Asian Journal of Chemistry Vol. 21, No. 2 (2009), 1081-1089

Heavy Metal Uptake by *Aptenia cordifolia* as Utility for Sewage Sludge Compost Recuperation using Leachate

ZEYNEP ZAIMOGLU, REYHAN ERDOGAN†, SECIL KEKEC, M. YAVUZ SUCU* and FUAT BUDAK
Department of Environmental Engineering, University of Cukurova, Adana 01330, Turkey
E-mail: ysucu@cu.edu.tr

In this study, the use of composted sewage sludge as a binary component with tuff in growth media for a horticultural crop, *Aptenia cordifolia* was evaluated. Pot experiments were conducted using three different test media: First medium, the SS-W, consists of 50 % sewage sludge compost and 50 % tuff and tap water was used for its irrigation; the same medium was used in the second test, the SS-L, except leachate was used for the irrigation; the remaining test medium consisted of 100 % tuff, the Tuff-W and tap water for irrigation. Each treatment was composed of four repetitions. Plant growth and accumulation of Zn, Pb, Cd, Cr, Ni contents in plants roots and stems were determined. At the end of the study, heavy metal accumulation was highest with the test medium SS-L, which had sewage sludge compost as media and irrigated with leachate. Accumulation on the roots of *A. cordifolia* plant was higher compared to the stem. In conclusion, the use of sewage sludge compost and leachate irrigation is the most efficient test medium for heavy metal uptake by the plant *A. cordifolia* at raised levels of Zn, Pb, Cd, Cr, Ni and thus can be used as a cost-effective solution for recuperation of the soil from the heavy metal pollution.

Key Words: Heavy metal uptake, Phytoremediation, Sewage sludge, Leachate, *Aptenia cordifolia*.

INTRODUCTION

Heavy metals are natural components of the earth crust[1]. In addition to this native origin, some heavy metal may be supplied to soils by atmospheric deposition and by agronomic practices such as fertilizer and pesticide applications as well as the disposal of municipal wastes in the form of composts and sewage sludge on agricultural land[2-4].

The plant uptake of heavy metal depends on the metal concentration in soil. However, the uptake of heavy metal from soil is not a simple function of total heavy metal content of the soil. Medium characteristics regulate the availability of heavy metal for plant uptake. Some investigations have demonstrated that the availability of heavy metal for plants depends on several soil characteristics which

†Department of Landscape Architecture, University of Akdeniz, Antalya, Turkey

affect the binding and mobility of metals in the medium. These characteristics include soil pH, ion exchange properties, drainage status as well as clay and organic matter content[5,6]. On the other hand some investigations clearly demonstrated that the plant itself plays an active role towards mobilizing and uptake of metals bound in soil with considerable differences among plant species and cultivars[7-10].

Sewage sludge is an organic waste which usually contains high levels of nitrogen and phosphorous as well as significant concentrations of micronutrients[11,12]. The use of sewage sludge in soil restoration has beneficial effects on the quantity and availability of nutrients, on the structural stability of the soil and on its resistance to erosion[13].

Phytoremediation can be defined as the combined use of plants, soil amendments like solid waste disposal site and agronomic practices to remove pollutants from the medium[14]. This technique has many advantages compared with other remediation procedures such as low economic costs, the generation of recyclable residues and the possibility of being applied to soils and waters, causing a controlled and limited environmental impact[15,16]. To find the optimum plant species for remediation of a determined soil will be the main point controlling the success of the process, as well as the selection of adequate soil amendments which would improve soil conditions, allowing plant survival and growth[17].

However, the use of sewage sludge compost with high heavy metal concentrations could result in an increase in the metal accumulation in the plants roots and leaves. Such a phenomenon may have an effect on plant development and health. Heavy metal accumulation in the tissue of different plants resulted in a decrease of the biomass and the chlorophyll concentration in the leaves/stems[18-21].

The leachates of various hazardous constituents of solid wastes contaminate soil as well as water bodies. Contamination potentials of various leachates were reported in a number of studies using multiple bioassays[22-24].

This research is carried out in order to demonstrate the effect of heavy metal accumulation in the development of *A. cordifolia*, which is very frequently used in restoration work and to relate the specie with possible utilization in uptake of heavy metals from polluted soils.

EXPERIMENTAL

Plant material and growth conditions: *Aptenia cordifolia*, belonging to the Aizoaceae family, is a perennial herb native to South Africa and has now largely spread throughout Europe. The most commonly grown plant, usually grown under the cultivar name of Red Apple, is considered by some botanists to be actually a hybrid between *A. cordifolia* and the closely related Platythyra (Aptenia) haeckeliana[25]. It is known as Ice Plant and Baby Sun Rose in some regions.

A. cordifolia is a plant which is generally grown in the regions that have moderate climate condition and used as a covering plant for landscape applications. The main reason of using this plant in this study is the capability of rapid growing and covering the land surface. *A. cordifolia* grows rampant and leggy with water and/or shade and compactly when not watered. Its morphological characteristics indicate that it can over-summer without water and then grow vigorously during the rainy season. It spreads vegetative and nodes root when they touch the ground[26]. It blooms in spring and summer. Seeds grow well in sandy, well drained soil and germinate at 15-18 ºC.

During the experiment live plant rate and growth characteristics were observed. Visual assessments for roots and upper parts of plants were done according to Kolb visual assessment techniques[27]. It was described as (1) impression insufficient, (3) impression sufficient, (5) impression satisfying, (7) impression good and (9) impression very good, at the assessment scale.

Experimental set up and heavy metal analysis: The sewage sludge compost was produced by wastewater treatment plant in Adana. The chemical characteristics of the sewage sludge, tuff and the leachate are shown in Table-1. The final material used in the pots was a mixture of 50 % sewage sludge compost and 50 % tuff.

TABLE-1
TYPICAL CHARACTERISTICS OF THE SEWAGE SLUDGE COMPOST, TUFF AND THE LEACHATE

Parameters	Sewege sludge (mg/kg)	Tuff (mg/kg)	Leachate (mg/L)
Cd	1.00	0.43	0.08
Pb	271.75	3.50	0.46
Zn	931.75	31.02	0.30
Cr	91.75	5.21	1.50
Ni	134.25	2.85	0.04

The experiment was carried out in shaded area between March 2005-July 2005. The minimum, maximum and average temperature values for this experiment are given in Fig. 1. The mean humidity was measured 73.6 % for March, 70.5 % for April, 60.6 % for May and 67.3 % for June.

Each pot test medium had four separate pots. Total 12 pots were used in this study. One *Aptenia cordifolia* plant, which was taken from the green houses of Cukurova University, planted in each of the pot. 50 % Sewage sludge compost and 50 % tuff mixed was used for both of SS-W and SS-L trial set. The plants of SS-W trial set were irrigated with 100 mL tap water in every three days. But, the plants of SS-L trial set was irrigated with 100 mL leachate which was carried from Sofulu solid waste material collecting area of Adana district in every three days. The remaining Tuff-W trial set's media was consisted of 100 % tuff and this plants were irrigated with 100 mL tap water in every three days.

At the end of the experiment the plants were harvested and divided into roots and stems. Plant parts were oven-dried at 80 ºC for 2 d and ground. For heavy metal (Pb, Zn, Cd, Cr and Ni) and as analysis, media samples (< 60 µm) were digested

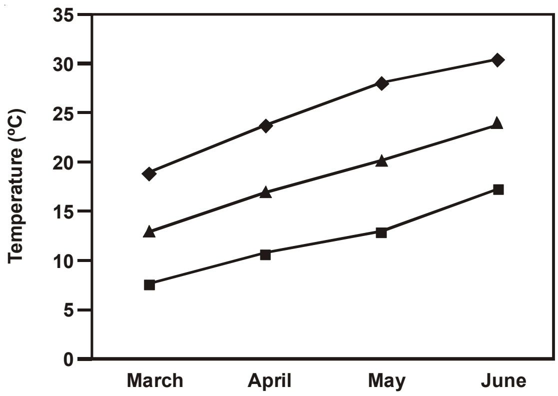

Fig. 1. (▲) Monthly mean, (■) minimum and (◆) maximum ambient temperature values during the experimental period

with concentrated nitric acid. Heavy metal analysis on the media and plants parts solutions were performed using and inductively coupled plasma (ICP) spectrometer Perkin-Elmer Model SCIEX-Elan-5000A[28].

Statistics method: Significant differences between treatments for all measured variables were tested with ANOVA. SPSS 10.0 was used to describe and analyze the sets of data. Tests of multiple comparisons between the means were done by the Duncan test.

RESULTS AND DISCUSSION

The results obtained from the study were evaluated in two ways. First, formed differences originated from general aspects such as growing characteristics. Second, Zn, Pb, Cd, Cr, Ni intake characteristics.

Grown for plant: *Aptenia cordifolia* had growth in all the three treatments. However in the Tuff-W treatment, the plant was weaker and light colour. The best growth was observed in the SS-L treatment with 34 cm plant height and 7 cm root length (Fig. 2). The blossom was also observed in this treatment contrary the others. All the phenological observation values are summarized at Table-2, as interpreted according to Kolb[27] scale values.

TABLE-2
PLANT GROWTH RESULTS OF APPLICATIONS

Treatment	Root	Stem	Colour	Survival rate (%)
SS-W	7	7	Dark green	100
SS-L	9	7	Light green	100
Tuff-W	9	5	Yellow-green	100

SS-W = Sewege sludge compost + tap water, SS-L = Sewege sludge compost + Leachate, Tuff-W = Tuff + tap water

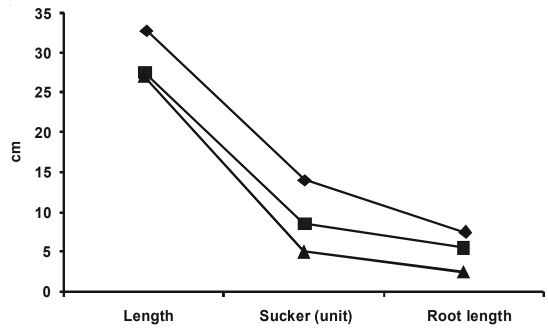

Fig. 2. *Aptenia cordifolia*'s length, sucker and root length values for (◆) SS-L, (■) SS-W and (▲) Tuff-W treatment sets

Uptake of heavy metal in *Aptemia cordifolia*: *Aptenia cordifolia* has high tolerance for Zn, Pb, Cd, Cr and Ni. Heavy metal uptake by plants were planted on sewage sludge compost is more than which were planted on tuff.

Despite of these general trends, the analyses of variance suggested that the application of SS-L treatment affected the metals in different ways. Differences belong to treatment are significant for Pb ($F = 75.625$; $df = 2$; $p = 0,000$), Zn ($F = 31.129$; $df = 2$; $p = 0.000$), Cd ($F = 10.998$; $df = 2$; $p=0.000$), Cr ($F = 6.758$; $df = 2$; $p = 0.004$) and Ni ($F = 63.144$; $df = 2$; $p = 0.000$).

The results obtained from the analysis of roots, stems and medias made it possible to clearly differentiate concentration of Pb ($F = 88.926$; $df = 2$; $p = 0.000$), Zn ($F = 32.862$; $df = 2$; $p = 0.000$), Cd ($F = 23.353$; $df = 2$; $p = 0.000$), Cr ($F = 85.650$; $df = 2$; $p = 0.011$) Ni ($F = 108.345$; $df = 2$; $p = 0.000$) is significant ($p < 0.01$). According to the figures obtained from the study, comparing with the other two treatments, considerably lower accumulation determined in stem and root at control treatment of Tuff-W. The highest accumulation, next to SS-W treatment, was observed in SS-L treatment.

The average values of the applications effect of which were accepted as important according to the results of variance analysis done, are shown at Table-3 which formed according to multiple comparison test.

TABLE-3
MULTIPLE COMPARISONS AND FORMED GROUPS ACCORDING TO ENVIRONMENTS (n = 12) DUNCAN

Treatment	Pb (g kg^{-1})	Zn (g kg^{-1})	Cd (g kg^{-1})	Cr (g kg^{-1})	Ni (g kg^{-1})
SS+W	58.0867b	246.2000b	0.7208a	21.5083b	31.1792b
SS+L	82.5608a	322.8725a	0.9592a	30.7325a	42.4950a
Tuff+W	2.1150c	68.6850c	0.4308b	3.4950c	0.9892c

Treatment groups were set up as; SS-W = Sewege sludge compost + tap water; SS-L = Sewege sludge compost + Leachate; Tuff-W = Tuff + tap water; a = the maximum value; b = the intermediate value; c = the minimum value and Alpha = 0.05

The concentrations of heavy metals in the tissues of *A. cordifolia* increased from root to stems. This is not a typical behaviour of accumulator species[29]. Pb, Cd, Cr and Ni were also found in higher concentrations in the root. There was not any previous study concerning *A. cordifolia*. So, intake of heavy metal was evaluated by comparing heavy metal concentrated in the plant, with different grassy plants.

When examined the intake amount of zinc by *A. cordifolia*, the highest value was obtained namely for root 311.69 ± 194.99 g kg^{-1} (mean ± standard deviation), for stem 102.60 ± 30.93 g kg^{-1} from the treatment group of SS-L (Fig. 3a). Contrary to *A. cordifolia*, Clemente *et al.*[30] observed with their study that the highest accumulation of zinc was in the upper parts of *B. juncea* plant. Ebb and Kochain[31] also reported almost the same figures for *B juncea*. Walker *et. al.*[32] found 118 g kg^{-1} in stem for *Chenopodium album*. Del Rio *et al.*[33] found 353 g kg^{-1} Zn accumulation in root for *Cynodon dactylon*. This value is quite close to *A. cordifolia*'s Zn accumulation in root.

TABLE-4
MULTIPLE COMPARISONS AND FORMED GROUPS ACCORDING TO BLOCKS (n = 12)

	Pb (g kg^{-1})	Zn (g kg^{-1})	Cd (g kg^{-1})	Cr (g kg^{-1})	Ni (g kg^{-1})
Root	48.1767b	217.8283b	0.9717a	17.0400b	18.7925b
Stem	2.5783c	76.0775c	0.2700b	2.0075c	0.3300c
Media	92.0075a	343.8517a	0.8692a	36.6883a	55.5408a

a = the maximum value; b = the intermediate value; c = the minimum value and Alpha = 0.05

In this study, maximum lead accumulation became in the roots of *A. cordifolia*. Treatment of SS-L had two times more than treatment of SS-W as far as this accumulation is concern (Fig. 3b). While the accumulation of lead in roots for the treatment of SS-L was 96.56 ± 37.77 g kg^{-1}, it was 45.50 ± 11.61 g kg^{-1} for the treatment of SS-W. Srivastava *et al.*[34] found the accumulation of lead in the roots of *Allum cepa* as 20.62 ± 0.17 g kg^{-1} as *Aptenia cordifolia*'s stem can collect 3.66 ± 1.98 g kg^{-1} lead, according to Matejon *et al.*[35] *Sorgum halepens*'s stem can collect 4.9 g kg^{-1} and *C. dactylon*'s stem can collect 16 g kg^{-1}. It is possible to say that according to this result *A. cordifolia*'s lead uptaking is like to *S. halepens*'s lead uptaking for stem. At the other side *C. dactylon* can collect lead approximately five times more than *Aptenia cordifolia* in stem.

Cadium accumulation of *A. cordifolia* in the roots is three times more then that of stem (Fig. 3c). Maximum average value of cadium accumulation in roots is 1.12 ± 0.45 g kg^{-1} in the treatment of SS-L and 1.08 ± 0.40 g kg^{-1} in the treatment of SS-W. The treatment of SS-L has three times more cadium accumulation (0.46 ± 0.30 g kg^{-1}) in stem than that of treatment of SS-W (0.16 ± 0.08 g kg^{-1}). Ortiz *et al.*[36] found cadium intake of the plant as 3.218 ± 1.629 by conducting a study made with *Dactlis glomerata*.

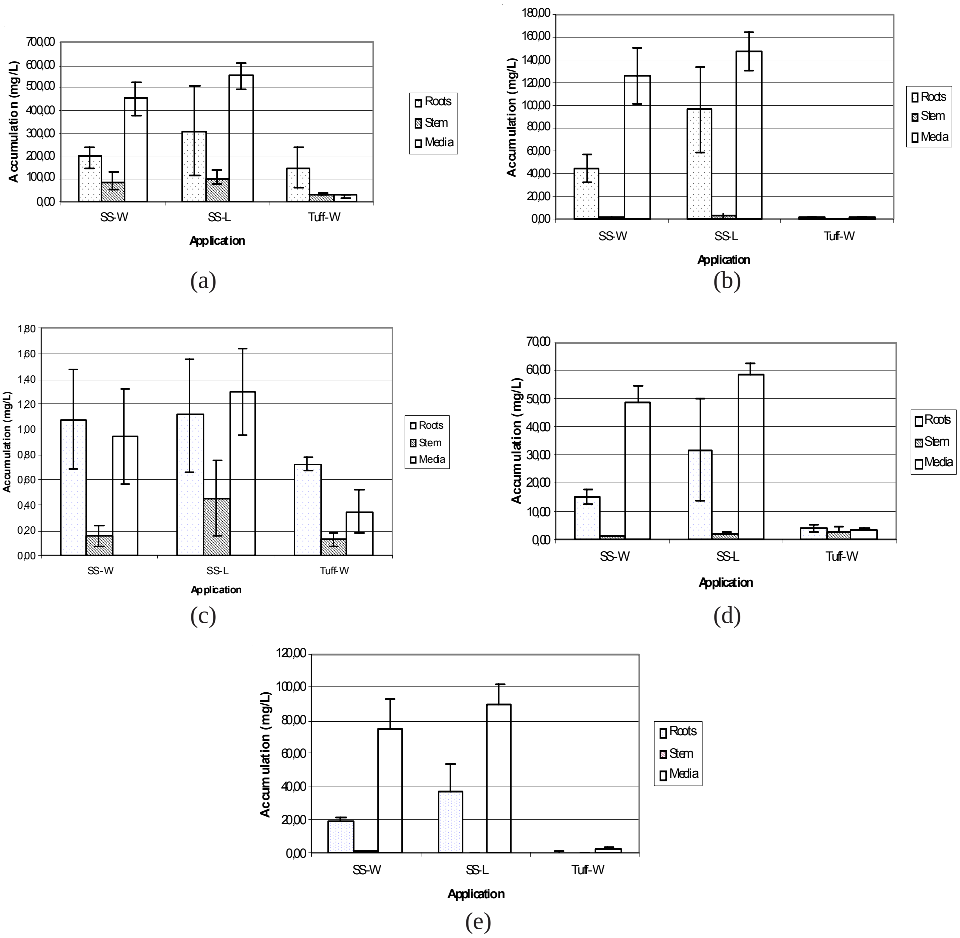

Fig. 3. Uptake of (a) Zn, (b) Pb, (c) Cd, (d) Cr and (e) Ni by *Aptenia cordifolia*

Chromium accumulation in roots was measured as 15.19 ± 2.64 g kg^{-1} in the treatment of SS-W and 31.81 ± 17.70 g kg^{-1} in the treatment of SS-L (Fig. 3d). Srivastava *et al.*[34] found that chromium accumulation in the roots of *A. cepa* plant as 17.1 ± 0.52 g kg^{-1} when irrigated with leachate. Accumulation in stem was higher in the treatment of SS-L than that of the treatment of SS-W. These figures are 2.23 ± 0.95 g kg^{-1} and 0.99 ± 0.38 g kg^{-1}, respectively. This situation shows that chromium absorbed in the roots can not be carried to the structure of the plant and cannot be taken from soil and irrigation water by phytoextraction.

A. cordifolia can absorb nickel in its roots on the SS-LL. (37.20 ± 1.17 g kg^{-1}) treatment two times more than SS-W (18.59 ± 3.44 g kg^{-1}) (Fig. 3e). Srivastava *et al.*[34] found that *Allium cepa* can uptake 7.57 ± 1.13 g kg^{-1} in its roots. This value is very lover than *A. cordifolia*'s nickel uptake by its roots. In releated to nickel uptake in stem, similar to the other heavy metal accumulation in root is quite low.

Conclusion

It is determined that by use of sewage sludge compost and leachate irrigation is the most efficient test medium for heavy metal uptake by the plant *A. cordifolia* at raised levels of zinc, lead, cadmium, chromium and nickel and thus can be used as a cost-effective solution for recuperation of the soil of from heavy metal pollution. *A. cordifolia* is an effective plant for possible remediation treatment in some contaminated soils landfill areas. Consequently, using this plant contaminated and spoilt landscapes can be recovered.

The results also indicate that sewage sludge and leachate, which are serious pollution problems all over the world, could be used as a media for recovering green landscapes and this can be achieved using *Aptenia cordifolia*.

REFERENCES

1. K.H. Wedepohl, in ed.: E. Merian, The Composition of the Upper Earth's Crust and The Natural Cycles of Selected Metals, Metals and their Compounds in the Environment, VCH/Verlagsgesellschaft, Weinheim, pp. 3-17 (1991).
2. H.H. Cramer, A. Kloke, H.J. Jarczyk and H. Kick, Ground Contamination, Uhlmans Encyclopaedia, The Technical Chemistry, Band 6, Verlag Chemie, Weinheim, pp. 501-506 (1981).
3. D. Sauerbeck, Funktionen, Goodness and Loading Capacity of the Ground from Agriculture-Chemical View, Verlag W. Kohlhammer, Stuttgart, Mainz (1985).
4. H.W. Schmidt and H. Sticher, in ed.: E. Merian, Heavy Metal Compounds in the Soil, Metals and their Compounds in the Environment, VCH/Verlagsgesellschaft, pp. 311-331 (1991).
5. M.L. Berrow and J.C. Burridge, in ed.: E. Merian, Uptake, Distiribution and Effects of Metal Compounds on Plants, Metals and Their Compounds in Environment, VCH/Verlagsgesellschaft, Weinheim, pp. 399-410 (1991).
6. D. Sauerbeck and S. Lübben, Consequencies of Settlement Rubbish on Grounds, Ground Organisms and Plants, Research Centre, Jülich (1991).
7. H.M. Helal, European Society of Agronomy, Congress Abstr. 3, p. 21 (1990).
8. T.D. Hinsley, D.E. Alexander, E.L. Ziegler and G.L. Barrett, *Agron. J.*, **70**, 425 (1978).
9. M. Mench, J. Tancogne, I. Gomez and C. Juste, *Biol. Fert. Soils*, **8**, 48 (1989).
10. O. Petterson, *Swed. J. Agric.*, **7**, 21 (1977).
11. E. Epstein, J.M. Taylor and R.L. Chaney, *J. Environ. Qual.*, **5**, 422 (1976).
12. W.E. Sopper, Municipal Sludge Use in Land Reclamation, Lewis Publishers, Boca Raton (1993).
13. K. Debosz, S.O. Petersen, L.K. Kure and P. Ambus, *Appl. Soil Ecol.*, **19**, 237 (2002).
14. D.E. Salt, R.D. Smith and I. Raskin, *Ann. Rev. Plant Physiol. Plant Molecul. Biol.*, **49**, 643 (1998).
15. J.L. Schnoor, Phytoremediation of Soil and Groundwater, Technology Evaluation Report TE-02-01, Ground-Water Remediation Technologies Analysis Center (GWRTAC) (2002).
16. Z. Sogüt, B.Z. Zaimoglu, R. Erdogan and M.Y. Sucu, *J. Environ. Biol.*, **26**, 13 (2005).
17. Z. Zaimoglu, *J. Environ. Biol.*, **27**, 293 (2006).
18. M. Burzynski and J. Buczek, *Acta Physiol. Plant.*, **11**, 137 (1989).
19. G. Ouzounidou, E.P. Eleftheriou and S. Karataglis, *Can. J. Bot.*, **70**, 947 (1992).
20. S.S. Sharma and J.P. Gaur, *Ecol. Eng.*, **4**, 37 (1995).
21. R. Abdel-Basset, A.A. Issa and M.S. Adam, *Photosynthetica*, **31**, 421 (1995).
22. R.D. Cameron, E.C. McDonald, M.G. Mager, S.C. Liptak and P.D. Parkinson, Toxicity of Landfill Leachates, Environment Canada Report EPS: 4-EC-82-7.41 (1982).
23. S. Plotkin and N.M. Ram, *Arch. Environ. Contam. Toxicol.*, **13**, 197 (1984).
24. A. Calleja, J.M. Baldasano and A. Mulet, *Toxicity Assess.*, **1**, 73 (1986).

25. D.J. Von Willert, D.A. Thomas, W. Lobin and E. Curdts, *Oecologia*, **29**, 67 (1977).
26. L.H. Bailley, Manual of Cultivated Plants, Macmillan Publishing, New York (1949).
27. W. Kolb, Pflegeaufwand bei bodendeckenden Stauden und Gehölzen. Freising: Dissertation an der TU München, FB Landwirtschaft und Gartenbau, Germany, pp. 38-39 (1981).
28. M. Simon, I. Ortiz, I. Garcia, E. Fernandez, J. Fernandez, C. Dorronsoro and J. Aguilar, *Sci. Total Environ.*, **242**, 105 (1999).
29. A.J.M. Baker, *J. Plant Nutr.*, **3**, 643 (1981).
30. R. Clemente, D.J. Walker and M.P. Bernal, *Environ. Pollut.*, **138**, 46 (2005).
31. S.D. Ebbs and L.V. Kochian, *Environ. Sci. Technol.*, **32**, 802 (1998).
32. D.J. Walker, R. Clemente and M.P. Bernal, *Chemosphere*, **57**, 215 (2004).
33. M. del Río, R. Font, J.M. Fernández-Martínez, J. Domínguez and A. de Haro, *Fresenius Environ. Bull.*, **9**, 328 (2000).
34. R. Srivastava, D. Kumar and S.K. Gupta, *Bioresour. Technol.*, **96**, 1867 (2005).
35. P. Madejon, J.M. Murillo, T. Maranon, F. Cabrera and R. Lopez, *Sci. Total Environ.*, **290**, 105 (2002).
36. O. Ortiz and J.M. Alcañiz, *Bioresour. Technol.*, **97**, 545 (2005).

(*Received*: 12 December 2007; *Accepted*: 19 September 2008) AJC-6877