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PHYTOEXTRACTION OF HEAVY METALS FROM SEWAGE SLUDGE BY PLANTS

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Abstract

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In 2008 and 2009, studies made contents of cadmium and lead in the soil and their uptake by non-traditional plants were studied in a small-plot trial. At the same time also the effect of bio-algeen preparations on phytoextraction of heavy metals by these plants was investigated. Experimental plots were established on the reclaimed land after closing down mining operations in the town of Žacléř (North-East Bohemia) where a layer of sewage sludge from a wastewater treatment plant 0.6–0.8 m thick was subsequently applied. The locality is situated in the altitude of 612 m, its average annual temperature is about 6.8 °C and the mean annual precipitations are 857 mm.
Analyses revealed higher concentrations of heavy metals in the applied sewage sludge. The average concentrations of lead and cadmium were 180 mg.kg^{-1} and 6.89 mg.kg^{-1}, respectively. The experiment had two variants: Variant 1 – sewage sludge without any other substances, and Variant 2 – sewage sludge + bio-algeen preparations (B. A. S-90 or B. A. Root Concentrate). To find the most suitable plant species for the phytoextraction of cadmium and lead, the following non-traditional plants were cultivated in both variants: fodder mallow (*Malva verticillata* L.), rye (*Secale cereale* L. *var. multicaule* METZG. *ex* ALEF.) and white sweet clover (*Melilotus alba* MEDIC.). The highest accumulation of cadmium and lead in the aboveground biomass was found out in rye, viz 14.89 mg.kg^{-1} DM and 14.89 mg.kg^{-1} DM of Cd and Pb, respectively., As compared with other plants under study, white sweet clover exhibited the significantly lowest capability to extract both heavy metals from soil (viz 0.22 and 3.20 mg.kg^{-1} DM of Cd and Pb, respectively). A positive effect of bio-algeen on phytoextraction of cadmium and lead was evident in all plants. The highest yield of aboveground biomass was recorded on the plot with white sweet clover with added alginate (496 g.m^{-2}). Of plants under study, the fodder mallow seems to be the most suitable crop for the phytoextraction of both metals (0.35 and 5.87 mg.m^{-2} of Cd and Pb, respectively).

phytoextraction, phytoremediation, sewage sludge, cadmium, lead, bio-algeen, non- traditional plants

Soil contamination is caused by both organic and inorganic substances. Soil contamination is defined as soil pollution caused mostly by contaminants (foreign, often toxic substances) such as heavy metals, petroleum-based substances, solvents, polyaromatic substances, etc. The occurrence of contaminants may vary considerably. They penetrate into the soil either during emergencies such as accidents, dump lakes, floods, or may be caused by previous agricultural and non-agricultural land uses, e.g. abandoned dump sites and storage places (Raclavská, 1998). Repeated use of metal-enriched chemicals, fertilizers and organic amendments such as sewage sludge as well as wastewater may cause a large-scale contamination (He *et al*., 2005; Čásová *et al*., 2009).

On the other hand, a proper land utilization and application of stabilized sewage sludge may positively influence agriculture, forestry, horticulture, and city development. Heavy metals, organic pollutants and pathogens concentrated in sewage sludge during wastewater treatment are the main obstacles to land application of sewage sludge (Wang, 1997). Limit values for the concentration of heavy metals in

soil and sludge are defined in the Council Directive 86/278/EEC.

Rather than by the idea of sustainability (Horn *et al.*, 2003), the decision to apply organic wastes on agricultural land should be governed by the knowledge of the resource characteristics of the soils on a regional scale, i. e. their specific local potential to buffer the input of heavy metals.

Časová *et al.* (2009) studied the cadmium balance between its input and removal in a long-term field trial with sewage sludge application. They found out that of the total amount of cadmium that got into the soil by sewage sludge application only a small portion was removed during the harvest of cultivated crops. They also pointed out that the cadmium uptake was significantly affected by soil conditions.

Roselli *et al.* (2003) studied the capability of woody species to extract heavy metals from the sewage sludge compost polluted soil and accumulate them in their aboveground tissues. Estimated was content of metals in leaves and twigs was determined.

The sewage sludge compost used as a substrate component in an experiment performed by Manios *et al.* (2003) was highly contaminated with heavy metals which, however, did not impose any significant effect on the development and growth of cattails (*T. latifolia*) plants.

The objective of this study was to investigate phytoextraction of cadmium and lead from sludge-contaminated soils with regard to the capability of plants to absorb and subsequently accumulate hazardous substances in their aboveground biomass. The effect of application of supportive bio-algeen substances on the uptake of these metals by plants was also examined. Bio algeen-based products represent a hydrolyzate of brown alga seaweed *Ascophyllum nodosum* and contain a concentrate of specific plant gels and natural polysaccharides composed of polyuron acids of seaweed (Vostoupal *et al.*, 2007). Moreover, their molecular structure is identical with grey humic acid, which constitutes, for example with fine soil particles, a favourable clay-humus complex. Besides, bio-algeen products serve as micro-biostimulants and, predominantly, as a nutrient medium for mycorrhizal communities (Vostoupal, 2007).

MATERIALS AND METHODS

In 2007, a small-plot trial was established in the locality of a former coal mine at Žacléř (N-E Bohemia) to study extraction capabilities of plants. In this locality, operations connected with land reclamation and re-development were carried out. Their main objective was to remove physical residues of the mining activity and reduce impacts of former mining activities (sludge ponds, gangue mineral deposits etc.). Besides, also other reclamation, sanitary and re-developmental operations were performed. The locality is situated at an altitude of 612 m, its average annual temperature is about 6.8 °C and the mean annual precipitations are 857 mm.

The trial was established on a sewage sludge layer (Wastewater Treatment Plant in Nové Město nad Metují), where sewage sludge was spread evenly over the reclaimed area. The thickness of the sludge layer was about 0.6–0.8 m and the sludge was mixed with soil in the ratio 10:1 (sludge: soil) just with the aim to establish experimental plots. The size of each plot was cca 4 m^2.

A trial with two variants was designed to study phytoextraction of heavy metals by plants

Variant 1 – sewage sludge without alginate application

Variant 2 – sewage sludge + alginate application.

A bio-algeen preparation or alginate is a supportive substance or a plant growth promoter.

Bio algeen-based products are concentrates of selected plant gels and natural polysaccharides composed of polyuron acids of seaweed *Ascophyllum nodosum*. Additionaly, this seaweed contains a wide spectrum of biologically active substances: amino acids, peptides, organic acids, mineral substances, trace elements and phytohormones (auxins).

Two alginate products were used in the experiment: (i) B. A. S – 90, which stimulates root system development and is a necessary precondition of good shoot development and higher resistance to drought, diseases and pests and (ii) B. A. Root Concentrate, which is used to activate the root system. It acts in close vicinity of rootlets as gray humic acid and also as a nutrient medium for mycorrhiza.

To determine the most suitable phytoextractive capability, non-traditional plants were sown because of their rapid shoot growth. The plants were bred and selected developed in the Research Institute for Fodder Crops, Ltd.

1. White sweet clover (*Melilotus alba* MEDIC.) (Fig. 1):

An annual form of the biennial population of sweet clover; its stem is upright and grows to the height of 15 or more centimeters. It grows well also on less fertile or barren soils and does not tolerate waterlogged and very heavy soils. It is cultivated as a forage crop, a land reclamation crop for infertile

1: *White sweet clover*

soils, and/or a good green-manure crop. It is grown either as a monoculture or in mixtures with kidney vetch (*Anthyllis vulneraria*) and crimson clover. In monocultures, the sowing rate is 20 kg.ha^{-1}.

2. Fodder mallow (*Malva verticillata* L.) (Fig. 2):

An annual forage crop of the family *Malvaceae*, the stem is upright and resistant to lodging; in high density stands it does not branch while in low density stands it branches from the base. It has no special requirements for soil; the most suitable are deeper soils with good seedbed preparation, good soil water conditions, sufficient amount of lime, and well-balanced content of nutrients. As a late catch crop it should be sown by the end of August at the latest. It is sown into rows 12.5–25 cm wide; its sowing rate is 15 kg.ha^{-1}, and the sowing depth 1–2 cm. Dicotyledonous weed control is based on the methodologies and guidelines laid down by the Central Institute for Supervising and Testing in Agriculture (ÚKZÚZ).

2: *Cluster mallow*

3. Rye (*Secale cereale* L. *var. multicaule* METZG. *ex* ALEF.) (Fig. 3):

A forage crop belonging to the family *Poaceae*; it has no special soil and/or climatic requirements.

3: *Rye*

By autumn, it attains a height of 20 to 30 cm. It has a longer growing period, extensive tiller formation and rich foliage. It is sown into rows 12.5 cm wide into the depth of 3–5 cm, and its sowing rate is 100–150 kg.ha^{-1}; the sowing date is best before the end of August. Weed control is the same as in other cereal crops.

The seed was incorporated into soil manually by even spreading over the surface and subsequent incorporation with the aim of creating more favourable conditions for the emergence of tested plant stands. In Variant 2, a dose of 100 ml of algeen product B. A. S-90 mixed with 10 l of water was applied to white sweet clover and rye. A dose of 100 ml of alginate in the form of B. A. Root Concentrate mixed with 10 l water was applied to fodder mallow. At the same time starting soil samples were collected and analysed for cadmium and lead content in soil; concentrations of these metals in the aboveground biomass were estimated as well. In each variant, the aboveground biomass was sampled in three improper replications. Soil and biomass samples were taken after the end of flowering and decomposed in concentrated hydrogen nitrate with added hydrogen peroxide and concentrations of cadmium and lead were determined by atomic emission spectrometry according to ČSN EN ISO 11885 in the accredited laboratory of GEOtest, a.s. in Brno.

Results of initial analysis of soil mixture: lead – 180 mg.kg^{-1}, and cadmium – 6.89 mg.kg^{-1}. Soil pH_{KCl} was neutral (7.6); the content of phosphorus low (39 mg.kg^{-1}) while contents of potassium and magnesium were very high (953 mg.kg^{-1} and 1,920 mg.kg^{-1}; respectively). The total content of nitrogen (N) was very low (0.46 %) and that of combustible substances was 17.11 %.

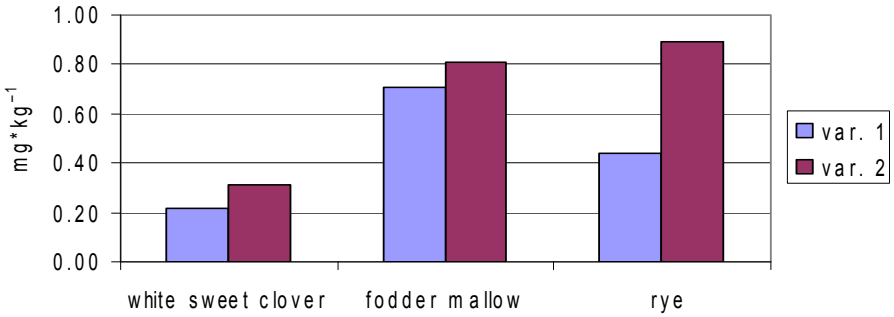
Experimental results were obtained in years 2008–2009.

RESULTS AND DISCUSSION

Experimental results were statistically evaluated by multifactorial analysis of variance and then by Tukey's tests of simple contrasts. The relationships between individual traits under study were evaluated by means of correlation analysis. For statistical analysis, the program Statistica 7.1 was used.

The results obtained when monitoring the uptake of heavy metals by plants in years 2008–2009 are graphically presented in Figs 4 and 5. These data represent averages of three replications. Contents of heavy metals in the aboveground biomass are given in mg per kg of dry matter (DM). Contents of cadmium (Cd) and lead (Pb) in plants ranged from 0.22 to 0.89 mg.kg^{-1} DM and from 3.20 and 14.89 mg.kg^{-1} DM, respectively.

The highest content of Cd in the aboveground biomass (Fig. 4) was found out in rye, Variant 2 (i. e. with alginate addition). On average, the highest Cd uptake was found out in both variants of fodder mallow crop. The difference between both variants of rye crop was statistically significant (Tabs I, II).



4: *Cadmium content in the aboveground biomass of plants (mg.kg^{-1} DM) – averages of years 2008–2009*

The obtained results indicated that the application of alginate products caused a considerable increase in Cs uptake by plants. This increase was manifested also in white sweet clover and fodder mallow crops; however, in these crops the results were statistically not significant. As compared with other plant species, the lowest statistically significant uptake of Cd was found in both variants of the white sweet clover experiment (Tab. III).

I: *Analysis of variance for contents of cadmium and lead in the aboveground biomass*

Efect	Cadmium		Lead	
	d.f.	Mean square	d.f.	Mean square
Year	1	0.1314**	1	5.507 n.s.
Crop	2	0.81434***	2	198.617***
Variant	1	0.43340***	1	267.977***
Replication	2	0.00085 n.s.	2	0.403 n.s.
Year * Crop	2	0.05234 n.s.	2	22.402 n.s.
Year * Variant	1	0.00562 n.s.	1	21.099 n.s.
Crop * Variant	2	0.12841**	2	36.862 n.s.
Year * Replication	2	0.00272 n.s.	2	1.216 n.s.
Crop * Replication	4	0.00069 n.s.	4	0.433 n.s.
Variant * Replication	2	0.00028 n.s.	2	0.843 n.s.

Note: *** P = 0.001; **P = 0.01; *P = 0.05; n.s. non-significant

II: *Multiple range analysis for crop and variant (cadmium) (Method: 95 LSD)*

Crop	d.f.	Average content of Cd
White sweet clover	1	0.216667[a]
	2	0.315000[a]
Rye	1	0.435000[a]
	2	0.893333[b]
Fodder mallow	1	0.705000[b]
	2	0.806667[b]

Note: Average values indicated by various letters are statistically significantly different (P = 0.05)

III: *Multiple range analysis for crop (Method: 95 LSD)*

Crop	Average value	
	Cadmium	Lead
White sweet clover	0.265833[b]	4.33583[b]
Rye	0.664167[a]	8.85750[a]
Fodder mallow	0.755833[a]	12.45500[a]

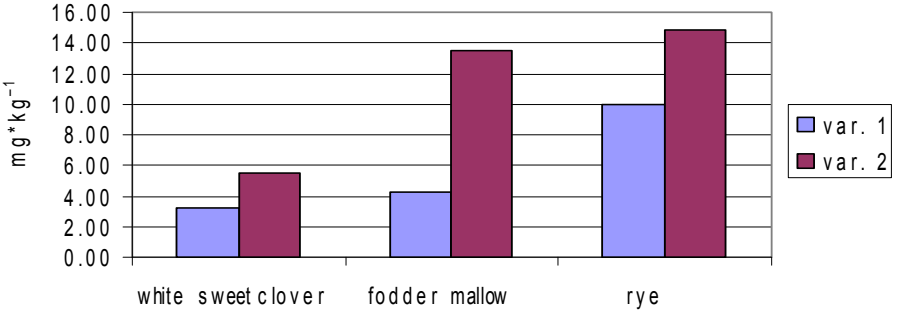
Note: Average values indicated by various letters are significantly different (P = 0.05)

The highest average content of Pb in the aboveground biomass (Fig. 5) was also found in rye (Variant 2, i.e. with alginate addition). As compared with other plant species, in this crop the phytoextraction of Pb by this plant was the highest (the average value of both variants).

When evaluating the average value of both variants of the experiment with white sweet clover, the lowest statistically significant capability of Pb phytoextraction by aboveground biomass was found out just in this plant species (Tab. III). The lowest content of Pb was found in Variant 1 (i.e. without alginate application) of experiments with all three species. The application of alginate preparations showed a positive effect on all plant species under study, even though the observed differences were statistically not significant.

As compared with other plant species, the lowest statistically significant uptake of cadmium was found our in both variants of the experiment with white sweet clover (Tab. III).

After the statistical evaluation of the difference between both variants regardless to the plant spe-



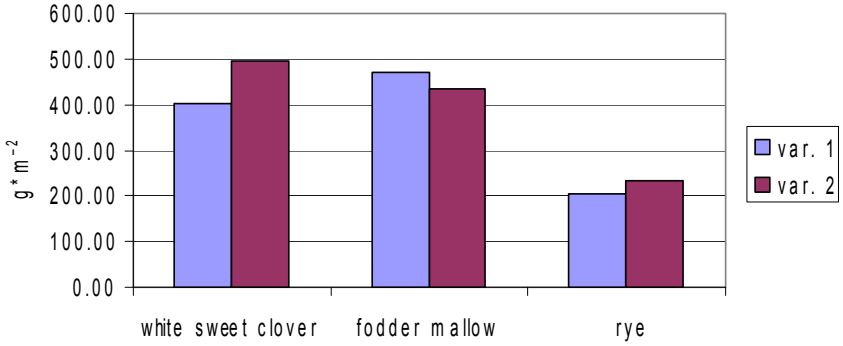
5: *Lead content in the aboveground biomass (mg.kg^{-1} DM)*

IV: *Multiple range analysis for variants (Method: 95 LSD)*

Variant	Average Cd	Average Pb
1	0.452222[a]	5.82111[a]
2	0.671667[b]	11.27778[b]

Note: Average values indicated by various letters are statistically significantly different (P = 0.05)

cies and year it was possible to conclude that there was a significant increase in Cd and Pb uptake in Variant 2 (i.e. with application of alginate preparations; Tab. IV). The obtained results indicated that the application of a large amount of sewage sludge may result in soil contamination with heavy metals; however, this contamination may be partially eliminated by phytoextraction. Similar conclusions were



6: *Yield aboveground biomass (g.m^{-2})*

V: *Analysis of variance for content of yield of the aboveground biomass (g.m^{-2})*

Effect	Yield	
	d.f.	Mean square
Year	1	263169 ***
Crop	2	217977 ***
Variant	1	7511 n.s.
Year * Crop	2	56101 **
Year * Variant	1	14803 n. s.
Crop * Variant	2	12229 n. s.

*** P = 0.001; **P = 0.01; *P = 0.05; n. s. = non significant

VI: *Multiple range analysis for crop (Method: 95 LSD)*

Crop	Average yield
Rye	218.5000[b]
White sweet clover	450.0000[a]
Fodder mallow	453.8333[a]

Average values indicated by various letters are significantly different (P = 0.05)

also mentioned by Čásová *et al.* (2009). However, if properly managed, the incorporation sewage sludge into soil may show a lot of beneficial effects without any risk of soil contamination (Klír *et al*, 2008; Wang, 1997), e.g. utilization of sludge nutrients. The major benefits of sludge application are, among others, an increased supply of macroelements (in particular N and P) and also some of the essential micronutrients (e.g. Zn, Cu, Mo, and Mn) as well as an improvement of the soil physical properties, i.e. better soil structure, increased soil water capacity, and improved soil water transmission characteristics (Korentajer, 1991).

The highest yield of aboveground biomass was obtained in Variant 2 of white clover crop (Fig. 6). On experimental plots with fodder mallow the yield of aboveground biomass was also higher. The lowest yields were recorded in rye. As compared with other crops, this decrease was statistically significant (Tab. VI). As far as both experimental variants were concerned, no statistically significant differences were found out in all crops (Tab. V)

The suitability of individual crops for the phytoextraction of Cd and Pb was evaluated on the base of the total uptake of these metals per unit area ($mg.m^{-2}$). The obtained results are presented in Tab. VII. As far as the phytoextraction of Cd was concerned, fodder mallow showed to be the most suitable crop due to its higher yields and a better capability to accumulate Cd per unit area (0.35 $mg.m^{-2}$) while fodder mallow and rye were the most suitable for uptake of Pb (5.87 and 3.48 $mg.m^{-2}$, respectively). Although the yields of rye were low, it was clearly demonstrated that its capability to accumulate this heavy metal is high,

Various authors (e.g. Ewais, 1997; Sharma and Gaur, 1995) mentioned that each plant species has as different threshold capability to accumulate heavy metals. In case that this limit is exceeded, the toxic effects of these elements on plants are manifested (e.g. growth inhibition, decreased content of chlorophyll etc.). For that reason there are efforts to select such plant species that can produce sufficient amounts of biomass on the one hand and withstand unfavourable environmental conditions on the other.

Although yields of white sweet clover were higher, the total content of heavy metals under study in its biomass was very low. This means that this plant species seems to be the least suitable crop for the phytoextraction of Cd and Pb from soils contaminated with sewage sludge.

It is possible to conclude that alginate preparations showed a positive effect on phytoextraction of Cd an Pb by plant species under study. The application of alginates influenced positively accumulation of both these heavy metals in the aboveground biomass of plants.

VII: *Total uptake of cadmium and lead per unit area ($mg.m^{-2}$)*

Crop	Variant	Cd ($mg.m^{-2}$)	Pb ($mg.m^{-2}$)
White sweet clover	1	0.0876	1.2918
	2	0.1555	2.7027
Fodder mallow	1	0.3321	2.0010
	2	0.3517	5.8715
Rye	1	0.0885	2.0391
	2	0.2086	3.4768

SUMMARY

The objective of our research was to study phytoextraction of cadmium and lead from sludge-contaminated soils basing on the capability of non-traditional plants to uptake hazardous substances and subsequently to accumulate them in their aboveground biomass. Simultaneously, the effect of supportive bio-algeen preparations on the extraction capability of these plants was also studied. Experimental plots were established on the reclaimed area after closing down coal mining operations in Žacléř (N-E Bohemia) and subsequent application of a layer of sewage sludge from the wastewater treatment plant (0.6–0.8m thick). The size of a plot was ca 4 m^2. The soil analyses showed that the average concentrations of lead and cadmium were 180 $mg.kg^{-1}$ and 6.89 $mg.kg^{-1}$, respectively. The locality is situated at an altitude of 612 m, its average annual temperature is about 6.8 °C and the mean annual precipitations are 857 mm. The experiment involved two variants: Variant 1 – sewage sludge without any other substances, Variant 2 – sewage sludge with bio-algeen preparations (B. A. S-90 or B. A. Root Concentrate). The bio-algeen product is a concentrate of specific plant gels and natural polysaccharides composed of polyuron acids of brown alga seaweed (*Ascophyllum nodosum*), which is a plant growth promoter. The experiment involved some non-traditional plants which were developed in the Research Institute for Fodder Crops Ltd. They are as follows: fodder mallow (*Malva verticillata* L.), rye (*Secale cereale* L. *var. multicaule* METZG. *ex* ALEF.) and white sweet clover (*Melilotus alba* MEDIC.). In Variant 2 with white sweet clover and rye, 100 ml of algeen preparation B. A. S-90 mixed with 10 l of water was applied while in fodder mallow Variant 2, 100 ml of alginate in the form of B. A. Root Concentrate mixed with 10 l of water was applied. At the same time soil samples for were collected and analysed for concentrations of cadmium and lead in aboveground biomass of plants were estimated. Samples of aboveground biomass were taken as three improper replications of each variant. During a two-year study of cadmium and lead uptake by aboveground biomass of non-traditional plants it was found out that phytoremediation of contaminated soils by plants is feasible. The highest cadmium and lead uptake was reported in rye in Variant 2 with alginate (14.89 and 14.89 $mg.kg^{-1}$ DM of Cd and Pb, respectively). As for cadmium, the difference between both variants was statistically significant. As compared with other species under study, white sweet clover contained the significantly lowest amounts of cadmium and lead (0.22 and 3.20 $mg.kg^{-1}$ of Cd and Pb, respectively). Variant 2 with alginate showed a positive effect on cadmium and lead phytoextraction in all test plants. The obtained results suggest a possibility of using alginates as supportive agents for phytoextraction of heavy metals from soil. The highest yield of aboveground biomass was obtained in experiment with white sweet clover, Variant 2 with alginate (496 $g.m^{-2}$). However, due a low uptake of heavy metals this crop showed to be the least suitable for the phytoextraction of these elements. The best results with the total uptake of both Cd and Pb (as expressed by the content of both metals under study per unit of yield) were obtained in fodder mallow (i.e. 0.35 and 5.87 $mg.m^{-2}$ of Cd and Pb, respectively).

SOUHRN

Fytoextrakce těžkých kovů z odpadních kalů rostlinami

Předmětem našeho výzkumu byla metoda fytoextrakce kadmia a olova z kaly znečištěných půd založená na schopnosti netradičních rostlin přijímat a následně v nadzemní biomase akumulovat rizikové látky. Současně byl sledován vliv aplikovaných podpůrných bio-algeenových látek na fytoextrakční účinky těchto rostlin. Pokusné parcely byly založeny na rekultivované ploše po ukončené důlní činnosti v Žacléři a následném navežení kalu z ČOV ve vrstvě 0,6–0,8 m. Velikost 1 parcely činila cca 4 m^2. Podle provedených analýz půdy průměrné hodnoty olova činily 180 mg/kg a kadmia 6,89 mg/kg. Lokalita se nachází ve výšce 612 m n. m, průměrná roční teplota je zde kolem 6,8 °C a průměrné roční srážky činí 857 mm.V rámci pokusu byly založeny dvě varianty: Varianta 1 – kal bez aplikace dalších látek, Varianta 2 – kal s aplikací bioalgeenového přípravku (B. A. S-90 či B. A. Kořenový koncentrát). Bioalgeenový přípravek je koncentrát specifických rostlinných gelů a přírodních polysacharidů, složených z polyuronových kyselin hnědé mořské řasy *Ascophyllum nodosum*, který má stimulační vliv na růst rostlin. Vybrané netradiční rostliny pro testování byly vyšlechtěny ve Výzkumném ústavu pícninářském, spol. s r. o. Jedná se o sléz krmný (*Malva verticillata* L.), žito trsnaté (*Secale cereale* L. *var. multicaule* METZG. *ex* ALEF.) a komonice jednoletá (*Melilotus alba* MEDIC.). U varianty 2 u komonice bílé a žita trsnatého bylo aplikováno 100 ml algeenového přípravku B. A. S-90 rozmíchaného v 10 l vody, u slézu přeslenitého bylo aplikováno 100 ml alginátu ve formě B. A. Kořenového koncentrátu rozmíchaného v 10 l vody. Současně byly odebrány půdní vzorky na rozbor kadmia a olova, dále bylo sledováno množství těchto kovů v nadzemní biomase. Odběr vzorků nadzemní biomasy byl proveden formou tří nepravých opakování z každé varianty. Během dvouletého sledování odběru Cd a Pb nadzemní biomasou netradičních rostlin bylo zjištěno, že je možná fytoremediace kontaminovaných půd vybranými rostlinami.

Nejvyšší odběr Cd i Pb byl zjištěn u žita svatojánského u varianty s aplikací alginátů (Cd 14,89 $mg.kg^{-1}$ sušiny, Pb 14,89 $mg.kg^{-1}$ sušiny), u Cd byl tento rozdíl mezi variantami statisticky průkazný. Komonice bílá měla průkazně nejnižší obsah kadmia i olova oproti ostatním sledovaným rostlinám (Cd 0,22 $mg.kg^{-1}$ sušiny, Pb 3,20 $mg.kg^{-1}$ sušiny). Varianta s aplikovaným alginátem celkově pozitivně ovlivnila fytoextrakci Cd i Pb u všech testovaných rostlin. Dosažené výsledky naznačují možnost využití alginátů jako podpůrné látky při fytoextrakcích těžkých kovů z půdy. Nejvyššího výnosu nadzemní biomasy dosáhla komonice bílá na variantě s přidaným alginátem (496 $g.m^{-2}$), avšak vzhledem k nízkému odběru těžkých kovů se ukázala jako nejméně vhodná plodina pro fytoextrakci těchto kovů. Jako nejvhodnější plodinou pro celkový odběr kadmia i olova (obsah kovu v biomase vztažený k výnosu) se projevil sléz krmný (Cd 0,35 $mg.m^{-2}$, Pb 5,87 $mg.m^{-2}$).

fytoextrakce, fytoremediace, odpadní kal, kdmium, olovo, bioalgeenové přípravky, netradiční rostliny

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REFERENCES

ČÁSOVÁ, K., ČERNÝ, J., SZÁKOVÁ, J., BALÍK, J., TLUSTOŠ, P., 2009: Kadmium balance in soils under different fertilization managements including sewage sludge application. *Plant Soil Environment*, 55 (8): 353–361. ISSN 1214-1178.

DOHÁNYOS, M., ZÁBRANSKÁ, J., JENÍČEK, P., 2009: Současné směry výzkumu a nakládání s kaly z ČOV. Odpadové fórum 2009 [online] [cit. 2010–04–9]. <http://www.odpadoveforum.cz/OF2009/CD2009/Program_OF.htm.>

EWAIS, E. A., 1997: Effects of cadmium, nickel and lead on growth, chlorophyll kontent and proteins of weeds. *Biologia Plantarum*, 39 (3): 403–410. ISSN 0006-3134.

HE, Z. L. L., YANG, X. E., STOFFELLA, P. J., 2005: Trace elements in agroecosystems and impacts on the environment. *Journal of Trace elements in Medicine and Biology*, 19 (3–4): 125–140. ISSN 0946-6722X.

HORN, A. L., DÜRING, R. A., GÄTH, S., 2003: Comparison of decision support systems for an optimised application of compost and sewage sludge on agricultural land based on heavy metal accumulation in soil. *The science of the Total Environment*, 311: 35–48. ISSN 0048-9697.

KORENTAJER, L., 1991: Review of the agricultural use of sewage sludge. Benefits and potentional hazards. *Water S. A.*, 17 (3): 189–196. ISSN 0378-4738.

KLÍR, J., KUNZOVÁ, E., ČERMÁK, P, 2008: Rámcová metodika výživy rostlin. Praha, 48 s. ISBN 978-80-87011-61-4.

MANIOS, T., STENTIFORD, E. I., MILLNER, P. A., 2003: The effect of heavy metals accumulation on the chlorophyll concentration of *Typha latifolia* plants, growing in a substrate containing sewage sludge compost and watered with metaliferous water. Ecological Engineering, 20: 65–67. ISSN 0925-8574.

RACLAVSKÁ, H., 1998: Znečištění zemin a metody jejich dekontaminace. Ostrava, 111 s.

ROSSELLI, W., KELLER, C., BOSCHI, K., 2003: Phytoextraction capacity of trees growing on a metal contaminated soil. *Plant and soil*, 256: 265–272. ISSN 1573-5036.

SHARMA, S. S., GAUR, J. P., 1995: Potential of *Lemna polyrrhiza* for removal of heavy metals. *Ecological Engineering*, 4: 37–43. ISSN 0925-8574.

VOSTOUPAL, B., 2007: Metodická studie o možnostech použití bioalginátových přípravků při řešení experimentů, vyplývajících z projektu WD-44-07-1. České Budějovice, 31 s.

VOSTOUPAL, B., ŠOCH, M., VRÁBLÍKOVÁ, J., ZAJÍČEK, P., HRUBÝ, J., GJUROV, V., 2007: Hydrolyzátory mořských řas použitelné v programech asanace důlních výsypek. In: *Území ovlivněné těžbou uhlí – cesty k udržitelnému rozvoji*. RE REGIONS za podpory EU, Most, 7 s. ISBN 978-80-239-9095-9.

WANG, M., 1997: Land application of sewage sludge in China. *Science of The Total Environment*, 197 (1–3): 149–60. ISSN 0048-9697.

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