

## THE USE OF HEAVY METAL ACCUMULATING PLANTS FOR DETOXICATION OF CHEMICALLY POLLUTED SOILS

J. Antonkiewicz, Cz. Jasiewicz, P. Ryant

Received: August 30, 2003

### Abstract

ANTONKIEWICZ, J., JASIEWICZ, Cz., RYANT, P.: *The use of heavy metal accumulating plants for detoxication of chemically polluted soils*. Acta univ. agric. et silvic. Mendel. Brun., 2004, LII, No. 1, pp. 113-120

The studies conducted from 1997 to 1999 in a vegetation hall were performed as a pot experiment on ordinary silt soil. Jerusalem artichoke, maize, *Sida hermaphrodita* Rusby, amaranth and hemp were used as indicator plants. The results confirmed, great diversification of the element contents which depends not only on the species but also on the part of individual plants. Analysis of the data revealed also another dependence: increased concentration of heavy metals in the soil corresponded to a higher content of heavy metals in the plants. Significant differences in this respect were observed for the plant species grown in unpolluted or differently contaminated soil.

detoxication, heavy metals, plants, polluted soils, *Helianthus tuberosus* L., *Zea mays* L., *Sida hermaphrodita* Rusby, *Amaranthus* L., *Cannabis sativa* L., Jerusalem artichoke, maize, amaranth, hemp

Industrial activities cause a fast and considerable degradation of soil and vegetation cover, which necessitates seeking for suitable methods of management to restore industrial lands. On a chemically polluted soil vegetation may play an important ecological and sanitary role. Proper management of such areas including selection of plants to grow may significantly contribute to recovery of soil (SIUTA, 1995). Numerous efforts have been undertaken recently to remove heavy metals from soils, among others through phytoremediation (JASIEWICZ and ANTONKIEWICZ, 1999, KUCHARSKI et al., 1998, SAS-NOWOSIELSKA, 1999). Plants revealing high capability for heavy metal accumulation have been also sought (GAMBUŚ, 1997b, JASIEWICZ and ANTONKIEWICZ, 2000ab). The selection of plant species resistant to enhanced concentration of heavy metals and accumulating high amounts of them could support reclamation of the contaminated areas (KUCHARSKI et al., 1999). Among species

with enhanced tolerance to heavy metals in soil belong *Sida hermaphrodita* Rusby, amaranth, Jerusalem artichoke and fibre plants: hemp and linseed (NALBORCZYK, 1995, GRZEBISZ et al., 1998ab, BORKOWSKA and STYK, 1997, JASIEWICZ and ANTONKIEWICZ, 1999).

The aim of the investigation was to determine the effect of the soil pollution with heavy metals (Cd, Pb, Ni, Cu and Zn) on the yield of studied plants species and accumulation of heavy metals in plant biomass.

### MATERIALS AND METHODS

The studies were conducted in 1997-1999 as pot experiments in a vegetation hall. An ordinary silt soil with cation exchange capacity (CEC) 811 mmol (+) · kg<sup>-1</sup>, pH<sub>KCl</sub> = 6.0 and organic C content 9.5% was used. Heavy metal contents determined in 65% solution of HNO<sub>3</sub> and 70% HClO<sub>4</sub> were as follows: 1.2 mg Cd, 54.3 mg Pb, 5.0 mg Ni, 13.8 mg Cu and 226.6 mg Zn · kg<sup>-1</sup> soil d.w. The experimental design

comprised the following 8 treatments (each in 4 replications): control without heavy metal addition and 7 treatments with increasing doses of heavy metals (tab. I). The heavy metals were applied as water solutions of the following salts:  $3\text{CdSO}_4 \cdot 8\text{H}_2\text{O}$ ,  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ ,  $\text{NiSO}_4 \cdot 7\text{H}_2\text{O}$ ,  $\text{Pb}(\text{NO}_3)_2$  and  $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ . All pots received the same basic fertilisation with: 0.3 g N as  $\text{NH}_4\text{NO}_3$ ; 0.08g P in  $\text{KH}_2\text{PO}_4$ ; 0.20 g K in  $\text{KH}_2\text{PO}_4 + \text{KCl}$  and 0.05g  $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$  per 1 kg of soil d.w. The heavy metals and fertilisers were mixed with the soil one week prior to the seed sowing. Jerusalem artichoke, maize, *Sida hermaphrodita* Rusby, amaranth and hemp were the indicator plants. Vegetation periods for individual plants were diversified

and the average duration in three years experiments was: for Jerusalem artichoke, maize, *Sida*, amaranth and hemp: 127, 99, 153, 88 and 99 days, respectively. During the vegetation period the plants were watered with redistilled water and soil moisture maintained at 60% of maximum water holding capacity. The plants were harvested at full ripeness. They were dried at 75°C and then the aerial parts yield amount was determined by weighting. The contents of Cd, Pb, Ni, Cu and Zn were determined after dry incineration with flame technique in a Philips PU 9100 X atomic absorption spectrophotometer (AAS) (OSTROWSKA et al., 1991).

I: *Experimental design*

Treatments	Doses of metals mg · kg <sup>-1</sup> d.w. soil
0	Control
I	Cd 5, Cu 20, Ni 15, Pb 30, Zn 50
II	Cd 10, Cu 40, Ni 30, Pb 60, Zn 100
III	Cd 20, Cu 80, Ni 60, Pb 120, Zn 200
IV	Cd 40, Cu 160, Ni 120, Pb 240, Zn 400
V	Cd 80, Cu 320, Ni 240, Pb 480, Zn 800
VI	Cd 160, Cu 640, Ni 480, Pb 960, Zn 1600
VII	Cd 320, Cu 1280, Ni 960, Pb 1920, Zn 3200

## RESULTS

The yield of tested plants was diversified and dependent on the species, level of soil contamination with heavy metals and the year of the experiment (tab. II).

It was found that Jerusalem artichoke could not be cultivated at soil contamination exceeding 80 mg Cd, 480mg Pb, 240 mg Ni, 320 mg Cu and 800 mg Zn · kg<sup>-1</sup> soil d.w. because high concentrations of heavy metals in treatments VI and VII proved toxic for this plant. Toxic influence of heavy metals on the yield of aerial parts, roots and tubers of Jerusalem artichoke was registered from the third level of soil contamination with heavy metals. Depending on the year of the experiment decreases in the yield of aerial parts and roots ranged respectively between 20-96% and 17-90% in 1997; from 12-98% and 39-92% in 1998 and from 17-97% and 41-92% in 1999 in comparison with the control. A decline in tuber yield was noticed also from the third level of soil contamination with heavy metals and depending on the treatment and year of the experiment was as follows: 26-91% in

1997; 36-97% in 1998 and 36-96% in 1999 in comparison with the control.

It was found that maize could not be cultivated in soil treatments VI and VII where the highest levels of soil contamination with heavy metals were applied. Irrespective of the year of the experiment a decline in maize aerial parts was registered already from the second level of soil contamination with heavy metals. The decrease was 6% in the first year, 12% in the second year and 11% in the third year in comparison with the control. A decline in maize aboveground yields at increasing doses of heavy metals (treatments III-V) were more pronounced in 1997 and ranged from 19% to 81%; in 1998 from 29% to 76% and in 1999 from 24% to 72% in comparison with the control. Decreased yielding of maize roots was noticed, like in case of its aerial parts, also from the second level of soil contamination with heavy metals and in comparison to the control was respectively: in 1997 from 29 to 68%; in 1998 from 21 to 72% and in 1999 from 27 to 75%.

II: Plant yields (g d.m. · pot<sup>-1</sup>)

Year	Treat-ments	Plant species								
		Jerusalem artichoke		Maize		Sida herm.	Amaranth		Hemp	
		Aerial	Roots	Aerial	Roots	Aerial	Aerial	Roots	Aerial	Roots
1997	0	112.4	19.9	203.3	27.3	118.0	155.3	17.5	199.1	9.5
	I	108.3	19.7	210.0	27.4	123.9	157.9	17.3	197.2	9.5
	II	105.9	19.2	194.5	19.5	111.9	155.8	17.4	152.5	8.7
	III	89.9	16.4	176.4	17.6	115.4	136.5	15.6	135.8	8.8
	IV	35.1	8.2	122.2	15.9	106.0	82.9	8.8	139.9	8.1
	V	4.8	2.0	38.3	8.7	63.7	-	-	6.4	1.2
	LSD <sub>0.05</sub>	17.2	2.08	8.9	2.9	54.5	14.3	1.12	8.6	0.9
1998	0	323.1	41.2	223.4	31.3	590.2	173.0	18.3	167.3	12.6
	I	340.0	41.9	224.1	29.7	593.9	169.1	17.5	168.5	11.0
	II	323.4	41.0	196.7	24.7	577.2	171.7	17.3	148.5	9.4
	III	283.9	25.2	158.6	24.5	572.8	134.3	16.2	151.2	9.9
	IV	38.0	6.0	82.7	16.6	566.3	83.4	8.6	104.7	8.9
	V	7.5	3.2	54.3	8.9	374.8	-	-	5.6	0.4
	VI	-	-	-	-	231.8	-	-	-	-
	VII	-	-	-	-	11.3	-	-	-	-
	LSD <sub>0.05</sub>	17.2	2.08	8.9	2.9	54.5	14.3	1.12	8.6	0.9
1999	0	331.4	39.9	216.7	31.5	855.2	172.7	18.0	169.1	12.5
	I	337.3	41.1	216.8	32.0	883.6	171.4	17.6	166.0	12.2
	II	324.1	38.7	193.1	23.0	837.7	172.5	17.7	146.2	10.9
	III	275.7	23.3	164.8	20.7	852.3	140.0	15.8	144.9	9.7
	IV	35.5	7.0	82.3	15.7	844.1	86.3	9.9	109.8	8.8
	V	9.9	3.3	60.2	7.8	628.8	-	-	5.4	0.9
	VI	-	-	-	-	414.3	-	-	-	-
	VII	-	-	-	-	395.7	-	-	-	-
	LSD <sub>0.05</sub>	17.2	2.08	8.9	2.9	54.5	14.3	1.12	8.6	0.9

In case of *Sida hermaphrodita* Rusby, which is a perennial, only the effect of heavy metals on the amount of aerial parts yield was studied. In the first year of the experiment (1997) the plants did not germinate at VI and VII levels of soil contamination with heavy metals. However, in the second year another attempt was made to cultivate *Sida hermaphrodita* Rusby on the above mentioned treatments by planting the root seedlings instead of seeds. The data in table II show the plants adapted to these conditions. In the first year a considerable decline in *Sida* aerial parts yields was noticed in treatment V. A decrease in *Sida* aboveground part yield reached 46% in relation to the control. In the second year of the experiment a decrease in the yields of tested plant was observed at level V of soil contamination with heavy metals and amounted to 36% in relation to the control. Higher

doses of heavy metals in soil caused a stronger decrease in *Sida* yields: 61% in treatment VI and 98% in treatment VII as compared to the control. In the third year (1999) a significant decline in *Sida* aerial parts yield, approximating 26% in relation to the control, was registered also at level V of soil contamination with heavy metals. In soil treatments V-VII the decrease in aerial part yield was milder than in 1998 and reached between 52 and 54% in comparison with the control.

It was stated that amaranth could not be cultivated at soil contamination exceeding 40 mg Cd, 240 mg Pb, 120 mg Ni, 160 mg Cu and 400 mg Zn · kg<sup>-1</sup>soil d.w. Amaranth seeds sown in treatments V, VI and VII with high concentrations of heavy metals, died back immediately after germination. A decline in amaranth yield in the investigated period was noticed from the

third level of soil contamination with heavy metals. A significant decrease in top parts yield in treatment III reached 12% in 1997, 22% in 1998 and 19% in 1999 in relation to the control respectively. In treatment VI a decrease in amaranth aerial parts yield was greater in 1997-1999 and reached 47%, 52% and 50% in comparison with the control respectively. Diversification of heavy metal dose in soil affected also the amount of root yield. In the studied period (1997-1999) a noticeable decline in amaranth root yield was obtained also from the third level of soil contamination with heavy metals. The decrease reached 11% in 1997, 11% in 1998 and 12% in 1999 in comparison with the control respectively. At the fourth level of soil contamination the decrease in root yield was respectively: 50%, 53% and 45% in relation to the control.

A high level of soil contamination with heavy metals in treatments VI and VII caused hemp seeds to die-back immediately after germination. Heavy metal toxic effect on hemp yield became apparent from the second level of soil contamination. In comparison with the control the decline in aerial parts yield in treatments II-V was between 9% and 96% in 1997, 11%-97% in 1998 and 14%-97% in 1999. Increasing doses of heavy metals also influenced a diversification of root dry matter yields. In the investigated period of experiment a significant decline in root yield was also registered at the second level of soil contamination with heavy metals, i.e. at 10 mg Cd, 60 mg Pb, 30 mg Ni, 40 mg Cu, and 100 mg Zn · kg<sup>-1</sup> soil d.w. The decrease in hemp root yield in treatments II-V was from 11% to 87% in 1997, 25%-91% in 1998 and 13%-93% in 1999 in relation to the control, resp.

The data in figures 1 and 2 reveal that an increase in soil concentration of heavy metals was accompanied by their increasing concentrations in the test plants. Relatively big differences of the tested metal contents became visible among the tested species already in the control and in the respective levels of soil contamination. It results from the specific tendency for heavy metal bioavailability and accumulation capacity. Heavy metal contents ranged, depending on the treatment and plant part, as follows: 0.19-29.84 mg Cd; 2.17-19.12 mg Pb; 1.58-40.59 mg Ni; 4.11-25.90 mg Cu; 15.93-222.12 mg Zn · kg<sup>-1</sup> d.m.; 0.22-70.08 mg Cd; 2.64-15.35 mg Pb; 1.16-296.65 mg Ni; 5.09-151.30 mg Cu and 33.60-724.39 mg Zn · kg<sup>-1</sup> d.m. in maize; 0.57-61.75 mg Cd; 1.48-29.22 mg Pb; 0.44-145.70 mg Ni; 2.30-35.27 mg Cu and 18.98-426.33 mg Zn · kg<sup>-1</sup> d.m. in *Sida hermaphrodita* Rusby; 1.20-60.41 mg Cd; 4.98-16.56 mg Pb; 1.10-24.87 mg Ni; 5.64-18.16 mg Cu and 73.96-417.59 mg Zn · kg<sup>-1</sup> d.m. in amaranth; 0.32-31.48 mg Cd; 2.69-32.13 mg Pb; 1.99-76.52 mg Ni; 4.90-38.09 mg Cu and 19-267.33 mg Zn · kg<sup>-1</sup> soil d.m. in hemp (figures 1 and 2).

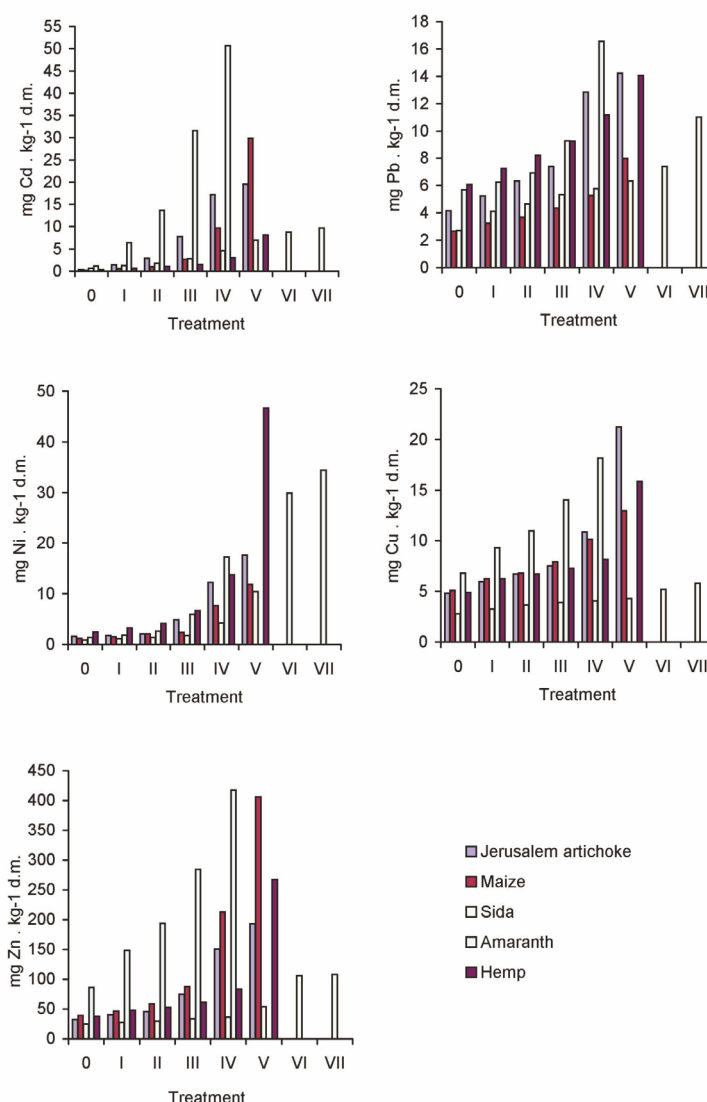
Considering heavy metal contents in their top parts,

the plants may be ranked from the highest to the lowest values in the following order: for Cd: amaranth, maize, Jerusalem artichoke, *Sida hermaphrodita* Rusby, and hemp; for Pb: amaranth, Jerusalem artichoke, hemp, *Sida hermaphrodita* Rusby and maize; for Ni: hemp, *Sida hermaphrodita* Rusby, Jerusalem artichoke, amaranth and maize; for Cu: Jerusalem artichoke, amaranth, hemp, maize and *Sida hermaphrodita* Rusby; for Zn: amaranth, maize, hemp, Jerusalem artichoke and *Sida hermaphrodita* Rusby. Root concentrations of heavy metals in the tested plants were more diversified than in their top parts. The plant ranking according to their highest to lowest element concentrations looked as follows: for Cd: maize, *Sida hermaphrodita* Rusby, amaranth, hemp and Jerusalem artichoke; for Pb: hemp, *Sida hermaphrodita* Rusby, Jerusalem artichoke, maize and amaranth; for Ni: maize, *Sida hermaphrodita* Rusby, hemp, Jerusalem artichoke and amaranth; for Cu: maize, hemp, *Sida hermaphrodita* Rusby, Jerusalem artichoke and amaranth; for Zn: maize, *Sida hermaphrodita* Rusby, Jerusalem artichoke and hemp.

## DISCUSSION

The effect of soil heavy metals on the plant yield reported in the paper was highly diversified. Inter-specific differences in the yields were found also by BARAN (2000) and GAMBUS (1997a). Negative effects of high concentrations of heavy metals on the growth, development and yield of plants is a well known phenomenon (JASIEWICZ and ANTONKIEWICZ, 2000ab, KABATA-PENDIAS and PENDIAS, 1999). Studies conducted by other authors also revealed that at high soil concentrations of heavy metals plants take up considerable amounts of elements but at the same time a rapid decrease of biomass occurs (BORKOWSKA and STYK, 1997, GRZEBISZ et al., 1998 a,b, JASIEWICZ and ANTONKIEWICZ, 1999).

The plants are characterised by species dependent differences in the ability of heavy metal uptake and different tolerance to their high concentrations (KABATA-PENDIAS and PENDIAS, 1999, WÓJCIK and TUKENDORF, 1995). Different specific plant resistance to heavy metal contents in soil was also observed in the studies of GALLER (1992) and GAMBUS (1997b). Inhibitory influence of heavy metals on growth and development of plant top parts and roots is also very important for reclamation and phytoremediation processes in chemically polluted areas (BREJ and FABISZEWSKI, 1983, BORKOWSKA and STYK, 1997). Obtained results confirmed the earlier information about a considerable diversification in the element contents depending on the plant species and analysed plant parts. An increased heavy metal concentration increased in soil



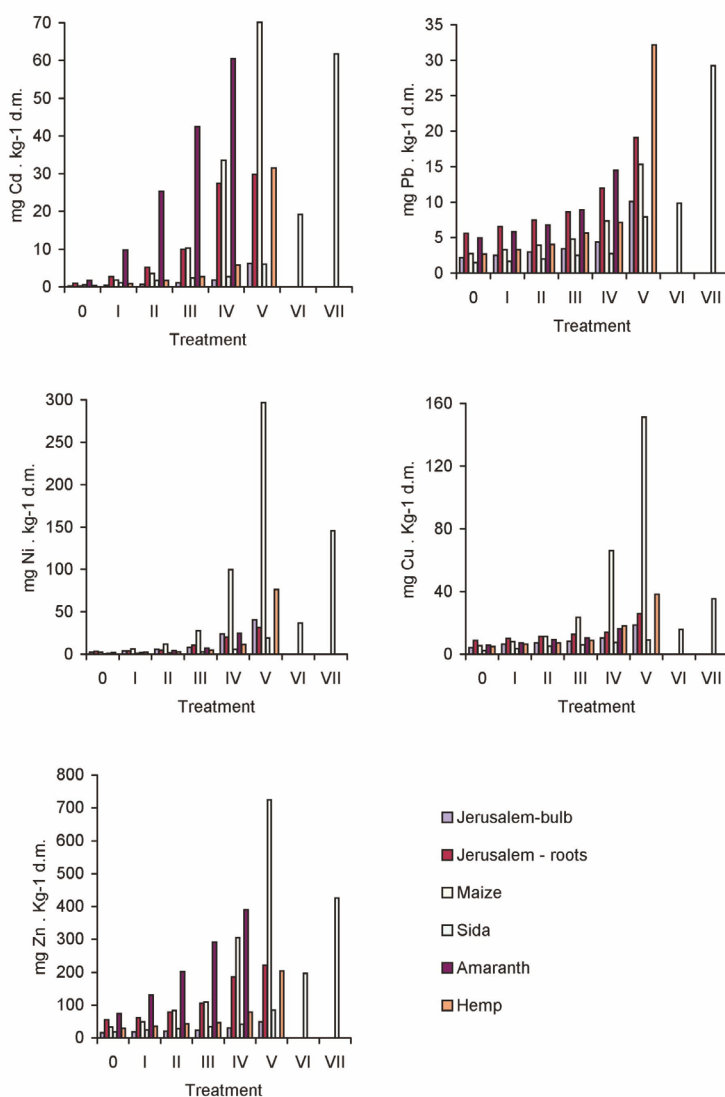
1: Concentration of heavy metals in aerial parts (mean values, 1997-1999)

correlates with enhanced metal contents in plants. Relatively large differences in heavy metal contents were revealed among plant species from the unpolluted soil and those grown in soil with various levels of contamination.

### CONCLUSIONS

Results obtained from the conducted pot experiments allow the following conclusions:

1. A high diversification in plant yield as depending on the level of soil contamination with heavy metals was found. A significant decline in the plant yield was registered for maize and hemp from the second level, for Jerusalem artichoke and amaranth from the third level and for *Sida hermaphrodita* from the fifth level of soil contamination with heavy metals.
2. A strong differentiation in the contents of heavy metals was found as depending on the plant species. The contents of heavy metals in the tested plant species correlated also with the level of soil contamination and increased with raising heavy metal concentrations in soil.
3. An ability for heavy metal accumulation in the aerial parts at the highest tolerated level of soil contamination with heavy metals decreases in the following order:
  - Cadmium: amaranth > maize > Jerusalem artichoke > *Sida hermaphrodita* Rusby > hemp
  - Lead: amaranth > Jerusalem artichoke > hemp > *Sida hermaphrodita* Rusby > maize



2: Concentration of heavy metals in roots (mean values, 1997-1999)

- Nickel: hemp > *Sida hermaphrodita* Rusby > Jerusalem artichoke > amaranth > maize
  - Copper: Jerusalem artichoke > amaranth > hemp > maize > *Sida hermaphrodita* Rusby
  - Zinc: amaranth > maize > hemp > Jerusalem artichoke > *Sida hermaphrodita* Rusby
4. Ability for heavy metal accumulation in plant roots at the highest tolerated level of soil contamination with heavy metals decreases in the following order:
- Cadmium: maize > *Sida hermaphrodita* Rusby > amaranth > hemp > Jerusalem artichoke
  - Lead: hemp > *Sida hermaphrodita* Rusby > Jerusalem artichoke > maize > amaranth
  - Nickel: maize > *Sida hermaphrodita* Rusby > hemp > Jerusalem artichoke > amaranth
  - Copper: maize > hemp > *Sida hermaphrodita* Rusby > Jerusalem artichoke > amaranth
  - Zinc: maize > *Sida hermaphrodita* Rusby > Jerusalem artichoke > hemp



## SOUHRN

## Využití rostlin akumulujících těžké kovy při detoxikaci chemicky kontaminovaných půd

Problematika akumulace těžkých kovů rostlinami byla řešena v letech 1997-1999 formou nádobových pokusů se sprašovou půdou ve vegetační hale. Pokusnými rostlinami byl topinambur, kukuřice, sida, laskavec a konopí. Výsledky potvrdily velké rozdíly v obsazích těžkých kovů v závislosti nejen na rostlinném druhu, ale také na analyzované části jednotlivých rostlin. Současně byla prokázána závislost rostoucí koncentrace těžkých kovů v rostlinách na zvyšujícím se obsahu těžkých kovů v půdě. Významné rozdíly byly zaznamenány také mezi rostlinami pěstovanými na půdě nezatížené těžkými kovy a na půdách s různou kontaminací.

detoxikace, těžké kovy, kontaminované půdy, rostliny, *Helianthus tuberosus* L., *Zea mays* L., *Sida hermaphrodita* Rusby, *Amaranthus* L., *Cannabis sativa* L., topinambur, kukuřice, sida, laskavec, konopí

## REFERENCES

- BARAN, S.: Ocena stanu degradacji i rekultywacji gleb. Wyd. AR w Lublinie, 2000, pp.244.
- BREJ, T., FABISZEWSKI, J.: Testy wzrostu i rozwoju korzeni w ocenie skażenia roślin metalami ciężkimi. Bioindykacja skażeń przemysłowych i rolniczych. Materiały pokonferencyjne pod redakcją J. Fabiszewskiego. PAN oddział we Wrocławiu. Komisja Nauk o Ziemi, Wrocław, 1983, 223-236.
- BORKOWSKA, H., STYK, B.: Ślázowiec pensylwański (*Sida hermaphrodita* Rusby). Uprawa, wykorzystanie. Wyd. AR Lublin, 1997, pp.50. ISBN 83-86761-63-6.
- GALLER, J.: Schwermetalltransfer in der Nahrungskette. Der Förderungsdienst, Beratungsservice, 1992, 9, 61-69.
- GAMBUŚ, F.: Pobieranie metali ciężkich przez różne gatunki roślin uprawnych. Cz. I. Wrażliwość roślin na metale ciężkie. Acta Agr. et Silv., ser. Agr., 1997a, vol. 35, 21-29. PL ISSN 0065-0919.
- GAMBUŚ, F.: Pobieranie metali ciężkich przez różne gatunki roślin uprawnych. Cz. II. Akumulacja metali ciężkich przez rośliny. Acta Agr. et Silv., ser. Agr., 1997b, vol. 35, 31-44. PL ISSN 0065-0919.
- GRZEBISZ, W., DIATTA, J.B., BARŁÓG, P.: Ekstrakcja metali ciężkich przez rośliny włókniste z gleb zanieczyszczonych emisjami huty miedzi. Cz. I. Konopie siewne. Zesz. Probl. PNR., 1998a, vol. 460, 685-695.
- GRZEBISZ, W., POTARZYCKI, J., CIEŚLA, L.: Ekstrakcja metali ciężkich przez rośliny włókniste z gleb zanieczyszczonych emisjami huty miedzi. Cz. II. Len. Zesz. Probl. PNR., 1998b, vol. 460, 697-708.
- JASIEWICZ, CZ., ANTONKIEWICZ, J.: Badania nad możliwością wykorzystania ślázowca pensylwańskiego (*Sida hermaphrodita* Rusby) do rekultywacji terenów zdegradowanych chemicznie. Zesz. Nauk. AR w Krakowie, 1999, Nr 349, Sesja Naukowa z.64,157-163.
- JASIEWICZ, CZ., ANTONKIEWICZ, J.: Ekstrakcja metali ciężkich przez rośliny z gleb zanieczyszczonych metalami ciężkimi. Cz. I. Ślázowiec pensylwański (*Sida hermaphrodita* Rusby). Zesz. Probl. PNR., 2000a, vol. 472, 323-330.
- JASIEWICZ, CZ., ANTONKIEWICZ, J.: 2000b. Ekstrakcja metali ciężkich przez rośliny z gleb zanieczyszczonych metalami ciężkimi. Cz. II. Konopie siewne (*Cannabis sativa*). Zesz. Probl. Post. Nauk Roln., 2000b, vol. 472, 331-339.
- KABATA-PENDIAS, A., PENDIAS, H.: Biogeochemia pierwiastków śladowych. Wyd. Nauk. PWN, Warszawa, 1999, pp. 398. ISBN 83-01-12823-2.
- KUCHARSKI, R., SAS-NOWOSIELSKA, A., POGRZEBA, M., MALKOWSKI, E.: Technology of phytoextraction of lead and cadmium in Poland. Problems and achievements. Fourth International Symposium and Exhibition on Environmental Contamination in Central and Eastern Europe. Warsaw, 1998, Proceedings, 55.
- KUCHARSKI, R., SAS-NOWOSIELSKA, A., POGRZEBA, M., KRYŃSKI, K., MALKOWSKI, E.: Perspektywy stosowania metody fitoekstrakcji do oczyszczania gleb w warunkach polskich. Ochr. Środ. i Zasob. Natur. vol. 1999, 18, 469-475.
- NALBORCZYK, E.: Biologia amarantusa oraz perspektywy jego uprawy i wykorzystania w Polsce. *Amaranthus*. Nowe rośliny uprawne. Wyd. SGGW, Warszawa, 1995, 8-28.
- OSTROWSKA, A., GAWLIŃSKI, S., SZCZUBIALKA, Z.: Metody analizy i oceny właściwości gleb i roślin. Katalog. Wyd. IOŚ, Warszawa, 1991, pp.334.
- SAS-NOWOSIELSKA, A.: Występowanie zjawiska stresu u roślin podczas oczyszczania gleb metodą fitoekstrakcji. Zesz. Probl., PNR, 1999, vol. 469, 481-488.

SIUTA, J.: Gleba, diagnozowanie stanu i zagrożenia. Wyd. IOŚ, Warszawa, 1995, pp. 219. ISBN 83-85-805-27-3.

WÓJCIK, A., TUKENDORF, A.: Strategia unikania stresu w odporności na metale ciężkie. Wiad. Bot., 1995, vol. 39(3/4), 33-40.

#### Address

Dr. inż. Jacek Antonkiewicz, Prof. Dr. hab. Czesława Jasiewicz, Katedra zemědělské chemie, Zemědělská univerzita v Krakově, ul. Mickiewicza 21, 31-120 Krakov, Polská republika, Ing. Pavel Ryant, Ph.D., Ústav agrochemie a výživy rostlin, Mendelova zemědělská a lesnická univerzita v Brně, Zemědělská 1, 613 00 Brno, Česká republika