots. The shoots better accumulate Cr, Ni and Co. EC for all investigated metals in the root and shoot of the studied species were higher than (1), while, TF for Cr and Co in both species and Ni in *C. maritima* shoots were higher than (1). The studied plants have no ability to hyperaccumulate heavy metals as their concentrations were below the hyper accumulation threshold criteria.

1. Introduction

Heavy metals are currently of much environmental concern. They are harmful to humans, animals and tend to bioaccumulate in the food chain. The threat that heavy metals pose to human and animal health is aggravated by their long-term persistence in the environment. In nature, heavy metals are removed by many processes (Kadlec and Knight, 1996). Phytoremediation is a process defined as using plants and vegetation to remove, detoxify or stabilize pollutants from the environment. Phytoremediation can provide a cost-effective, long-lasting and aesthetic solution for remediation of contaminated sites (Ma *et al.*, 2001 and Yoon *et al.,* 2006). Plant species have a diverse capacity for accumulating and removing heavy metals through filtration, adsorption, cation exchange and root-induced chemical changes in the rhizosphere (Wright and Otte, 1999). Some of the plant species can accumulate very high concentra-

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tions of toxic metals; significantly higher than those of the soil levels. All plants accumulate heavy metals essential for their growth and development such as Mg, Fe, Mn, Zn, Cu, Mo and Ni. Certain plants also accumulate heavy metals which have no known biological function. These include: Cd, Cr, Pb, Co, Ag, Se and Hg (Memon *et al.,* 2001; Van der Ent *et al.,* 2013; Brankovie *et al.,* 2015).

Plants having the ability to hyper-accumulate heavy metals. A hyper-accumulator has been defined as a plant that can accumulate, copper >1000 mg kg^{-1}, lead >1000 mg kg^{-1}, or zinc >10,000 mg kg^{-1} in their shoot dry matter. In hyper-accumulating plants, the metal concentrations in shoots are invariably greater than that in roots, demonstrating a special ability of the plant to absorb and transport metals and store them in their aboveground components (Wei *et al.,* 2002). The first hyper-accumulators to be characterized were members of the Brassicaceae and Fabaceae families (Salt *et al.,* 1998). Therefore, it will be useful to identify plants having the ability to hyperaccumulate heavy metals (Haque *et al.,* 2007).

However, about 1% of the species of land plants can grow and reproduce in coastal or inland saline sites. These remarkable plants, halophytes, are able to survive and reproduce in environments where the salt concentration is around 200 mM NaCl or more and tolerate salt concentrations that kill 99% of other species Flowers and Colmer (2008), Among these salt-adapted halophytes are annuals and perennials, monocotyledonous and dicotyledonous species, shrubs, and some trees (Manousaki and Kalogerakis, 2011).

Halophytes are of significant interest since these plants are naturally present in environments with an excess of toxic ions and research findings suggest that these plants also tolerate other environmental stresses, especially heavy metals as their tolerance to salt and to heavy metals may, at least partly, rely on common physiological mechanisms. Therefore, halophytic plants have been suggested to be naturally better adapted to cope with heavy metals compared to glycophytic plants commonly chosen for phytoremediation research. The uptake of metals by halophytic plants depends upon their mobility and availability in sediments. Metals in halophytes are mainly accumulated in the roots with small quantities translocated to the stems and leaves, except in the case of more mobile elements such as Mn, Cd and Zn (Reboreda and Caçador, 2007).

The overall objectives of this research were: 1) to determine the concentrations of Aluminium (Al), iron (Fe), lead (Pb), cadmium (Cd), copper (Cu), manganese (Mn), arsenic (As), Barium (Ba), Chromium (Cr), Cobalt (Co), Nickel (Ni), and Zinc (Zn) in plant biomass growing on the coastal area of the Mediterranean sea; 2) to compare metal concentrations in the aboveground biomass to those in roots and in sediments, and 3) to assess the feasibility to use these plant species for phytoremediation purpose.

2. Materials and Methods

2.1. Study area

The study area lies between longitudes 31o 50`-32o 20` E and latitudes 31o 15`–31o 33` N. It is a coastal area extends for about 60 km from Damietta to Port-Said as a narrow continuous strip up to about 0.5 km maximum width. It bordered on the north by the Mediterranean Sea, from the east by the entrance of Suez Canal, from the west by Damietta promontory and from the south by Lake Manzala (Figure 1).

2.2. Samples collection

Samples of plants and sediments were collected from 12 sites in the Mediterranean coastal area (Figure 1). The sampling locations were recorded (Latitudinal and Longitudinal position) using hand-held Global Positioning System (GPS). 16 Samples of plants were taken from the selected sites where these plants were the most numerous. Plants were collected by hand, carefully washed with the water to remove sediment, and stored in plastic bottles. 12 sediment samples were collected, five samples associated with the first plant, 3 samples associated with the second type, and 4 samples jointed). Sediments were oven dried, grounded, homogenized, sealed in clean polythene bags, and stored in a refrigerator until further processing.

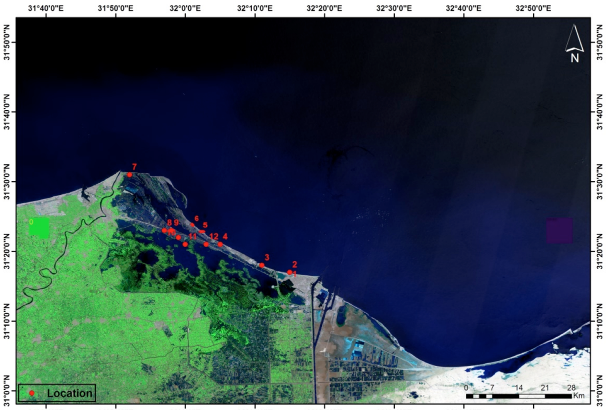

Fig. 1. The sampling locations of the studied species

2.3. Studied species

We select two halophytic plants according to its abundance in the studied coastal area. The first plant is *Senecio glaucus* L, which belonging to the family Asteraceae, while the second is *Cakile maritima* S, belonging to the family Brassicaceae. 9 samples of *S. glaucus*, and 7 samples from *C. maritima* were collected and analyzed for metal concentrations.

2.4. Heavy metal analysis

Twelve metals were analyzed in sediments and plant materials, including: Aluminium (Al), iron (Fe), lead (Pb), cadmium (Cd), copper (Cu), manganese (Mn), arsenic (As), Barium (Ba), Chromium (Cr), Cobalt (Co), Nickel (Ni), and Zinc (Zn).

Live plant parts, i.e. shoots and roots were air-dried for seven days. The samples were oven-dried at 60 ℃ for 24 h to constant mass and ground to powder. Dried samples were digested with a mixture (3:1) of concentrated nitric acid and hydrochloric in microwave assisted Kjeldahl digestion (APHA, 2005). Each microwave extraction vessel was added to 6 ml of nitric acid and 2 ml of hydrochloric acid together with 0.5g of plant sample. The vessels were capped and heated in a microwave unit at 800 W to a temperature of 190 ℃ for 20 min with a pressure of 25 bars. The digested samples were diluted to 50 ml and subjected to analysis of the metals by using the Inductively Coupled Plasma-Mass Spectrometry (ICP-OES) with Ultra Sonic Nebulizer (USN). Results are expressed on a dry weight basis of each component (mg/Kg).

Soil samples were air dried and sieved through a 0.2 mm sieve. The fine part was then used for the analysis, and particles larger than 0.2 mm mesh size were discarded. Bed sediment samples were digested using microwave digestion techniques as reported by Loska and Wiechula (2006) in which 0.1 gm of soil sample is placed in Teflon vessel with 6 ml HNO_3 (65 %), and 2 ml HCl (95 %) to determine the heavy metal contents of soil using the method as described in (APHA, 2005) by using Microwave digestion system, model MILESTONE mls-1200 mega with microwave digestion rotor (MDR) technology. An aliquot of the filtration of the samples was taken (about 100 ml). Digestion solutions were measured for total heavy metals in the vessels were capped and heated in a microwave unit at 800 W to a temperature of 210 ℃ for 20 min with apressure of 40 bars. The digested samples were analyzed for the metals by using the Inductively Coupled Plasma-Mass Spectrometry (ICP-OES) with Ultra Sonic Nebulizer (USN). This Nebulizer decreases the instrumental detection limits by 10 %. The ICP model is Perkin Elmer optima, USA. The Results are expressed on dry weight basis (mg/Kg).

2.5. Translocation Factor (TF) and Enrichment Coefficient (EC)

The translocation factor (TF) or mobilization ratio was calculated to determine relative translocation of metals from the growing medium to other parts (root and shoot) of the plant species (Barman *et al.,* 2000; Gupta *et al.,* 2008). The enrichment coefficient (EC) has been calculated to derive the degree of contamination and heavy metal accumulation in growing medium (drain water) and in plants growing on contaminated site (Kisku *et al.,* 2000).

Translocation factor (TF) and enrichment coefficient (EC) of heavy metals in a plant are calculated as follows:

EC for root = Metal (root) / Metal (sediments)
EC for shoot = Metal (shoot) / Metal (sediments)
TF for shoot = (Metal) shoot / (Metal) root

TF for root = Metal (root) / Metal (sediments).

2.6. Statistical analysis

Descriptive statistics including average, maximum, minimum, and standard deviation analysis are performed after heavy metals analysis using SPSS22.

3. Results and Discussion

3.1. Concentration of heavy metals in sediments

A range of metals was identified in twelve sediment samples collected from the studied area. Metals concentrations were variable among sites. The mean concentrations were 13.19 ± 5.83, 0.24 ± 0.11, 0.014 ± 0.01, 0.187 ± 0.26, 0.04 ± 0.02, 0.52 ± 0.35, 35.66 ± 14.30, 0.95±0.82, 0.12 ± 0.08, and 0.22 ± 0.08 mg kg^{-1} for aluminum, barium, cadmium, chromium, cobalt, copper, iron, manganese, nickel, and zinc, respectively. Concentrations of lead and arsenic were not detected in sediments because their concentrations were lower than the detection limit of the method (for Pb < 0.003 mg L^{-1}, for As < 0.001 mg L^{-1}).

3.2. Accumulation of heavy metals in plant tissues

Metal concentrations in the root and shoots of the studied halophytes species (*S. glaucus* and *C. maritima*) were found to be in variably higher than the corresponding sediments. The mean concentrations of metals in the whole plant of *S. glaucus* had the following order: Fe > Al > Mn > Zn > Ba > Cu > Cr > Co > Ni. The root of *S. glaucus* contained the highest concentration of Al, Fe, Pb, Cd, Cu, Mn, As, Ba, Ni, and Zn in comparison to that found in the investigated shoots, which have the highest concentration of Cr and Co. The mean concentrations of metals in the whole plant of *C. maritima* had the following order: Fe > Al > Mn > Cu > Zn > Cr > Ba > Co > Ni. The root of *C. maritima* contained the highest concentration of Al, Fe, Pb, Cd, Cu, Mn, As, Ba, Cr, Co, Ni, and Zn in comparison to that found in the investigated shoots. The shoot of *C. maritima* has the highest concentrations of Cr, Ni and Co. The content of Pb, Cd and As were not detected in plant organs because their concentrations were lower than the detection limit of the method (for Pb < 0.003 mg kg Metal concentrations in the root and shoots of the studied halophytes species (*S. glaucus* and *C. maritima*) were found to be in variably higher than the corresponding sediments. The mean concentrations of metals in the whole plant of *S. glaucus* had the following order: Fe > Al > Mn > Zn > Ba > Cu > Cr > Co > Ni. The root of *S. glaucus* contained the highest concentration of Al, Fe, Pb, Cd, Cu, Mn, As, Ba, Ni, and Zn in comparison to that found in the investigated shoots, which have the highest concentration of Cr and Co. The mean concentrations of metals in the whole plant of *C. maritima* had the following order: Fe > Al > Mn > Cu > Zn > Cr > Ba > Co > Ni. The root of *C. maritima* contained the highest concentration of Al, Fe, Pb, Cd, Cu, Mn, As, Ba, Cr, Co, Ni, and Zn in comparison to that found in the investigated shoots. The shoot of *C. maritima* has the highest concentrations of Cr, Ni and Co. The content of Pb, Cd and As were not detected in plant organs because their concentrations were lower than the detection limit of the method (for Pb < 0.003 mg kg^{-1}, for Cd and As < 0.001 mg kg^{-1}). Cr and Co have the highest ratio between metal concentrations in the above-ground and in below-ground parts with values of 1.98 and 2.18 respectively in S. *glaucus*, and 3.33 and 3.75 respectively in *C. maritima* in addition to Ni with a ratio of 1.59 (Table 1 , 2).

Roots of the both investigated halophytes species can much better accumulate AL, Fe, Cu, Mn, As, Ba, and Zn than shoots. The capacity of halophyte plants to influence the concentration and speciation of metals in the sediment within the roots is well documented (Otero and Macı´as, 2002; Sundby *et al.,* 2003; Almeida *et al.,* 2004; Aksoy *et al.,* 2005; Reboreda and Caçador, 2007; Carranza-Alvarez *et al.,* 2008). The root system is the main uptake pathway of metals from the sediment. Metals accumulation in root tissues restricts its distribution to above-ground parts. Cr and Co accumulated in *S. glaucus* and *C. maritima* shoots much greater than roots, similarly Ni in *C. maritima*. There have been efforts to define typical concentrations of metals and metalloids in plants. The worldwide 'standard reference plant' has elemental concentrations (μg/g) of Ni (1.5), Zn (50), Cd (0.05), Pb (1), Cu (10), Co (0.2), Cr (1.5), Mn (200), and As (0.1) (Markert, 1994; Dunn, 2007).

Table 1. Mean concentrations (mg kg^{-1} of dry weight) in different parts of *S. glaucus* L., and the ratio of metals concentrations between above-ground and below-ground parts (AG/BG) and its surrounding sediments.

Elements	Whole plant	Shoot	Root	AG/BG	Sediment
Al	1919.26±1419.98	873.51±453.68	2965.00±2386.28	0.29	12.40±5.88
Ba	60.38±41.74	41.31±30.48	79.45±53.00	0.52	0.21±0.09
Cr	43.98±65.94	58.49±118.12	29.48±13.76	1.98	0.20±0.30
Co	7.41±5.08	10.16±5.04	4.66±5.12	2.18	0.04±0.02
Cu	44.42±13.38	37.76±13.23	51.09±13.53	0.74	0.48±0.29
Fe	2524.47±1941.16	1056.18±622.58	3992.77±3259.73	0.26	34.31±15.83
Mn	144.80±74.00	127.16±59.17	162.45±88.83	0.78	0.78±0.34
Ni	5.19±3.60	5.16±3.91	5.23±3.30	0.99	0.13±0.10
Zn	101.36±128.45	63.58±56.41	139.14±200.49	0.46	0.22±0.10
As	<0.001	<0.001	<0.001	-	<0.001
Pb	<0.003	<0.003	<0.003	-	<0.003
Cd	<0.001	<0.001	<0.001	-	0.01±0.00

Table 2. Mean concentrations (mg kg^{-1} of dry weight) in different parts of *C. maritima* S., and the ratio of metals concentrations between above-ground and below-ground parts (AG/BG) and its surrounding sediments.

Elements	Whole plant	Shoot	Root	AG/BG	Sediment
Al	1481.71±602.68	768.89±184.99	2194.54±1020.37	0.35	10.98±5.72
Ba	50.93±26.72	41.83±19.62	60.02±33.83	0.70	0.23±0.14
Cr	64.27±73.02	98.86±121.50	29.69±24.55	3.33	0.25±0.34
Co	12.09±5.71	19.09±8.34	5.09±3.09	3.75	0.03±0.01
Cu	109.46±119.43	101.77±104.34	117.15±134.52	0.87	0.45±0.39
Fe	2759.10±1320.57	1446.49±885.87	4071.72±1755.28	0.36	30.49±10.74
Mn	166.57±69.75	158.97±61.08	174.18±78.43	0.91	0.94±1.09
Ni	11.05±8.77	13.57±12.88	8.52±4.67	1.59	0.09±0.03
Zn	67.73±44.38	47.40±25.15	88.07±63.62	0.54	0.23±0.11
As	<0.001	<0.001	<0.001	-	<0.001
pb	<0.003	<0.003	<0.003	-	<0.003
Cd	<0.001	<0.001	<0.001	-	0.01±0.00

In hyper-accumulating plants, the metal concentrations in shoots are invariably greater than that in roots (Wei *et al.,* 2002). The first hyper-accumulators to be characterized were members of the Brassicaceae and Fabaceae families (Salt *et al.,* 1998 and Brankovie *et al.,* 2015). Therefore, it will be useful to identify plants having the ability to hyperaccumulate heavy metals. Hyper-accumulation threshold criteria for different metals and metalloids in dried foliage: 100 µg/g for Cd, Se and Tl; 300 µg/g for Co, Cu and Cr; 1,000 µg/g for Ni, Pb and As; 3,000 µg/g for Zn; and 10,000 µg/g for Mn, with plants growing in their natural habitats (Van der Ent *et al.,* 2013). On this basis, we have no hyper-accumulators species in our study.

3.3. Enrichment coefficient (EC) and Translocation factors (TR)

Two bio-concentration factors computed from the compartment concentrations, will be used in discussing the results of this study. Concentrations in all compartments were calculated on a dry weight basis. Enrichment coefficient (EC) is an important factor when considering the phytoremediation potential of a plant species (Castañeda *et al.,* 2012; Naji *et al.,* 2012). As shown in Table (3), the Enrichment Coefficient (EC) values of all studied samples varied between 30.78 to 632.47 for *S. glaucus* and 47.45 to 676.46 for *C. maritima*. The highest EC was observed in zinc in *S. glaucus* and in coblet in *C. maritima*. Enrichment Coefficient of all the plant species was found to be more than (1). The enrichment coefficient greater than (1) shows a special ability of the plant to absorb metal ions from soils and transport it to the aerial parts (Wei *et al.,* 2002; Khan *et al.,* 2006; and Djenontin *et al.,* 2012). Plants can immobilize heavy metals through absorption and accumulation by the roots, adsorption onto roots, or precipitation within the rhizosphere (Taskila *et al.,* 2012). However, EC for the shoot is a very important factor, which indicates phytoremediation capacity of a given species (Zhao *et al.,* 2003) *S. glaucus* and *C. maritima* species accumulated all studied metals (AL, Fe, Cu, Mn, As, Ba, Zn, Cr, Co and Ni) in their roots (EC > 1), while the remaining quantity was translocated from the roots to shoots, which is the outermost pathway and point of final accumulation. All of the results of our investigation indicate that the root use only a part of the absorbed quantity of essential elements of metabolic processes and the remaining part of them translocated to other organs, in which they are accumulated and stored in cells via different mechanisms. As for non-essential elements, root and rhizome are also the place of their accumulation and storage, the purpose of which is to protect other vegetative organs, in particular, reproductive organs from their harmful effects (Brankovie *et al.,* 2015).

A plant's ability to translocate metals from sediment to roots or from roots to shoots is measured using the TF, which is defined as the ratio of metal concentration in the sediment to the roots or the shoots to the roots (Stoltz and Greger, 2002). The lowest value of TFs (Table 4) observed in Fe (0.26) in *S. glaucus* shoots. TF values were ranged between 0.35 (Al) and 390.79 (Zn) in *C. maritima*. TF higher than (1) indicates a very efficient ability to transport concentrations from roots to shoots, most likely due to efficient metal transport systems (Zhao *et al.,* 2007). In the root of the studied species the translocation factors for all investigated metals were higher than (1). While, shoots had translocation factors for Cr and Co in two species and Ni in *C. maritima*, higher than (1). Some factors could be led to the bioaccumulation of Cr, Co, Ni in shoots of the studied species. Exceeding of the root storage capacity and increasing transpiration by leaves may lead to higher water uptake, and this can result in higher flux of metals into the entire plant (Fritioff and Gregor, 2003). The obtained results agree with Vardayan and Ingole (2006); and Kumar *et al.,* 2006 in the fact that the plants translocate the essential trace elements from the roots into the above-ground tissues for metabolic use, but disagree with their assumption that there are no pathways for the transport of toxic trace elements (Cr, Ni or Pb) to these above-ground tissues.

Table 3. The enrichment coefficients (EC) for root and shoot of *S. glaucus* and *C. maritima*.

Species	**Factors**	**Elements**											
		Al	**Ba**	**Cr**	**Co**	**Cu**	**Fe**	**Mn**	**Ni**	**Zn**	**As**	**Pb**	**Cd**
S. glaucus	EC(Sh)	70.44	196.72	292.44	253.89	78.66	30.78	163.02	39.66	288.99	-	-	-
	EC (R)	239.11	378.32	147.39	116.54	106.43	116.37	208.26	40.21	632.47	-	-	-
C. maritima	EC(Sh)	70.05	179.63	394.30	676.46	224.73	47.45	168.54	155.74	210.33	-	-	-
	EC (R)	199.94	257.77	118.41	180.45	258.69	133.56	184.66	97.77	390.79	-	-	-

Table 4. The translocation factors (TF) for root and shoot of *S. glaucus* and *C. maritima*.

Species	**Factors**	**Elements**											
		Al	**Ba**	**Cr**	**Co**	**Cu**	**Fe**	**Mn**	**Ni**	**Zn**	**As**	**Pb**	**Cd**
S. glaucus	TF(Sh)	0.29	0.52	1.98	2.18	0.74	0.26	0.78	0.99	0.46	-	-	-
	TF (R)	239.11	378.32	147.39	116.54	106.43	116.37	208.26	40.21	632.47	-	-	-
C. maritima	TF (Sh)	0.35	0.70	3.33	3.75	0.87	0.36	0.91	1.59	0.54	-	-	-
	TF (R)	199.94	257.77	118.41	180.45	258.69	133.56	184.66	97.77	390.79	-	-	-

4. Conclusion

The halophytic plants naturally growing in coastal areas of the Mediterranean sea is unique and quite suitable as phytoremediation materials. The concentration of metals in the root and shoots of the studied halophytes species was found to be in variably higher than the corresponding sediments. Results showed that the roots of both investigated halophytes can much better accumulate Al, Fe, Cu, Mn, As, Ba, and Zn than the shoots, Cr and Co accumulated in the shoot of two species much greater than roots, similarly Ni in *C. maritima*. The two species *S. glaucus* and *C. maritima* can be considered as accumulator species, which have different capacity for metal absorption, translocation and accumulation of their organs, which provides advantages if they were combined for the purpose of remediation of coastal ecosystems.

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الملخص العربى

دراسة إمكانية إزالة المعادن الثقيلة من التربة باستخدام نوعين من النباتات الملحية

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تم دراسة ازالة المعادن الثقيلة من التربة باستخدام نوعين من النباتات الملحية الموجودة بالمنطقة الساحلية للبحر المتوسط. وقد تم تجميع عدد 16 عينة نبات وعدد 12عينة تربة من 12 موقعا من المنطقة الساحلية للبحر المتوسط (9 عينات من نبات المرار *Senecio glaucus* و 7 عينات من نبات صاروخ البحر *Cakile maritima*). تم تعيين تركيز بعض العناصر الثقيلة (12 عنصر) في التربة والنبات (الجذر والمجموع الخضري) باستخدام طريقة المطياف الكتلي البلازمي بالتقارن الحثي (ICP-OES) اظهرت النتائج ان تركيزات المعادن في الجذر والمجموع الخضري للنباتات المدروسة اعلى منها في التربة المقابلة. وبالنسبة لتركيزات المعادن في الجذر والمجموع الخضري للنباتات المدروسة فقد تبين ان الجذر في كلا النوعين يرسب الالومنيوم والحديد والنحاس والمنجنيز والزرنيخ والباريوم اكثر ممن المجموع الخضري . بينما يترسب الكروم والنيكل والكوبلت في المجموع الخضري اكثر من الجذر. تم دراسة أهم المعاملات التي تحدد كفاءة ازالة المعادن الثقيلة بالنباتات منها معامل التغذية (EF) ومعامل الانتقال (TF) . وقد اظهرت النتائج ان قيمة معامل التغذية في كلا النوعين كان اعلى من (1) لكل المعادن المدروسة في الجذر والمجموع الخضري. وكانت قيمة معامل الانتقال في كلا النوعين اعلى من (1) لكل من الكروم والكوبلت في المجموع الخضري فقط. كما سجل النيكل اعلى قيمة في نبات صاروخ البحر (*C. maritima*) في المجموع الخضري فقط. وبذلك فان كلا النباتين يظهر قدرة عالية على ازالة المعادن من التربة ويمكن استخدامها في تطبيق تقنية المعالجة بالنباتات. (phytoremediation) وبدراسة ظاهرة التراكم المفرط (hyperaccumulation للمعادن الثقيلة في نوعين النباتات المدروسة تبين ان هذه الظاهرة لا توجد في كلا النوعين حيث كانت تركيزات المعادن أقل من المعايير العتبية لظاهرة التراكم المفرط (hyperaccumulation) التي حددتها الدراسات السابقة.

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Phytoaccumulation of Heavy Metals by Two Coastal Halophytes

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