Biomass yields of shoots and roots of plants cultivated in soil amended by vermicomposts based on tannery sludge and content of heavy metals in plant tissues

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ABSTRACT

Sewage sludge application in agriculture is the simplest method of its management. Its content of organic and inorganic toxic components is a barrier to such management. Particular attention should be paid to the content of heavy metals whose presence in sewage sludge and later in soil poses hazard for plants, animals and people. The investigations aimed to determine the effect of vermicomposts obtained from tannery sludge on development of the root system and biomass of shoots as well as heavy metal concentrations in these organs. In the first year after the vermicomposts application their effect on the maize biomass increase was equal to the farmyard manure treatment but significantly worse than the mineral fertilization. The consecutive fertilizer effect of vermicomposts of tannery sludge ted on the increase in biomass of the shoots and roots of winter rape, sunflower and oats was comparable with the farmyard manure effect but notably better than the mineral fertilization. Heavy metal concentrations in individual plants were diversified; in the plants from vermicompost treatment they were as a rule lower than in the plants from mineral or farmyard manure treatment. Absorbed heavy metals accumulated primarily in the root systems, whereas the extremely high chromium content in vermicomposts did not cause its excessive accumulation in the cultivated plants.

Keywords: vermicompost; heavy metal; *Eisenia fetida*; yield; tolerance indices; contamination indices

Sewage sludge application in agriculture is the simplest method of its management. Its content of organic and inorganic toxic components (Borkowska et al. 1996) is a barrier to such management. Particular attention should be paid to the content of heavy metals whose presence in sewage sludge and later in soil poses hazard for plants, animals and people (Kabata-Pendias and Pendias 1993). Only occasionally is sewage sludge used for agricultural and environmental purpose without suitable treatment. One of the processes is sludge composting with various additives. The other is a method of biological treatment of sewage sludge using *Eisenia fetida* redworm resulting in an organic fertilizer, i.e. vermicompost (Hatanaka et al. 1983, Lee 1985, Kostecka 1994).

Heavy metals released into environment, among others by sewage sludge, pose a serious problem. While accumulating in living organisms they circulate in the trophic chain and moreover their dangerous concentrations persist in ecosystems for a long time (Tiller 1989, Kopcewicz and Lewak 1998, Tlustoš et al. 1997).

Plant roots participate primarily in the heavy metal cation uptake (Lasat 2002). The toxic effect of heavy metal activity is connected to their extremely high concentration in cells. This concentration cause disturbances in cell membrane functioning in the photosynthetic and mitochondrial electron transport and in the inactivation of many enzymes active in the basic cell metabolism regulation, which as the result leads to diminishing energy balance and disturbances in cell mineral nutrition (Kopcewicz and Lewak 1998). All these negative changes in the plant practical processes in the first place lead to limited growth of roots which are in direct contact with toxic substances in soil, to subsequent limited absorptive and conductive functions of these organs and resulting in limited growth of the top parts (Hara and Sonoda 1979, Kopcewicz and Lewak 1998, Lipiec 2001).

The presented investigations aimed to determine the effect of vermicomposts obtained from tannery sludge on development of the root system and plant shoot biomass as well as on the heavy metal concentration in these organs.

MATERIAL AND METHODS

The initial materials for the studies were composts based on tannery sludge from a biological-and-mechanical sludge treatment plant of the Krakow Tannery. The composts were prepared from the following components: tannery sludge with added 15% sawdust of coniferous trees (compost A), tannery sludge with added 15% cardboard (compost B), tannery sludge with added 15% of wheat straw (compost C), and in relation to the sludge dry mass. Composting time was 12 months. Prepared composts were settled with redworms. A hundred of sexually matured *Eisenia fetida* redworms were introduced into each compost. The vermicomposting was conducted in PVC vessels at the 75% mass moisture and the process lasted six months.

In a pot experiment the effect of obtained vermicomposts (A, B, C) on the increase of the shoot and root biomass and the plant biomass heavy metal concentrations were studied. The experiment was conducted in a vegetation hall of the Agricultural University of Krakow (in 1999–2001) in PVC pots with 5 kg of air-dried soil. The experiment was carried out on brown soil with the granulometric composition of clayey silt with 69% concentration of floatable particles. The experimental soil was characterised by pH 4.11 (determined in 1 mol/dm^3 KCl solution). The soil hydrolytic acidity determined by Kappen's method was 73.4 mmol(+)/kg. Other soil parameters measured prior to the experiment outset were as follows: total nitrogen content determined by Kjeldahl's method 1.90 g/kg and the organic carbon content assayed by Tiurin's method 14.1 g/kg of soil dry mass.

The experiment comprised seven treatments in four replications and was conducted according to the experimental design presented in Table 2. The difference of chromium content in untreated sludge and vermicomposts results from different dates of sludge sampling for composting and for vegetative studies. The doses of dried and ground organic fertilizers were calculated on the basis of their nitrogen content (1 g/pot), the phosphorous fertilization was dosed 0.6 g P/pot and potassium 1.2 g K/pot. In the object receiving mineral treatment nitrogen was applied in NH_4NO_3 as chemically pure salt, the complementary phosphorous and potassium treatments were applied on all objects except the control, phosphorus in $Ca(H_2PO_4)_2.H_2O$ and potassium in KCl.

Maize, KLG 2210 cv., planted 6 plants/pot, was cultivated in the first year of the experiment. The plant growth inhibition and nitrogen deficiency symptoms were observed during the vegetation. The topdressing with nitrogen as NH_4NO_3 in the rate 0.5 g/pot was applied. After 102 days of vegetation the plants were harvested at the cob formation phase. In the second year of the experiment after uniform mineral treatment (1 g N/pot, 1.2 g K/pot) winter rape, Górczański cv. was cultivated (12 plants/pot). After 52 days of vegetation the plants were harvested at the rosette phase. Sunflower, Lech cv. was chosen as the other test plant in the second year of the experiment. It was sown (9 plants/pot) after supplementary nitrogen treatment of 0.5 g/pot. After 62 days of vegetation the plants were harvested at the flowering phase. In the third year again uniform mineral fertilization was applied on all treatments (0.5 g N/pot, 1.0 g K/pot) and oat, Dragon cv. was sown, 25 plants/pot were left after emergence, which were then harvested at the full maturity after 89 days of vegetation. Supplementary doses of mineral fertilizers were used as water solutions of chemically pure salts (N-NH_4NO_3, P-$Ca(H_2PO_4).H_2O$, K-KCl). During the vegetation the plants were watered with distilled water to maintain 60% of soil maximum water capacity.

In vermicomposts the plant material dry weight was assessed at 70°C in a dryer with hot air flow. The other chemical analyses were conducted on dried and ground material.

The total nitrogen in vermicomposts was determined after wet mineralization in concentrated sulphuric acid(VI) by Kjeldahl's method in Kjeltec II Plus apparatus (Tecator). The contents of potassium, phosphorus, calcium, magnesium and sodium as well as heavy metal concentrations were assayed in vermicomposts after decomposing the annealed samples (at 500°C for 5 h) in nitric acid(V) (1:2). Phosphorus was assessed by collo-

Table 1. Chemical composition of materials used in experiment

Determination	Farmyard manure	Biological sludge	Vermicompost A (biological sludge + sawdust)	Vermicompost B (biological sludge + cardboard)	Vermicompost C (biological sludge + straw)
Dry mass (g/kg)	269	239	420	396	386
			g/kg of dry mass		
Organic C	313	305	137	126	144
Total N	25.4	38.2	26.3	26.6	27.7
P	6.9	3.3	7.9	7.0	11.1
K	13.0	4.9	2.1	1.6	2.4
Ca	21	80	127	134	128
Mg	6.4	2.4	3.5	3.2	3.1
Na	1.2	2.2	4.2	3.2	2.0
			mg/kg of dry mass		
Cu	146	20	50	44	43
Zn	460	108	405	329	341
Cr	11	3283	7937	7545	8262
Ni	10.0	55.0	21.1	17.3	18.9
Pb	15	16	48	42	42
Cd	2.10	0.20	0.94	0.66	0.81

rimetry using vanadium and molybdenum method in DU 640 spectrophotometer (Backman), potassium, sodium and calcium were determined by flame photometry (FES), magnesium and other heavy metals (Cu, Cd, Zn, Ni and Cr) by atomic absorption spectrometry (AAS) in PU 9100X Philips spectrophotometer.

The contents of studied heavy metals in the plant material were determined after sample mineralization in a muffle furnace (at 500°C for 5 h) and dissolving the ashes in nitric acid(V) (1:2). In such prepared solutions the contents of copper and zinc were assessed by atomic absorption spectrometry (AAS) in PU 9100X Philips spectrophotometer. Lead, chromium, cadmium and nickel concentrations were assayed by ICP-AES method in JY 238 Ultrace apparatus.

The presented results are the mean of two years of simultaneous replications. The result of chemical analysis was accepted as reliable if the error of two replications did not exceed 5%.

The obtained results were evaluated statistically using a single factor analysis of variance and the significance of differences between arithmetic means were evaluated by *t*-Student test at the significance level $p < 0.05$ (Stanisz 1998).

The toleration index (T_i) was calculated as a quotient of the yield dry mass of the plants from vermicompost and mineral treatments. The contamination degree index (C) was computed as a quotient of the metal content in the plant fertilized by vermicomposts and the one receiving mineral treatment (Kopcewicz and Lewak 1998).

RESULTS AND DISCUSSION

Table 1 shows the chemical properties of the materials used for the experiment. The fertilizer materials were diversified concerning their dry matter content (239–420 g/kg) and organic carbon (126–313 g/kg dry mass). Total nitrogen concentrations in vermicomposts were on the level comparable to farmyard manure (25.4 g/kg dry mass) and ranged between 26.3 and 27.7 g/kg dry mass. Biological sludge contained the highest quantities of nitrogen (38.2 g/kg dry mass). The phosphorus concentrations in the applied materials ranged between 3.3 and 11.1 g/kg dry mass. The potassium level in sludge and vermicompost was between 2.6- and 8-fold lower than in farmyard manure whereas the calcium content was very high, i.e. 134.1 g/kg dry mass in vermicompost with added cardboard. The magnesium content did not reveal any greater diversification and was lower in sludge and vermicomposts than in farmyard manure (6.4 g/kg dry mass), more sodium was detected in materials of tannery origin than in farmyard manure. The heavy metal content did not pose any hazard for the soil environment, except for chromium, the level of which exceeded 500 mg/kg, i.e. the value accepted as permissible (Reg. of the Ministry of Environment).

The yields of dry mass of the plants cultivated in the successive years of the experiment are presented in Table 2. The highest dry mass yield of maize cobs grown in the first year of the experiment was found in the NPK mineral treatment (28.27 g/pot) and in comparison with farmyard manure it was almost six fold higher. The notably higher yields of cobs, in comparison with the farmyard manure treatment, were obtained by soil fertilization with vermicompost made of sawdust (by 119%) and cardboard (by 50%). The plants in the control treatment did not develop any cobs. Total yields of leaves and stems at all fertilizer objects were on a similar level and obtained increases in yields proved statistically insignificant. The yields of maize roots were comparable in all objects re-

Table 2. Yields of plant dry matter (g/pot)

Treatment	Parts of plants		
Maize	cob	steam + leaves	roots
Control	–*	39.65	4.01
Mineral fertilization	28.27	157.38	23.20
Farmyard manure	4.75	110.49	11.29
Biological sludge	5.34	110.50	10.65
Vermicompost A	10.44	119.49	13.55
Vermicompost B	7.16	132.13	15.49
Vermicompost C	6.53	113.94	13.93
$LSD_{p<0.05}$	2.002	10.554	1.098
Rape	shoots	roots	
Control	9.89	2.64	
Mineral fertilization	41.47	8.11	
Farmyard manure	44.42	7.86	
Biological sludge	49.28	8.80	
Vermicompost A	49.24	8.63	
Vermicompost B	50.94	8.23	
Vermicompost C	49.23	9.03	
$LSD_{p<0.05}$	3.305	0.582	
Sunflower	shoots	roots	
Control	9.80	0.80	
Mineral fertilization	58.64	3.81	
Farmyard manure	67.50	4.41	
Biological sludge	64.98	3.65	
Vermicompost A	68.20	4.16	
Vermicompost B	70.95	4.91	
Vermicompost C	72.07	4.64	
$LSD_{p<0.05}$	5.152	0.653	
Oat	grain	straw	roots
Control	4.05	4.96	1.02
Mineral fertilization	24.85	22.82	4.58
Farmyard manure	25.75	23.78	4.68
Biological sludge	27.36	22.79	5.15
Vermicompost A	26.21	23.41	4.93
Vermicompost B	28.32	24.79	5.83
Vermicompost C	26.01	23.59	5.21
$LSD_{p<0.05}$	1.713	1.061	0.567

* absent of yield

Table 3. Content of heavy metals (mg/kg dry mass) in maize

Treatment	Cu	Zn	Ni	Cd	Pb	Cr
			Cob			
Control	–	–	–	–	–	–
Mineral fertilization	3.06	32.00	1.43	0.17	0.19	0.15
Farmyard manure	3.48	35.70	0.72	0.32	0.26	0.11
Biological sludge	3.01	27.20	0.80	0.23	0.17	0.14
Vermicompost A	2.50	28.10	0.47	0.15	0.36	0.13
Vermicompost B	2.70	29.10	0.57	0.11	0.28	0.10
Vermicompost C	3.01	31.55	0.71	0.17	0.28	0.09
$LSD_{p < 0.05}$	0.468	3.841	0.197	0.031	0.041	0.021
			Steam + leaves			
Control	1.91	101.30	1.68	0.56	2.45	0.39
Mineral fertilization	1.69	134.65	1.63	0.50	2.01	0.29
Farmyard manure	1.79	66.15	1.31	0.39	2.41	0.35
Biological sludge	1.39	42.65	1.23	0.25	1.47	0.23
Vermicompost A	1.54	24.00	2.06	0.19	1.63	0.42
Vermicompost B	1.29	20.00	1.08	0.21	1.50	0.19
Vermicompost C	1.64	26.50	1.20	0.25	2.02	0.73
$LSD_{p < 0.05}$	0.348	8.097	0.431	0.061	0.595	0.086
			Roots			
Control	15.27	64.81	7.82	1.67	3.01	3.91
Mineral fertilization	5.00	41.27	12.64	1.37	3.06	3.86
Farmyard manure	10.16	49.52	8.18	1.53	2.64	4.63
Biological sludge	12.31	39.52	5.01	1.20	2.25	5.75
Vermicompost A	12.74	33.95	5.89	1.33	3.92	7.55
Vermicompost B	9.89	35.70	5.43	0.99	3.12	7.95
Vermicompost C	11.73	34.75	6.97	1.25	3.27	6.71
$LSD_{p < 0.05}$	1.315	6.218	1.432	0.166	0.574	1.096

ceiving organic treatment. The increases of yield obtained in results of vermicompost fertilization (in relation to farmyard manure) ranged between 20 and 37% but proved statistically unimportant. Only the mineral fertilization caused a notable increase in the yield in comparison with farmyard manure (by 105%). In the study by Kopeć et al. (1996) the fertilizer effect of tannery sludge of chemical and biological origin on the yield proved a slightly poorer response than the mineral treatment in the maize cultivation.

The highest dry shoot yields of rape grown in the second year of the experiment were produced in the objects where vermicomposts and untreated tannery sludge were applied. The obtained increases in yields were statistically significant in comparison with the objects receiving mineral fertilization and farmyard manure (Table 2). An apparent increase in winter rape root dry mass yield (as compared to yields from mineral treatment and farmyard manure) was found as the consecutive effect of untreated tannery sludge and vermicompost with added straw (Table 2).

The fertilization with vermicomposts and untreated tannery sludge caused a statistically proved increase in the sunflower shoot yield as compared with the mineral treatment (Table 2). The increased yields were not statistically significant as compared with the farmyard manure treatment. The consecutive effect of organic treatment on the sunflower root yield caused a considerable growth of sunflower root system mass (in comparison with the mineral treatment) in the objects where vermicompost with added cardboard (by over 28%) and straw (by over 21%) was applied. The yields of sunflower roots from the farmyard manure and vermicompost treatment were equal but much lower in the object receiving untreated tannery sludge. In the third year of the experiment oat was cultivated as a test plant. The consecutive effect of organic treatment on the yields of oat grains, straw and roots was diversified (Table 2). The highest yields of grains, straw and roots, as compared with the mineral treatment and farmyard manure, were produced under the influence of fertilization with vermicomposts with added cardboard. The increases were statistically significant. In the other objects, except the control, the yields were equal.

The tolerance indexes (T_i) calculated for maize (grown immediately after fertilization) were lower than one, both for the farmyard manure and vermicompost treatment. The parameter values point to an inhibited growth of both the root system and shoots of the studied plant under the in-

Table 4. Content of heavy metals (mg/kg dry mass) in winter rape

Treatment	Cu	Zn	Ni	Cd	Pb	Cr
			Shoots			
Control	2.60	61.83	3.88	1.54	1.20	0.76
Mineral fertilization	3.68	90.13	7.68	4.55	1.11	2.23
Farmyard manure	3.37	87.43	4.85	3.15	1.21	1.44
Biological sludge	2.91	43.70	2.48	1.32	1.50	0.66
Vermicompost A	2.49	26.50	1.07	0.74	1.21	0.61
Vermicompost B	2.50	30.10	1.32	0.68	1.03	0.35
Vermicompost C	2.60	37.57	1.30	0.73	0.90	0.25
$LSD_{p < 0.05}$	0.523	11.858	0.480	0.342	0.356	0.309
			Roots			
Control	3.00	48.33	5.52	1.18	0.81	1.34
Mineral fertilization	2.63	46.05	6.98	0.93	0.70	0.94
Farmyard manure	2.63	42.57	6.47	0.81	0.86	1.17
Biological sludge	3.11	26.37	3.77	0.48	1.31	2.69
Vermicompost A	2.75	22.03	2.16	0.44	0.67	2.07
Vermicompost B	3.14	21.57	1.99	0.53	1.22	1.89
Vermicompost C	2.67	25.60	1.68	0.53	0.52	1.52
$LSD_{p < 0.05}$	0.410	5.439	1.571	0.349	0.461	0.550

fluence of applied fertilization. The obtained results do not necessarily testify a toxic effect of the materials used, more probably they point a deficiency of nitrogen, which as a whole was applied in organic fertilizers (except for the object receiving the mineral fertilization).

The values of toleration index (T_i) for the other plants cultivated in the subsequent years exceeded of experiment one, which confirms a lack of toxic consecutive effect of vermicomposts of tannery origin on the crop yield.

The copper concentrations in the shoots of maize cultivated immediately after the vermicompost fertilization and in rape and sunflower shoots grown in the second year of the experiment were below the content determined for these plant shoots fertilized with farmyard manure and mineral materials (Tables 3–5). Significantly more copper was found in grains and straw of oat treated with vermicompost than in the objects where mineral fertilizers were used (Table 6).

Table 5. Content of heavy metals (mg/kg dry mass) in sunflower

Treatment	Cu	Zn	Ni	Cd	Pb	Cr
			Shoots			
Control	21.59	283.33	13.05	9.07	3.06	2.18
Mineral fertilization	4.18	96.85	7.33	2.77	0.83	0.45
Farmyard manure	4.50	84.45	6.41	2.29	0.57	0.44
Biological sludge	4.44	53.74	4.91	1.64	0.57	0.46
Vermicompost A	3.94	26.43	2.24	0.74	0.50	0.34
Vermicompost B	4.06	22.43	1.78	0.67	0.60	0.36
Vermicompost C	3.83	27.30	1.81	0.81	1.17	0.37
$LSD_{p < 0.05}$	0.543	7.404	1.006	0.401	0.298	0.082
			Roots			
Control	15.05	243.50	9.03	1.13	0.65	3.78
Mineral fertilization	5.81	76.65	9.01	1.47	0.66	1.32
Farmyard manure	5.92	60.18	8.01	1.41	0.63	1.30
Biological sludge	6.26	38.09	4.92	1.02	0.49	1.51
Vermicompost A	8.03	25.55	2.74	0.59	0.20	2.33
Vermicompost B	7.56	19.93	3.07	0.60	0.45	1.62
Vermicompost C	8.53	24.43	2.63	0.67	0.42	1.27
$LSD_{p < 0.05}$	2.586	16.371	0.758	0.219	0.123	0.303

Table 6. Content of heavy metals (mg/kg dry mass) in oat

Treatment	Cu	Zn	Ni	Cd	Pb	Cr
			Grain			
Control	4.88	49.96	11.84	0.68	1.18	0.18
Mineral fertilization	4.44	37.70	16.75	1.19	1.05	0.19
Farmyard manure	5.95	45.47	15.25	1.46	1.31	0.20
Biological sludge	5.44	44.75	14.01	1.17	1.49	0.23
Vermicompost A	5.40	35.58	6.11	0.58	1.82	0.20
Vermicompost B	5.13	36.08	6.49	0.65	2.02	0.26
Vermicompost C	5.55	36.47	6.76	0.66	2.21	0.27
$LSD_{p < 0.05}$	0.564	2.502	1.028	0.098	0.177	0.035
			Straw			
Control	2.01	35.69	3.65	1.56	3.80	0.54
Mineral fertilization	2.53	25.76	3.38	1.81	4.25	0.55
Farmyard manure	2.70	31.44	3.95	1.80	4.92	0.52
Biological sludge	2.70	30.91	2.75	1.76	5.36	0.64
Vermicompost A	2.88	17.20	2.50	0.95	5.67	0.72
Vermicompost B	3.03	17.89	2.88	0.95	5.40	0.64
Vermicompost C	3.04	19.13	2.37	0.96	5.49	0.64
$LSD_{p < 0.05}$	0.183	3.256	1.543	0.210	0.412	0.066
			Roots			
Control	2.41	47.04	3.62	0.86	0.60	0.61
Mineral fertilization	5.03	61.00	22.70	2.31	2.66	2.63
Farmyard manure	5.75	65.14	21.92	2.56	4.44	1.78
Biological sludge	6.37	60.56	28.15	2.75	3.86	8.39
Vermicompost A	6.28	35.86	6.58	1.50	3.91	4.74
Vermicompost B	8.82	44.95	5.17	1.77	3.65	4.60
Vermicompost C	7.94	37.99	6.61	1.86	4.07	4.60
$LSD_{p < 0.05}$	0.767	6.842	4.920	0.192	1.083	1.158

In comparison with the farmyard manure treatment, the fertilization with vermicomposts based on tannery sludge lowered the copper concentrations in grains but significantly increased its straw content. The oat root system did not accumulate any excessive amounts of copper. The least quantities of copper accumulated in the rape roots, most of it accumulated in the maize roots (Tables 3–6). The copper concentrations in the plant shoots were deficient concerning animal nutritional requirements (Gorlach 1991). The copper concentrations determined in the plants resulted from its small concentrations in the applied tannery materials. This element availability is very strongly modified by the organic matter content, which reveals strong abilities for copper fixation. The plant copper concentrations might have been strongly influenced by the antagonism between copper and calcium in which vermicomposts prepared of tannery sludge are abundant and also by the low mobility of this element in the plant.

However, it should be emphasized that the plants blocked copper on the border between the root system and the shoots.

The zinc content in the cultivated crops, except for the interspecific differences, revealed some distinct regularity generally visible as a lower level of this element both in the shoots and roots of the plants from vermicompost treatments in comparison with mineral fertilization, farmyard manure and untreated tannery sludge (Tables 3–6).

The zinc distribution in individual plant parts was diversified and depended on the cultivated plant (Kuboi et al. 1986). Maize and oat accumulated more of the metal in their root systems, while rape and sunflower in the shoots (Tables 3–6). An excess of zinc was seen in the plants from the control, mineral treatment and farmyard manure.

The dependencies concerning the plant nickel content looked similarly as for the lower zinc concentration (Tables 3–6). The highest amounts of this element were usually detected in the shoots and roots of the plants fertilized with mineral materials, but they did not exceed the values permissible for fodder crops (Hara and Sonoda 1979, Anke 1987).

Among the cultivated crops rape and sunflower revealed higher cadmium concentrations in their shoots than in the roots (Tables 4 and 5). In the other crops the relations were the opposite. In all plants grown in vermicompost treatments cadmium concentrations in the plant parts, which may be the source of fodder, did not exceed

1 mg/kg assumed the limit value (Anke 1987). The crops receiving farmyard manure and mineral fertilizers accumulated most of the cadmium, especially in their shoots. An excessive amount of this element was also found, particularly in the shoots of plants, in the control and on the untreated tannery sludge treatment. The cadmium concentrations in the shoots of plants grown in the objects receiving mineral fertilizers and farmyard manure also proved over normative (Anke 1987). Over 1 mg of cadmium was also found in the shoots of rape and sunflower grown in the control. The obtained results confirm findings of Logan and Chaney (1983) who reported a bigger cadmium uptake under pot experiment conditions than in the field. According to Chaney (1982) cadmium is an element that is not affected by so called soil-plant barriers, which means that plants tolerate this element in their tissue (and do not reveal any toxicity symptoms) in amounts that are harmful for animals consuming these plants. On the other hand Kabata-Pendias and Pendias (1993) and Inouhe et al. (1994) stated that at an increased uptake cadmium mostly accumulates in the roots. According to the authors mentioned above the cadmium blockage in the roots probably involves formation of this metal bonding with sulfhydrol and with proteins forming so called phytochelatines (Kabata-Pendias and Pendias 1993). The accumulation of cadmium in plant biomass was not only affected by the soil properties but by the crop species planted on the soil as well (Tiller 1989, Tlustoš et al. 1997).

The lead content in the plant shoots did not reveal any bigger diversification among the treatments or exceed the limit value 25 mg Pb/kg (Anke 1987) (Tables 3–6). The biggest quantities of this metal in the shoots were detected in oat, where the grain concentrations ranged from 1.05 to 2.21 mg/kg and in straw between 3.80 and 5.67 mg/kg dry mass. The least amount was found in maize cobs, i.e. between 0.17 and 0.36 mg/kg dry mass. Significantly higher lead concentrations were determined only in the roots of maize grown in the first year of the experiment (Table 3). In the other plants no directed dependencies on this metal concentrations in the root system were found. The lead content depended on its groundwork concentrations and on plant specific features. Lead, like copper, cadmium and chromium was retained in the roots, which probably resulted from a formation of sparingly soluble lead forms in the root system. In their investigations of trace metals in oat and maize fertilized by mixed municipal and industrial sludge Dudka et al. (1991) found that the lead concentrations in these plants did not change significantly as the effect of applied sewage sludge doses. Maize contained more lead than oat.

Neither vermicomposts based on tannery sludge nor untreated sludge used for the experiment significantly increased the chromium concentrations in the plant shoots (Tables 3–6). As a rule these concentrations did not exceed 1 mg Cr/kg yield dry mass. The plants accumulated chromium primarily in their root systems. The biggest amounts were found in maize and oat roots (Tables 3 and 6). Despite high concentrations of this metal in the materials used for the treatments the chromium content in the plant shoots, which may be a source of animal fodder, remained on the deficient levels (Gorlach 1991), which may be explained by a passive uptake of this metal dependent on its solubility in soil (Kabata-Pendias and Pendias 1993). Chromium is found in sewage sludge almost exclusively as Cr(III) and its easy reduction in soil, according to Kabata-Pendias and Pendias (1993) and Czekała (1997), make it generally hardly available to plants. The mechanism of this process is probably due to trivalent chromium affinity to form complexes and chelates with cell wall components. According to Czekała (1997) such a process limits chromium penetration into cells and its translocation to the shoots, which would explain its low concentration in plant shoots. Although the results of hitherto experiments do not give reasons to include chromium among the elements indispensable for plants, still its role in various physiological processes in plants, e.g. in plant cell redox processes, activation of many enzymes including catalase and ascorbinase, regulation of plant cell plasma permeability is often emphasized, as well as its share in starch transformations and sugars accumulation (Czekała 1997).

The values of the degree of contamination indices (*C*) for plants grown in the soil fertilized with farmyard manure with added vermicomposts and untreated tannery sludge were diversified and depended on the plant species and studied element. Generally, the values of the computed parameters for zinc, nickel and cadmium were lower than one in the shoots of plants fertilized with vermicomposts, untreated tannery sludge and farmyard manure.

Above one were the values (*C*) for lead, especially in the shoots of maize and oat. The values of the discussed parameter for copper and chromium in the plant shoots were generally below one, except for oat grains and straw on all treatments. Similar dependencies were detected for the root system of the cultivated crops.

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ABSTRAKT

Výnos biomasy a obsah těžkých kovů v nadzemních částech a kořenech rostlin pěstovaných v půdě s přídavkem vermikompostů připravených na základě kalů z koželužen

Nejjednodušším způsobem likvidace čistírenských kalů je jejich aplikace v zemědělství. Toto využití je limitováno hromaděním anorganických a organických látek v těchto materiálech. Značná pozornost by měla být věnována zejména těžkým kovům, jejichž přítomnost v odpadních kalech a následně v půdách je riziková pro rostliny, zvířata a lidi. Cílem uvedených experimentů bylo stanovit vliv vermikompostů připravených z koželužních kalů na růst kořenů a nadzemních částí rostlin a na akumulaci těžkých kovů v uvedených rostlinných částech. V prvním roce po aplikaci kompostů byl jejich vliv na výnos kukuřice obdobný jako po aplikaci hnoje, ale průkazně nižší než na variantě hnojené minerálními hnojivy. Následný vliv vermikompostů na růst kořenů a nadzemních částí ozimé řepky, slunečnice a ovsa byl srovnatelný s aplikací hnoje a zřetelně lepší než v případě aplikace minerálních hnojiv. Obsah těžkých kovů se lišil v jednotlivých rostlinných druzích a jejich částech a v průměru byl nižší po aplikaci odpadních kalů než po aplikaci hnoje a minerálních hnojiv. Kovy se hromadily zejména v kořenech, extrémně vysoký obsah chromu v kalu nepůsobil jeho významnou akumulaci v rostlinách.

Klíčová slova: vermikompost; těžké kovy; *Eisenia fetida*; výnos; indexy tolerance; indexy kontaminace

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