Journal of Academia and Industrial Research (JAIR)
Volume 2, Issue 10 March 2014

ISSN: 2278-5213

RESEARCH ARTICLE

Assessment of NaCl Accumulation and Tolerance Potential of *Sesuvium portulacastrum* L.

R. Sundararaj[1]*, S. Nagaraj[2] and R. Rengasamy[3]
[1]Dept. of Botany, Government Arts College for Men, Nandanam, Chennai-600035, India
[2,3]Centre for Advanced Studies in Botany, University of Madras, Guindy Campus, Chennai-600025, India
sundarbot@gmail.com*; +91 9884131499

Abstract

Sesuvium portulacastrum L. is a dicotyledonous, halophyte, perennial plant belongs to the family Aizoaceae. *Sesuvium portulacastrum* is a promising plant for soil desalination. A field trial was made on *S. portulacastrum* at PepsiCo, Mamandur in different plots and each plot covered an area of 70 sq. ft. (6.3 m^2). Each experimental plot was planted with 638 apical vegetative cuttings of 2.8 kg *S. portulacastrum* and irrigated with 250 L/d (i.e. 125 L morning and 125 L evening). The amounts of Na^+ and Cl^- of the aerial dry biomass of *S. portulacastrum* were recorded from the I harvest made on 30^{th}, 60^{th}, 90^{th} and 120^{th} d and II harvest made on 60^{th}, 120^{th}, 180^{th} and 240^{th} d at the plots I, II, III and IV respectively. The study revealed that the accumulation of Cl^- was more than Na^+ and it is possible to remove ca. 1296.0 kg Cl^- and 114.0 kg Na^+ from 1.0 ha area of saline contaminated soil by growing the halophyte *S. portulacastrum* for a maximum a period of 90 d. Thus, *S. portulacastrum* could be a suitable candidate for reclamation of saline contaminated soil in near future.

Keywords: *Sesuvium portulacastrum*, NaCl, aerial dry biomass, halophyte, saline contaminated soil.

Introduction

Rapid industrialization and urbanization over the past decades have generated increasing amounts of wastewater, resulting in environmental deterioration and pressure on reliable water sources in many countries. Treatment of these effluents prior to disposal is an urgent concern worldwide. Effluents are typically toxic, coloured, and turbid with high inorganic and organic suspended solids (Ajaybabu *et al.,* 1999). The different industries engaged in release of wastewater into the environment can be classified as textile, paper, pharmaceutical, dye, tannery, distilleries and so on. In order to protect the environments from undesirable toxic materials, the effluent must be suitably treated before discharge (Kutty *et al.,* 2000). According to Odum (1971), 'Pollution is misplaced energy and matter'. In industrial water pollution excessive energy/matter is introduced into the aquatic system that in turn proves to be harmful to living organisms.

Salinity affects 19.5% of irrigated land and 2.1% of dry land agriculture. In India, *Salvinia* grows in pond abundantly and exhibits exorbitant potential to remove various contaminants including heavy metals, organic compounds, radionuclides from the environment (Sen and Bhattacharyya, 1993). A high uptake of Pb (II) detected by the experiments and also by another observation on a different species has been encouraging to undertake a systematic investigation for the removal of Pb (II) from wastewater using *Salvinia*.

In Tunisia, 1.5% million hectares are affected by salinity. Several methods of biological treatment of effluents have been tested; phytoremediation of effluent is the most widely accepted process due to its smooth handling and economic feasibility. Although the amount of salt-affected land (about 900×10^6 ha) is imprecisely known, its extent is sufficient to pose a threat to agriculture (Flowers and Yeo, 1995; Munns *et al.,* 2002) since most of plants and certainly most crop plants will not grow in high concentrations of salt; only halophytes (by definition) grow in concentrations of NaCl higher than 400 mM. *Salvinia* exhibits exorbitant potential to remove various contaminants including heavy metals, organic compounds, radionuclides from the environment (Olguin *et al.,* 2002; Benaroya *et al.,* 2004; Stepniewska *et al.,* 2005; Sun *et al.,* 2007). Among various species, *Salvinia* holds a distinct position because of several advantages including high productivity and tolerance to a wide range of temperatures (Olguin *et al.,* 2002). The potential of *Salvinia* for heavy metal removal has been studied extensively (Srivastav *et al.,* 1993; Banerjee and Sarker, 1997; Hoffmann *et al.,* 2004; Olguin *et al.,* 2002, 2005; Espinoza-Quinines *et al.,* 2005; Mukherjee and Kumar, 2005; Molisani *et al.,* 2006; Sun *et al.,* 2007). Plants of the Aizoaceae family accumulate large quantities of proline, an amino acid that often contributes to osmoprotection in various species when exposed to osmosis stress (Heun *et al.,* 1981; Delauney and Verma, 1993; Deuschle *et al.,* 2001).

Halophytes show a wide range of morphological and biochemical adaptations that include the ability to remove salt through glandular activity (Flowers, 1972; Flowers *et al.,* 1986). Although control of ion uptake is exercized at the root, the ability to secrete ions has evolved into a successful strategy for salt tolerance. Some halophytes utilize salt-secreting glands to remove excess ions from their leaves, reducing the need for very tight balancing of ion accumulation and growth (Flower, 1972). The halophyte *Sesuvium portulacastrum* L. belongs to the family Aizoaceae (sea purslane) exhibits a great potential for covering soil and landscaping. This species produces decorative branches with pink purplish and occasionally white flowers (Pasternak and Nerd, 1995). *Sesuvium portulacastrum* is able to express high growth potentialities under severe salinities and nutrient availability. Missedi *et al*. (2004) observed that *S. portulacastrum* growth was maximal in the presence of 100-400 mM NaCl (salt-induced growth stimulation) and maintained up to 800 mM NaCl when one part of root system was protected from salt effect. Against these backdrops, the present investigation was aimed to evaluate the NaCl accumulation and tolerance potential of *Sesuvium portulacastrum* for the reduction of different physico-chemical characteristics of primary effluent of PepsiCo, Mamandur, Tamil Nadu.

Materials and methods

Field trial on *Sesuvium portulacastrum:* Five plots in the premises of PepsiCo at Mamandur were made and each plot covering an area of 170 sq. feet (10'x7') was used. The plots were lined with a tarpaulin sheet in order to avoid percolation and kept with the mixture of river sand and FYM in a ratio of 1:1 (w/w) with a height of 12 cm and spread evenly. Each plot was planted with 638 vegetative fragments (12x36) with equal spacing of 2.8 kg *S. portulacastrum*. About 250 L primary effluent of PepsiCo was irrigated to each plot every day i.e. 125 L morning and 125 L evening. This experiment was conducted from May 2007 to Jan 2008.

First and second harvest: The plants grown in I plot was harvested on 30^{th} d by leaving the basal region for the next growth. Similarly in the II plot on 60^{th} d, III plot on 90^{th} d and IV plot on 120^{th} d by leaving their basal regions. The second harvest of the plants was made on 60, 120, 180 and 240 d after the first harvest from I, II, III and IV plots, respectively. In addition to the above, five plants from each plot were uprooted and estimated and recorded for the different parameters such as fresh weight (g), dry weight (g), chlorophyll a, chlorophyll b, total carbohydrate, protein, lipid (µg/mg fresh wt.), Na^+ and Cl^- of leaf, stem, root and entire plant.

Determination of sodium and chloride: The pre-weighed dried 1.0 g of *Sesuvium portulacastrum* sample was added with 10 mL of conc. H_2SO_4 in Kjeldahl flask and mixed well followed by mixing with 5 mL of conc. HNO_3 and heated gently until the organic matter was completely destroyed and white fumes of H_2SO_4 evolved. The above procedure was cooled and the digested sample was added with glass distilled water and transferred to a volumetric flask and made up to 100 mL with glass distilled water. This sample was used for the estimation of Na^+ and Cl^-.

Determination of Sodium: The flame photometric method is applicable for the determination of sodium for natural surface and ground water, drinking water, precipitation and wastewater. A detection limit of about 0.05 mg/L sodium is attainable and the practical upper working limit is about 100 mg/L. Higher Na^+ concentration can be conveniently measured by making appropriate sample dilutions.

Determination of Chloride: The amount of chloride was determined by Mohr's method. The chloride in the sample was titrated with silver nitrate using potassium chromate as indicator. Silver chloride is quantitatively precipitated and at the end point is the formation of red silver chromate. Chloride content was measured using the following formulae:

$$Cl^- \text{ (mg/L)} = (A-B) \times \text{Normality of } AgNO_3 \times 35.46 \times 1000/\text{mL of sample}$$

Where, A is mL of $AgNO_3$ for sample and B is mL of $AgNO_3$ for blank.

Results

Field trial on Sesuvium portulacastrum at PepsiCo, Mamandur: Experimental plots were prepared as per the descriptions given in the materials and methods (Fig. 1). The uprooted plant samples collected from I, II, III and IV plots on 30^{th} d, 60^{th} d, 90^{th} d and 120^{th} d as the I harvest (Figs. 2, 3 and 4) and 60^{th} d, 120^{th} d, 180^{th} d and 240^{th} d as the II harvest from the above experimental plots of I, II, III and IV were recorded for different parameters: fresh weight, dry weight, chlorophyll a, b, total chlorophyll, carbohydrate, total protein and total lipid. In addition, the leaf, stem, root and entire plants were estimated and recorded for Na^+ and Cl^-.

Fig. 1. Planting *S. portulacastrum* in the experimental plot.

Fig. 2. *Sesuvium portulacastrum* irrigated with primary effluent on 30th d.

Fig. 3. *Sesuvium portulacastrum* irrigated with primary effluent on 60th d.

Fig. 4. *Sesuvium portulacastrum* irrigated with primary effluent on 90th d.

Sodium and Chloride accumulation in S. portulacastrum in I Plot: Among the different samples, the accumulation of Cl^- was a maximum of 24%/dry wt. in the entire plant of II harvest which was more than 20% of the I harvest sample. The minimum amount of 5.0% Cl^-/dry wt. recorded from the stem sample of I harvest was less than 65.0% of the II harvest sample. The leaf samples of both I and II harvests had the maximum level of Na^+ when compared to stem, root and entire plant samples. The maximum of 11.0% Na^+/dry wt. recorded from the leaf sample of II harvest was more than 50.0% to that of the I harvest sample (Table 1).

Table 1. Accumulation of Na^+ and Cl^- in *S. portulacastrum* irrigated with primary effluent at Plot I under field trial.

I Harvest on 30th d		
Parameter	% Na^+ dry wt.	% Cl^- dry wt.
Leaf	5.0	16.0
Stem	1.6	5.0
Root	2.4	11.0
Entire plants	3.0	19.0
II Harvest on 60th d		
Leaf	11.0	18.0
Stem	5.0	14.0
Root	4.7	22.0
Entire plants	6.3	24.0

Sodium and Chloride accumulation in S. portulacastrum in II Plot: The accumulations of Na^+ and Cl^- were maximum in the samples collected from the I harvest made on 60th d than II harvest made on 120th d (i.e. 60 d after I harvest). Among the different samples, the accumulation of Cl^- was a maximum of 28%/dry wt. in the root sample collected from I harvest, which was more than 30.0% to that of II harvest. The minimum amount of 17.0% Cl^-/dry wt. recorded in the leaf sample of II harvest was less than 10.0% to that of I harvest sample. However, the leaf samples of both I and II harvests had maximum level of Na^+ when compared to the stem, root, and entire plant samples. The maximum amount of 10.0% Na^+/dry wt. recorded from the leaf sample of I harvest was more than 45.0% to that of II harvest sample (Table 2).

Table 2. Accumulation of Na^+ and Cl^- in *S. portulacastrum* irrigated with primary effluent at Plot II under field trial.

I Harvest on 60th d		
Parameter	% Na^+ dry wt.	% Cl^- dry wt.
Leaf	10.2	19.0
Stem	4.1	22.0
Root	5.1	28.0
Entire plants	5.4	21.0
II Harvest on 120th d		
Leaf	5.6	17.0
Stem	1.4	14.0
Root	2.6	19.0
Entire plants	2.6	19.0

Sodium and Chloride accumulation in S. portulacastrum in III Plot: The 90 d old plant had accumulated maximum of Cl^- 29.0%/dry wt. in the entire plant sample of the I harvest which was more than 75.0% to that of the sample collected from II harvest on 180 d (i.e. 90 d after I harvest). The minimum amount of 4.0% Cl^-/dry wt. recorded in the stem sample of I harvest was less than 60.0% of the II harvest sample. The leaf samples of both I and II harvests had maximum level of Na^+ when compared to the stem, root and entire plant samples. The maximum of 12.0% Na^+/dry wt. recorded from the II harvest leaf sample was more than 80.0% to that of I harvest sample (Table 3).

Table 3. Accumulation of Na^+ and Cl^- in *S. portulacastrum* irrigated with primary effluent at Plot III under field trial.

I Harvest on 90th d		
Parameter	% Na^+ dry wt.	% Cl^- dry wt.
Leaf	2.6	9.0
Stem	1.0	4.0
Root	1.2	10.0
Entire plants	1.1	29.0
II Harvest on 180th d		
Leaf	12.2	11.0
Stem	5.1	10.0
Root	4.6	9.0
Entire plants	5.2	7.0

Sodium and Chloride accumulation in S. portulacastrum in IV Plot: The accumulations of Na^+ and Cl^- were maximum in the II harvest samples made on 240th d than the I harvest made on 120th d. Among the different samples, the accumulation of Cl^- was maximum in the root sample (27.0%) of the II harvest which was more than 45.0% to that of I harvest. The minimum amount of 8.0% Cl^-/dry wt. recorded in the entire plant sample during the I harvest was less than 60% of the II harvest. The leaf samples of both I and II harvests contained maximum level of Na^+ when compared to the rest of samples. The maximum of 9.0% Na^+/dry wt. recorded from the leaf sample of II harvest was more than 20.0% to that of I harvest sample (Table 4).

Table 4. Accumulation of Na^+ and Cl^- in *S. portulacastrum* irrigated with primary effluent at Plot IV under field trial.

I Harvest on 120th d		
Parameter	% Na^+ dry wt.	% Cl^- dry wt.
Leaf	7.5	9.0
Stem	5.0	18.0
Root	6.2	15.0
Entire plants	6.2	8.0
II Harvest on 240th d		
Leaf	9.2	21.0
Stem	5.7	13.0
Root	3.6	27.0
Entire plants	6.4	21.0

Accumulation of Na^+ and Cl^- of aerial biomass of S. portulacastrum during I and II harvests

I Harvest: I harvest made on the aerial parts of *S. portulacastrum* on 30, 60, 90, and 120th d at the plots I, II, III and IV revealed that the accumulation of Cl^- was more than Na^+ (Fig. 4). There was a steady increase in biomass (dry wt.) up to 90th d. On 90th d, a maximum of 4.0 kg dry wt. was recorded. Whereas, only 2.1 kg dry wt. recorded on 120th d. The aerial biomass harvested from the III Plot on 90th d had a maximum of 800 g Cl^-/total dry wt. while at IV Plot on 120th day had only 138 g Cl^-/ total dry wt. (Table 5).

II Harvest: Among the II harvests made on the Plots I, II, III and IV, a maximum of 2.1 kg dry wt. of aerial biomass was recorded at the Plot III on 180th d (90th d after I harvest).

Table 5. Accumulation of Na^+ and Cl^- in harvested aerial dry biomass of *S. portulacastrum* during I and II harvests.

I Harvest				
Plots	I Plot	II Plot	III Plot	IV Plot
Day	30th d	60th d	90th d	120th d
Harvested dry biomass (Kg)	1.1	2.1	4.0	2.1
Na^+ (g/total dry wt.)	40	119	72	138
Cl^- (g/ total dry wt.)	132	609	800	273
II Harvest				
Harvested dry biomass (Kg)	0.9	1.7	2.1	1.4
Na^+ (g/total dry wt.)	70	54	121	85
Cl^- (g/total dry wt.)	163	272	168	266

A minimum of 0.9 kg dry wt. was recorded in the Plot I on 60th d (30th d after I harvest). In the present study also the accumulation of Cl^- was more than Na^+ in the aerial parts of *S. portulacastrum.* A maximum of 266 g Cl^-/total dry wt. was recorded from the aerial part on 240th d at Plot IV and 121 g Na^+/total dry wt. recorded from Plot III (Table 5).

Discussion

The field trial made on *Sesuvium portulacastrum* at PepsiCo, Mamandur revealed that there was a steady increase in biomass (dry wt.) up to 90th d. Maximum 4.0 kg dry wt. of biomass was obtained on 90th d, whereas, only 2.1 kg dry wt. was recorded on 120th d indicated that the decrement was due to ageing/disintegration/non-availability of nutrients for biomass productivity after 90th d. Therefore, it was suggested to grow the plant *S. portulacastrum* irrigated with the primary effluent for maximum biomass productivity only up to 90 d. The maximum accumulation of 29.0% Cl^-/dry wt. recorded from the entire plant sample of the I harvest made on 90th d was more than 75.0% to that of II harvest on 180th d. The minimum amount of 4.0% Cl^-/dry wt. recorded in the stem sample of the I harvest on 90th d was less than 60.0% to that of II harvest sample made on 180th d. The leaf sample collected on 60th d showed a maximum accumulation of Na^+ when compared to the stem, root and entire plant samples. The maximum of 10.0% Na^+/dry wt. recorded from the leaf sample of the I harvest made on 60th d was more than 45.0% to that of the II harvest sample made on 120th d. The amounts of Na^+ and Cl^- of the harvested aerial dry biomass of *S. portulacastrum* were recorded during the I harvest made on 30, 60, 90 and 120 d at Plots I, II, III and IV. It was revealed that the accumulation of Cl^- was more than Na^+. The aerial biomass harvested from the Plot III on 90th d had a maximum of 800 g Cl^-/total dry wt. while at Plot IV on 120th d had only 273 g Cl^- total dry wt. suggested the leaching of the element from the biomass.

The aerial biomass obtained from the II harvest showed less biomass and accumulations of Na^+ and Cl^- than I harvest in the respective plots. Therefore, by keeping the basal region of *S. portulacastrum* for the next growth period not only showed less growth but also exhibited less removal of Na^+ and Cl^- from the primary effluent. In view of the above, it was suggested to irrigate *S. portulacastrum* with the primary effluent only up to 90 d for achieving maximum removal of Na^+ and Cl^- and biomass productivity. Chandhri *et al.* (1964) reported that *Suaeda fruticosa* growing in high saline environment removed 2646 kg NaCl/ha from the soil every year. In the present attempt, *S. portulacastrum* irrigated with primary effluent within a period of 90 d can remove 1296 kg Cl^-/ha and 114 kg Na^+/ha. Therefore, the succulent, halophyte *Sesuvium portulacastrum* L. could be a suitable candidate for the removal of Na^+ and Cl^- apart from other nutrients such as nitrogen and phosphorous etc., from the primary effluent.

Conclusion

The present study indicated the possible utilization on *Sesuvium portulacastrum* L. for the maximum removal of Na^+ and Cl^- from the primary effluent within a period of 90 d. Therefore, it is possible to remove ca. 1296.0 kg Cl^- and 114.0 kg Na^+ from 1.0 ha area of saline contaminated soil by growing the halophyte *S. portylacastrum* for a maximum a period of 90 d. Thus, *S. portylacastrum* could be a suitable candidate for reclamation of saline contaminated soil.

Acknowledgements

The authors Prof. R. Rengasamy and Dr. R. Sundararaj are grateful to PepsiCo, Mamandur, Chennai, India, for providing financial support for this research from Centre for Advanced Studies in Botany, University of Madras, Guindy Campus, Chennai, India.

References

1. Ajaybabu, P., Sitaram Kumar, M., Reddy, G., Kumar, M.P. and Sadhukhan, A.K. 1999. Biodegradation or bulk drug industrial effluents by microbial isolates from soil. *J. Sci. Ind. Res.* 58: 431-435.
2. Banerjee, G. and Sarker, S. 1997. The role of *Salvinia rotundifolia* in scavenging aquatic Pb (II) pollution: A case study. *Bioproc. Engg.* 17: 295-300.
3. Benaroya, R.O., Tzin, V., Tel-Or, E. and Zamski, E. 2004. Lead accumulation in the aquatic fern *Azolla filiculodes. Pl. Physiol. Biochem.* 42: 639-645.
4. Chandhri, I.I., Nagri, N. and Mallik, J.A. 1964. Investigation on the role of *Suaeda fruticosa* in the reclamation of saline and alkaline soils of West Pakistan. *Pl. Soil.* 21: 1-7.
5. Delauney, A.J. and Verma, D.P.S. 1993. Proline biosynthesis and osmoregulation in plants. *Pl. J.* 4: 221-223.
6. Deuschle, K., Funk, D., Hellmann, H., Daschner, K., Binder, S. and Formmer, W.B. 2001. A Nuclear gene encoding mitochondrialdelta–pyrroline–5–carboxylate dehydragenase and its potential role in protection from proline toxicity. *Pl. J.* 27: 345-356.
7. Espinoza-Quinones, F.R., Zacarlein, C.E., Palacio, S.M., Obregon, C.L., Zenatti, D.C., Galante, R.M., Rossi, N., Rossi, F.L., Pereira, R.A., Welter, R.A. and Rizzulto, M.A. 2005. Removal of heavy metals from polluted river using aquatic macrophytes *Salvinia* sp. *Braz. J. Pl. Phy.* 35: 744-746.
8. Flowers, T.J. 1972. The effect of sodium chloride on enzyme activities from four halophytes species of cherropodiaceae. *Phytochem.* 11: 1881-1886.
9. Flowers, T.J. and Yeo, A.R. 1995. The mechanism of salt tolerance in Halophytes. *Ann. Rev. Pl. Physiol.* 280: 89-121.
10. Flowers, T.J., Bagheri, H.M.A. and Clipson, N.J.W. 1986. Halophytes. *Quart. Rev. Biol.* 61: 313-317.
11. Heun, A.M., Gorham, J., Lunge, U. and Jones, R.G. 1981. Changes of water relation characteristics and level of organic cytoplasmic solute during salinity induced transition of *Mesembryanthemum crystallinum* from C_3 photosynthesis to crassulacean acid metabolism. *Oecologia.* 50: 66-72.
12. Hoffmann, T., Kutter, C. and Santamaria, J.M. 2004. Capacity of *Salvinia minima* Baker to tolerate and accumulate As and Pb. *Engg. Life Sci.* 4: 61-65.
13. Kutty, R., Purohit, H.J. and Khanna, P. 2000. Isolation and characterization of a *Pseudomonas* sp. *Can. J. Microbiol.* 46: 211-217.
14. Missedi, D., Labidi, N., Grignon, C. and Abdelly, C. 2004. Limits imposed by salt to the growth of the halophyte *Sesuvium portulacastrum*. *J. Pl. Nature Soil. Sci.* 167: 720-725.
15. Molisani, M.M., Rochado, W., Barreto, R.C. and Lacerda, L.D. 2006. Mercury contents in aquatic macrophytes from two reservoirs in the paraiba do sul: Guandu river system, Se Brazil. *J. Biol.* 66: 101-107.
16. Mukherjee, S. and Kumar, S. 2005. Adsorptive uptake of arsenic (V) from water by aquatic fern *Salvinia natans. J. Water Supply Res. Tech.* 54: 47-53.
17. Munns, R., Greenway, H. and Krist, G.O. 2002. *Halotolerant Eukaryotes.* In: *Encyclopedia of Plant Physiology*. (Eds.) Lang, O.L., Nobel, P.S., Osmand, C.B., Ziegler, H. Springer-Verlay, Berlin. pp.59-83.
18. Odum, E.P. 1971. *In fundamentals of Ecology*. Natraj publishers, Dehrodun: India. p.432.
19. Olguin, J., Hernandez, E. and Ramos, I. 2002. The effect of both different light conditions and the pH value on the capacity of *Salvinia minima* Baker for removing cadmium, lead and chromium. *Acta Biotechnol.* 22: 121-131.
20. Pasternak, D. and Nerd, A. 1995. Research and utilization of halophytes in Israel. In: Chowkr-Allah, R. (Ed.), *Halophyte and Biosaline agriculture.* Marcell Delku, New York, pp.325-348.
21. Sen, A.K. and Bhattacharyya, M. 1993. Studies on uptake and toxic effects of lead on *Salvinia natans*. *Ind. J. Env. Health*. 35: 308-320.
22. Srivastav, R.K., Gupta, S.K., Nigam, K.D.P. and Vasudevan, P. 1993. Use of aquatic plants for the removal of heavy metals from wastewater. *Int. J. Environ. Studies.* 45: 43-50.
23. Stepniewska, Z., Nennicelli, R.P., Balakhnina, T.I., Szajnocha, K., Banach, A. and Wolinska, A. 2005. Potential of *Azolla caroliniana* for the removal of Pb and Cd from wastewaters. *Int. Agrophysics.* 19: 251-255.
24. Sun, N., Sanchez, G., Caffaratti, S. and Maine, M.A. 2007. Cadmium and chromium removal kinetics from solution by two, aquatic macrophytes. *Environ. Poll.* 145: 467-473.