The zinc mobility in three different soils amended by sewage sludge incubated with limestone and lime, and Zn uptake by oats

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ABSTRACT

The effect of sewage sludge application on three soils of different properties (Chernozems – location Suchdol, Luvisols – location Červený Újezd and Cambisols – location Humpolec) was investigated in pot experiment and the accumulation of Zn in above ground biomass of oat as well as availability of Zn released by 0.01 mol.l^{-1} $CaCl_2$ was evaluated. Stabilised sewage sludge was obtained from three wastewater factories in Czech Republic. Sewage sludge has been preincubated with addition of limestone and lime (7% of Ca w/w of sludge dry solid) in aerobic and anaerobic conditions and tested in pot experiment. The highest Zn mobility reduction was found at Humpolec soil. Sludge amended by lime and limestone reduced available Zn content in this soil (at sludge III by 86% after limestone and by 71% after lime application). Considerable reduction of Zn in plant showed in Humpolec soil treated by sludge with lime (by 20% compared with soil treated by nonincubated sludge – control) and limestone (by 30% after anaerobic incubation compared to control). The positive incubation and treatment effect was not confirmed in the other soils. Available Zn in Humpolec soil showed the strongest correlation among all soils with total Zn content in plant (at aerobic treatment $R^2 = 0.66$ and at anaerobic $R^2 = 0.83$).

Keywords: sewage sludge; zinc; oat; lime; limestone; pH; soil type

Sewage sludge is a solid waste accumulating during wastewater treatment. Worldwide growing problem is the disposal of sewage sludge. However, the recycling of waste sludges to agricultural land is a cost-effective disposal route (McGrath et al. 1999). Primary constituents as organic matter, nitrogen and phosphorus are agronomically beneficial to the crop growth, but municipal sludges always contain potentially hazardous trace elements (Kim et al. 1988).

The main factors controlling mobilization of metals in soil or sludge are pH, redox conditions (Chuan et al. 1996), organic matter, and clay mineral content (Kabata-Pendias and Pendias 1986, Alloway 1990). The length of sewage sludge decomposition in soil also controls available forms of metals, which are apparently related to decomposition of sludge (Lake et al. 1984). The ameliorative compounds such as lime are used for an increase of pH (Lubben and Sauerbeck 1991). The results showed positive effect of addition of lime to the acid soils to provide significant reduction of Zn concentrations in plant tissues (Lubben and Sauerbeck 1991, Miller et al. 1995). The addition of lime more affected content of Zn and Cd in oat biomass than bentonite application (Balík et al. 2000). The mobilization of Zn in soil is also controlled by soil microorganisms (Zamani et al. 1984). Potential Zn phytotoxicity from excess Zn input into soils exists because Zn is fairly immobile in soil and binding of Zn to unavailable forms occurs slowly in soils (Adriano 2001). The rate of element uptake by plant biomass is also substantially affected by crop species grown on different soils (Tiller 1989, Tlustoš et al. 1997, 2001).

The objective of this study was focused on the accumulation of Zn by above ground biomass of oat grown on three soils with different soil properties treated by incubated sewage sludge amended by lime and limestone and on the changes of availability of Zn in soil when sewage sludge was applied.

MATERIAL AND METHODS

The accumulation of Zn was investigated in pot experiment with three different soils treated by sewage sludge. Mean agrochemical parameters of these soils are presented in Table 1.

Stabilised sewage sludge was obtained from three wastewater factories in Czech Republic situated in towns of different population (Table 2). Three treatments were set up for each sludge: control treatment, treatment with addition of lime (7% of Ca w/w of sludge dry solid) and treatment with addition of limestone (7% Ca w/w of dry solid). Each treatment was carried out in triplication. The components of each replication were weighted separately, thoroughly mixed and homogeneous matter was inserted into the plastic pot. The amount of mixture differed in water content of sewage sludge and in added material. All treatments were incubated as follows:

- under aerobic conditions, each 14 days mixed thoroughly, air conditioned, and watered (60% of matter lost was added as water to control moisture content)
- under anaerobic conditions, homogeneic mixture was pressed into a pot, covered by plastic bag and sealed by elastic band

Table 1. Main parameters of soils used in the experiment

Location	Soil type	pH_{KCl}	$K_{Mehlich\ III}$	$Mg_{Mehlich\ III}$	$P_{Mehlich\ III}$	Zn_{total}	Zn_{CaCl_2}	C_{ox}
			mg.kg^{-1}					(%)
Suchdol	Chernozems	7.2	174	161	155	112	0.028	1.39
Č. Újezd	Luvisols	6.8	316	164	188	85.5	0.095	1.71
Humpolec	Cambisols	5.1	207	109	107	141	0.322	1.64

Table 2. Main parameters of sewage sludge at the beginning of preincubation

Sewage sludge	I	II	III
Dry matter content (%)	28	17	18
pH ($CaCl_2$)	8.01	8.21	8.00
The total Zn content (mg.kg^{-1})	1554	984	1653
Zn content in $CaCl_2$ (mg.kg^{-1})	0.515	0.883	1.35

Pots were incubated in controlled incubation room (20°C and 80% relative humidity) for four months.

Soils were passed through a 5 mm sieve, air-dried, and 5 kg of each soil (based on dry weight) was thoroughly mixed with N, P, K applied in ammonium nitrate and potassium hydrogen phosphate in control treatments and with the same amount of nutrients plus incubated sewage sludge from incubation experiment described above in equivalent to 20 t.ha^{-1}. Sewage sludge from the beginning of the incubation experiment and after four months of incubation was used.

Prepared soil + sludge mixture was placed into plastic pots, sown with oat (*Avena sativa* L., cv. Pan) and grown up to harvest. Soil moisture was regularly controlled and kept at 60% of MWHC. After harvest, above ground biomass was checked for fresh and dry biomass, grounded and analysed.

Plant material was decomposed by modified dry ashing procedure in the mixture of oxidizing gases by APION equipment (Miholova et al. 1993). Available portion of Zn was determined in the extract of 0.01 mol.l^{-1} $CaCl_2$ solution in the ratio of 1:10 (w/v) (Novozamsky et al. 1993). Content of elements was determined by atomic absorption spectrometry using flame techniques on VARIAN SpectrAA-300 equipment in laboratory of Agrochemistry and Plant Nutrition Department of Czech University of Agriculture in Prague. Quality of plant analyses was controlled by reference materials RM 12-02-03 Lucerne. Result of analysis is shown in Table 3.

RESULTS AND DISCUSSION

Figure 1 illustrates amount of available Zn in the soil treated by aerobically incubated sludge after harvest of oat. Different properties of soils and sludges affected Zn availability. As the control treatment was introduced soil treated by nonincubated sludge. The available Zn content increased in Suchdol soil (Figure 1a) treated by incubated sewage sludges II and III. In sludge treated by limestone was observed the highest increase (almost five times compare to control treatment). The different way of Zn behaviour was found at sludge I. The Zn content was decreased by 65% at treatment sewage sludge + limestone compared to control. Incubated sludge II delivered the highest amount of available Zn compared to control of all sludges into Červený Újezd soil (Figure 1b). Incubation showed positive effect on Zn content in Humpolec soil (Figure 1c). The lowest values of available Zn was reached in III and II sludge with limestone (13.6% and 35.1%, respectively compared to control) and with lime (sludge III 29% and sludge II 45.5% compared to control). This effect can be explained by changes of pH in microsites of soil + sludge and binding of Zn on surface of organic matter derived by sludge.

Figure 2 illustrates amount of available Zn in soil treated by anaerobically incubated sludge after harvest of plant. Anaerobically incubated sludge had considerably higher pH (average values for individual treatments were 7.88–9.63) than aerobically incubated sludge (6.31–7.32). The effect of anaerobically incubated sludge (Figure 2a) in Suchdol soil (pH = 7.2) was more considerable on Zn reduction compared to aerobically incubated sludge (Figure 1a). The lime application into sludge I and III in Červený Újezd soil (Figure 2b) brought about considerable reduction of available content of Zn (pH of anaerobic sludge was 9.63, aerobic 7.32). The available Zn content dropped to 45% at anaerobic sludge I treatment, meanwhile aerobic incubation increased the Zn content to 183%, both compared to control. Tlustoš (1999) reported that CaO application into soil significantly decreases Zn

Table 3. Quality control of plant and sewage sludge analyses

Reference materials	Certified (mg Zn.kg^{-1})	Obtained (mg Zn.kg^{-1})
RM 12-02-03 Lucerne	33.2 ± 0.5	33.7 ± 0.6
RM 12-03-12	1310 ± 40	1371 ± 98

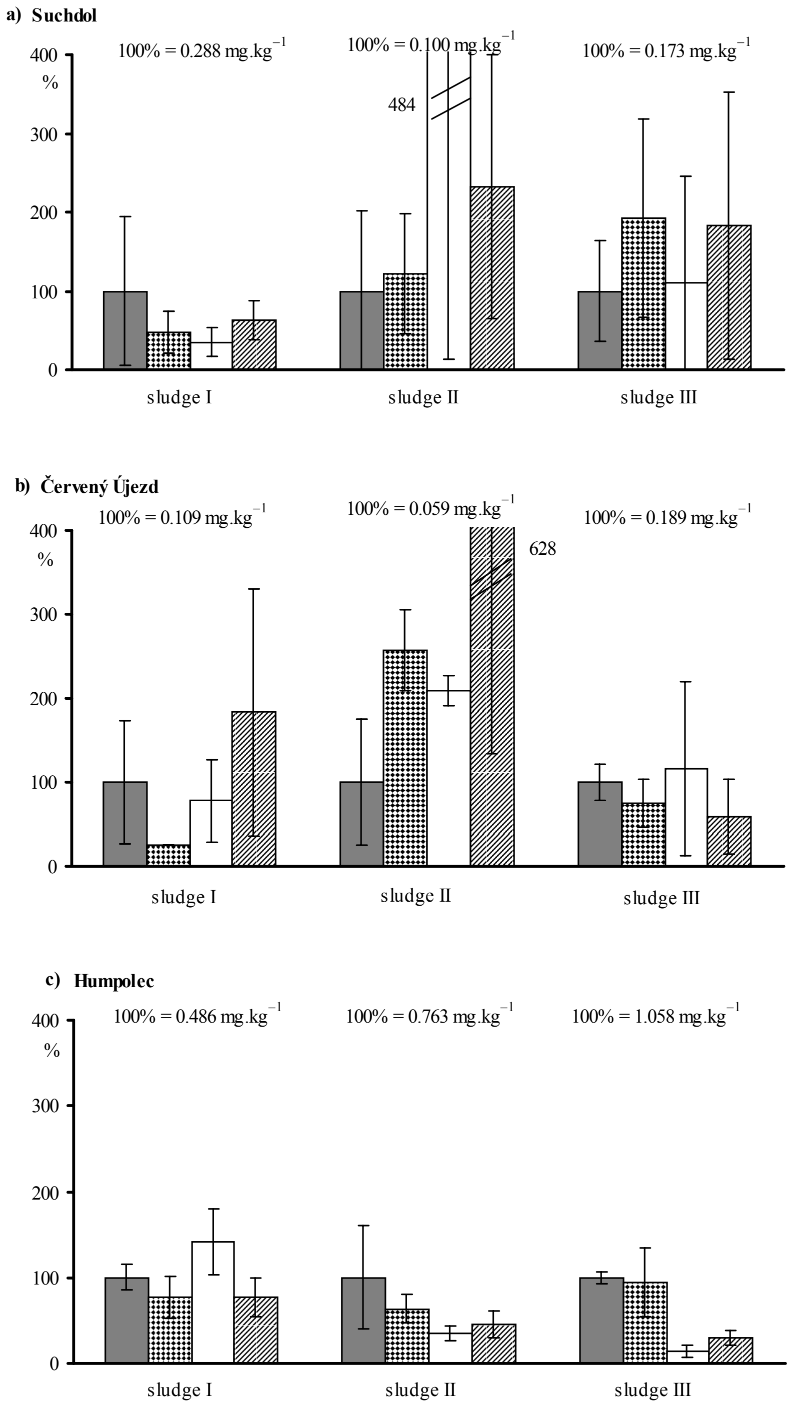

Figure 1. The changes of Zn availability in three soils treated with sewage sludge incubated under aerobic conditions (%)

Explanations to the figure (from the left):
1st bar: soil + sludge – time 0
2nd bar: soil + sludge – time 4 months
3rd bar: soil + sludge with limestone – time 4 months – with limestone
4th bar: soil + sludge with lime – time 4 months – with lime

mobility. Zn behaviour in Humpolec soil with anaerobically incubated sludge (Figure 2c) showed similar trend as with aerobically incubated sludge. It was caused by limitation of soil acidity by application of alkaline sludge.

Humpolec soil showed best results in Zn mobility reduction. The highest statistically significant differences were found among treatments in sludge III. Sludge amended by lime and limestone reduced Zn content in this soil (in sludge III by 86% after limestone and by 71% after lime application). Similarly, Sloan and Basta (1995) reported that lime or limestone treatments seem to be important only for soils with low pH.

The risk element concentration in plants is convenient parameter to compare the availability of elements supplied by sludge uptake by plants. It is important criteria for quality assessment of agricultural plants.

Figures 3 and 4 showed the effect of soil type amended with aerobically and anaerobically incubated sludge on Zn accumulation in above ground oat biomass. Assumed Zn behaviour was confirmed at treatments with addition of I and II aerobically incubated sludge. The highest Zn content was found in soil with nonincubated sludge (exception of Červený Újezd soil). Lime and limestone application into sludge was substantially more effective on

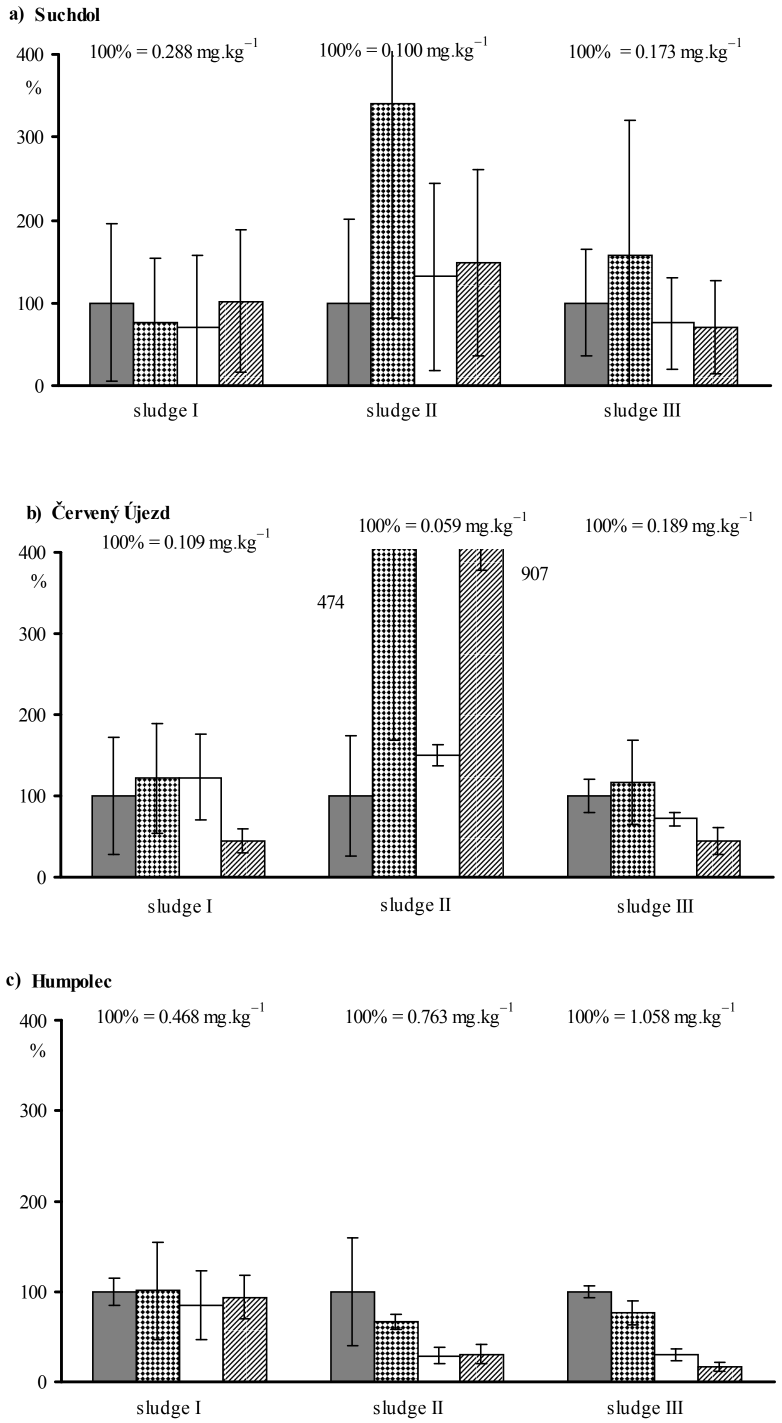

Figure 2. The changes of Zn availability in three soils treated with sewage sludge incubated under anaerobic conditions (%)

Explanations to the figure (from the left):
1st bar: soil + sludge – time 0
2nd bar: soil + sludge – time 4 months
3rd bar: soil + sludge with limestone – time 4 months – with limestone
4th bar: soil + sludge with lime – time 4 months – with lime

Zn content decrease in plant in Humpolec soil compare with the other soils. The application of anaerobic sludge with lime into the same soil decreased Zn in oats to 80% and with limestone to 71% compared to control. Tlustoš et al. (1995) found that lime application into the soil decreased Zn concentration in spinach. In oat grown in Suchdol soil was found the highest Zn content at aerobic and anaerobic sludges treatments with lime (in aerobic 109% and anaerobic 128% compared to control). In oat grown in Červený Újezd soil was the highest Zn content in aerobic treatment with untreated incubated sludge (112% compared to control – average of all sludges). After anaerobic incubation (in Červený Újezd soil) was found the highest Zn uptake at treatment with sludge amended by lime (110% compared to control).

The highest absolute Zn content was measured in plants grown in Humpolec soil (sandy soil with low clay content and pH). There is small sorption in this soil and a lot of zinc is in the plant available form. Available Zn in Humpolec soil showed strong correlation among all soils with total content in plant (at aerobic treatment $R^2 = 0.66$ and at anaerobic even $R^2 = 0.83$). The application of sludge into this soil is not suitable, only treated sludge by ameliorative compound (lime or limestone) can be used.

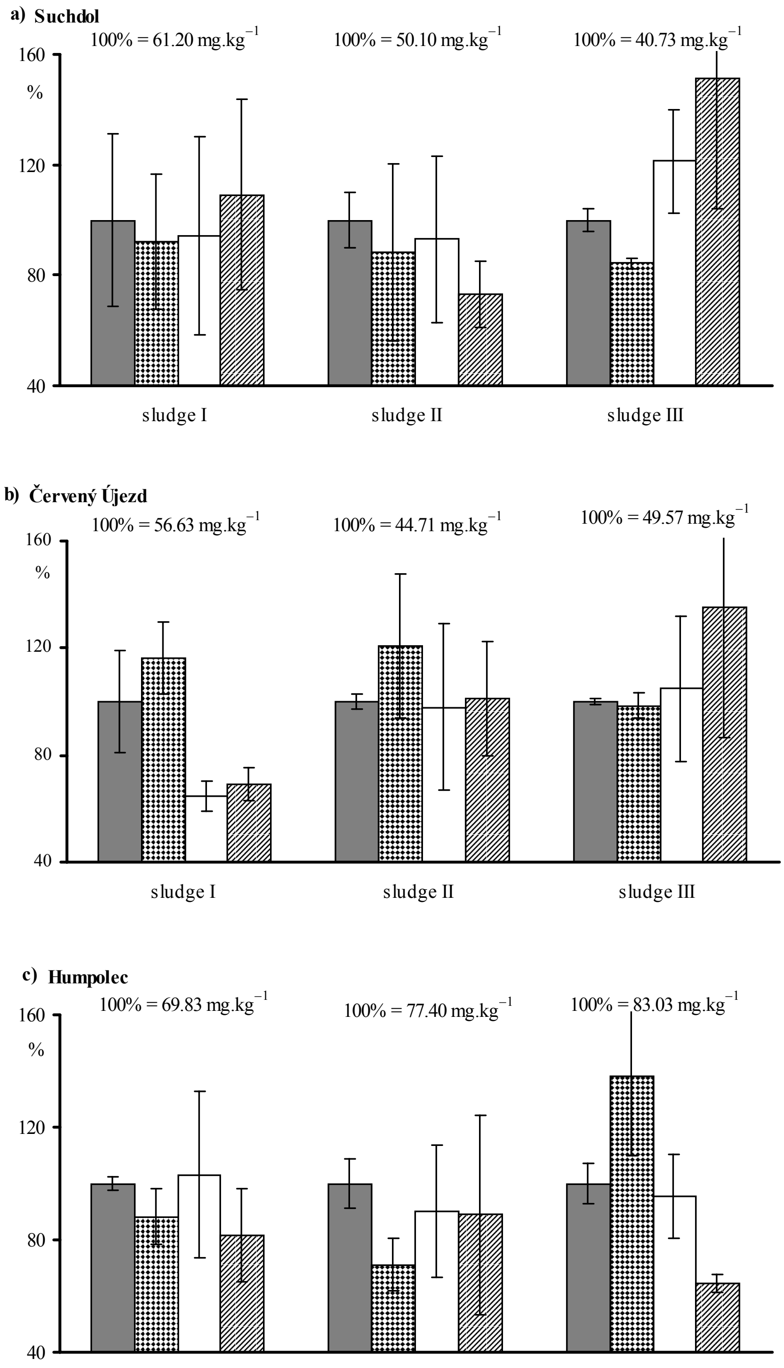

Figure 3. The changes of available Zn content in oats grown in three soils treated with sewage sludge incubated under aerobic conditions (%)

Explanations to the figure (from the left):
1st bar: soil + sludge – time 0
2nd bar: soil + sludge – time 4 months
3rd bar: soil + sludge with limestone – time 4 months – with limestone
4th bar: soil + sludge with lime – time 4 months – with lime

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REFERENCES

Adriano D.C. (2001): Trace elements in terrestrial environment: biogeochemistry, bioavailability and risks of metals. Springer-Verlag, New York.

Alloway B. (1990): Heavy metals in soils. John Wiley and Sons, New York

Balík J., Tlustoš P., Pavlíková D., Száková J., Kaewrahun S., Hanč A. (2000): Cadmium and zinc uptake by oat from soils amended by sewage sludge incubated with lime and bentonite. Rostl. Výr., *46*: 273–280.

Chuan M.C., Shu G.Z., Liu J.C. (1996): Solubility of heavy metals in a contaminated soil: effects of redox potential and pH. Wat. Air Soil Pollut., *90*: 543–556.

Kabata-Pendias A., Pendias H. (1986): Trace elements in soils and plants. CRC Press, Inc. Boca Raton, Florida.

Kim S.J., Chang A.C., Page A.L., Warneke J.E. (1988): Relative concentrations of cadmium and zinc in tissue of select-

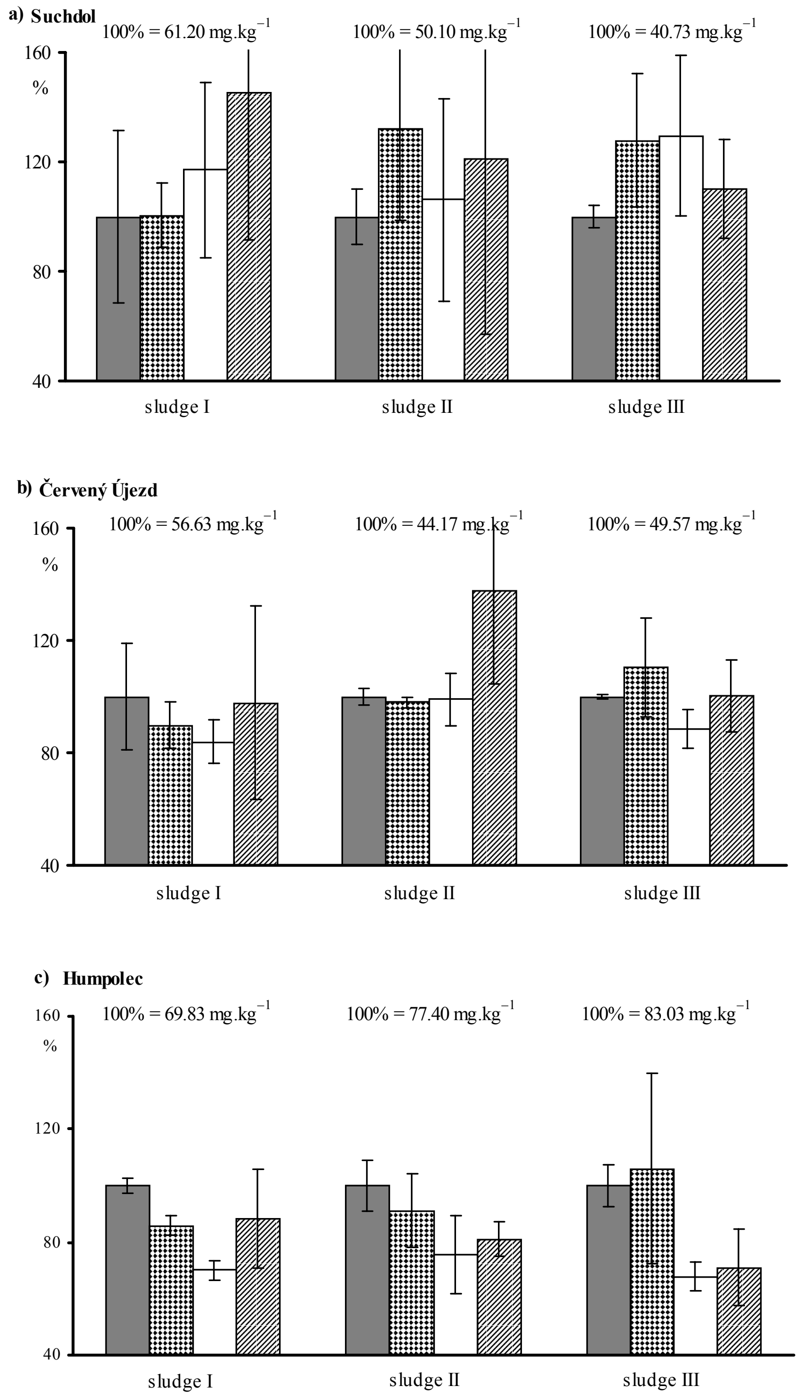

Figure 4. The changes of available Zn content in oats grown in three soils treated with sewage sludge incubated under anaerobic conditions (%)

Explanations to the figure (from the left):
1st bar: soil + sludge – time 0
2nd bar: soil + sludge – time 4 months
3rd bar: soil + sludge with limestone – time 4 months – with limestone
4th bar: soil + sludge with lime – time 4 months – with lime

ed food plants grown on sludge-treated soils. J. Envir. Qual., *17*: 568–573.

Lake D.L., Kirk, P.W.W., Lester J.N. (1984): Fractionation, characterization and speciation of heavy metals in sewage sludge-amended soils: A review. J. Envir. Qual., *13*: 175–183.

Lubben S., Sauerbeck D. (1991): The uptake and distribution of heavy metals by spring wheat. Wat. Air Soil Pollut., *57–58*: 239–247.

McGrath S.P., Knight B., Killham K., Preston S., Paton G.I. (1999): Assessment of the toxicity of metals in soils amended with sewage sludge using a chemical speciation technique and a lux-based biosensor. Envir. Toxicol. Chem., *18*: 659–663.

Miholova D., Mader O., Szakova J., Slamova A., Svatos Z. (1993): Czechoslovak biological certified reference materials and their use in the analytical quality assurance system in a trace element laboratory. Fresenius J. Anal. Chem., *51*: 256–260.

Miller R.W., Al-Khazraji M.L., Sisson D.R., Gardiner D.T. (1995): Alfalfa growth and absorption of cadmium and zinc from soils amended with sewage sludge. Agric. Ecosyst. Envir., *53*: 179–184.

Novozamsky J., Lexmond T.M., Houba V.J.H. (1993): A single extraction procedure of soil for evaluation of uptake of some heavy metals by plants. Int. J. Envir. Anal. Chem., *51*: 47–58.

Sloan J.J., Basta N.T. (1995): Remediation of acid soils by using alkaline biosolids. J. Envir. Qual., *24*: 1097–1103.

Tiller K.G. (1989): Heavy metals in soils and their environmental significance. Adv. Soil Sci., *9*: 113–142.

Tlustoš P. (1999): Mobilita arsenu, kadmia a zinku v půdách a možnosti omezení jejich příjmu rostlinami. [Habilitace.] ČZU, Praha.

Tlustoš P., Balík J., Dvořák P, Száková J., Pavlíková D. (2001): Zinc and lead uptake by three crops planted on different soils treated by sewage sludge. Rostl. Výr., *47*: 129–134.

Tlustoš P., Balík J., Pavlíková D., Száková J. (1997): Uptake of cadmium, zinc, arsenic and lead by different crops. Rostl. Výr., *43*: 487–494.

Tlustoš P., Vostal J., Száková J., Balík J. (1995): Přímá a následná účinnost vybraných opatření na obsah kadmia a zinku v biomase špenátu. Rostl. Výr., *41*: 31–37.

Zamani B., Knezek B.D., Dazzo F.B. (1984): Biological immobilization of zinc and manganese in soil. J. Envir. Qual., *13*: 269–273.

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ABSTRAKT

Mobilita zinku ve třech různých půdách ošetřených inkubovanými kaly s přídavkem vápence a vápna a příjem Zn ovsem

V nádobovém pokusu byl zkoumán vliv odpadních kalů aplikovaných do tří různých půd (černozem – Suchdol, hnědozem – Červený Újezd, kambizem – Humpolec). Zemina byla po sklizni ovsa vyluhována 0,01 mol.l^{-1} CaCl$_2$ ke zjištění přístupnosti Zn. Dále byla hodnocena akumulace Zn v nadzemní biomase ovsa. Stabilizované odpadní kaly byly získány ze tří čistíren odpadních vod (obsah celkového zinku v kalu I = 1554 mg.kg^{-1}, v kalu II = 984 mg.kg^{-1} a v kalu III = 1653 mg.kg^{-1}). Odpadní kaly byly preinkubovány s přídavkem vápence a vápna (7% Ca z množství sušiny kalu) v aerobních a anaerobních podmínkách a použity v nádobovém pokusu se zeminami. Nejlepších výsledků s omezením mobility zinku bylo dosaženo na zemině Humpolec. Kaly s vápnem a vápencem snížily obsah Zn na této zemině (u kalu Tábor po aplikaci vápence o 86,4 % a o 71 % po aplikaci vápna). Ke značnému snížení zinku v rostlinách došlo na zemině Humpolec ošetřené kalem s vápnem (o 20 % ve srovnání se zeminou ošetřenou neinkubovaným kalem – kontrolou) a vápencem (o 30 % po anaerobní inkubaci ve srovnání s kontrolou). U ostatních zemin nebyl prokázán kladný vliv inkubace ani ošetření kalu na obsah zinku v rostlinách. Nejvyšší korelační koeficient přijatelného zinku v půdě a celkového obsahu v rostlině byl zjištěn na zemině Humpolec (při aerobním skladování kalu $R^2 = 0,66$ a při anaerobním dokonce $R^2 = 0,83$).

Klíčová slova: odpadní kaly; zinek; oves; vápno; vápenec; pH; půdní typ

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