The influence of soil treatment by untreated and composted tannery sludge on yield, nutrient status, and chromium content in selected crops

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ABSTRACT

The research is aimed to determine the effect of fertilization with untreated or composted tannery sludge on yielding, macroelement and chromium contents in plant biomass. The biggest yield diversification was observed in the first and second year of the experiment, whereas in the subsequent years no major differences in yields were discerned. The mechanism of diversified plant response to organic fertilizers supplied to the soil resulted from their different ability to utilize nutrients but was also due to crop succession and different tolerance of subsequent species to the amount of supplied chromium. Nitrogen contents in plants were diversified, despite supplementing its dose to an equal level in all treatments (except the control). It may be concluded that the nitrogen in the applied materials occurred mostly in organic forms and its availability depended on the mineralization rate. Phosphorus and magnesium content depended on the plant species and applied fertilization. Potassium was more available if applied in a mineral form whereas calcium and sodium contents increased significantly in the plant biomass after fertilization with tannery sludge containing materials. Chromium content in tannery materials did not affect the content of this element in the aboveground plant parts and the absorbed chromium was retained mainly in the plant root system.

Keywords: tannery sludge; compost; vermicompost; plant; yield; macroelement; chromium

A factor limiting biological utilization of tannery sludge is their excessive chromium burden (Filipek-Mazur 1997). Chromium level in this sludge depends on the tanning technology and the sewage treatment technology. A number of experiments on tannery sludge have demonstrated a positive effect of this waste, both raw and composted, on plant yield and soil properties (Sommers 1977, Dreiss 1986, Filipek-Mazur et al. 2000, Gondek 2002). On the other hand, a high content of chromium in this material can result in an increased chromium level in the soil (Wickliff and Tindey 1982, Filipek-Mazur et al. 1998). Regulations determining the conditions for biological use of sewage sludge are based on common levels of elements in sewage sludge. Thus, tannery sludge usually exceeded the threshold values for this element. In the European Union countries the amount of heavy metal supplied to the soil is limited by the sewage sludge dose or by the material based on it. Moreover German sewage sludge used for arable field or garden soil fertilization is classified as fertilizer and element contents in this material are assessed according to the rules for fertilizers. The regulation was supplemented by the requirements for recyclable materials, including sewage sludge for treatment (McLachlan et al. 1996, Molina et al. 2000, Oleszek-Kudlak and Rosik-Dulewska 2002).

As can be seen from some previous research, chromium in composts and vermicomposts from tannery sludge, despite its high concentrations, occurs in mobile forms extractable in small quantities by H_2O and 0.05 mol/dm^3 $CaCl_2$ (Filipek-Mazur et al. 2001). The conducted experiments have demonstrated that the application of composts and vermicomposts based on tannery sludge with excessive chromium content did not affect plant yield, quality of obtained biomass, and soil concentrations of most bio-available chromium forms (Gondek 2002, Gondek and Filipek-Mazur 2002).

The research aimed to determine the effect of fertilization with untreated or composted tannery sludge on yield, macroelement and chromium contents in plant biomass.

MATERIAL AND METHODS

Pot experiment

The pot experiment was conducted in a vegetation hall of the Department of Agricultural Chemistry,

Table 1. Chemical composition of materials used in the experiment

Determination	Soil	Farmyard manure	Sewage sludge (not converted)	Compost (sewage sludge + straw)	Vermicompost (sewage sludge + straw)
Dry mass (g/kg)	–	190	295	328	340
g/kg dry matter					
Organic C	9.10	237	163	160	166
Total N	0.87	16.7	24.0	19.2	10.5
C:N ratio	10.5	14.2	6.8	8.3	15.8
P_2O_5	192.9*	9.3	1.9	2.5	2.4
K_2O	221.8*	13.7	0.7	1.3	1.2
Ca	–	9.3	27.5	22.7	22.4
Mg	–	3.9	2.4	3.4	2.9
Na	–	1.8	4.6	7.6	5.3
mg/kg of dry matter					
Cu	5.1	3.6	11.2	10.1	9.5
Zn	103	170	195	297	300
Cr	8.0	15.1	875	458	386
Ni	5.6	4.1	24.0	15.0	14.2
Pb	21.9	9.2	20.3	40.7	29.8
Cd	1.57	0.55	0.39	0.27	0.27

* mg/kg dry matter

Agricultural University of Krakow in 1996–1999. Mitscherlich's pots containing 5 kg of air-dried soil each were applied. Sewage sludge from chemical tannery sewage treatment plant and composts and vermicompost prepared on the basis of this sludge with the addition of wheat straw were tested. The wheat straw supplement represented 10% of the sludge dry mass and composting time was 9 months. After this time a part of the compost was vermicomposted by *Eisenia fetida* redworm for 6 months. Farmyard manure and mineral salts (NPK) were used as a comparative treatment. Tannery materials used for the treatment were more abundant in nitrogen, calcium and sodium than farmyard manure, contained comparable amounts of magnesium, but far less phosphorus and potassium (Table 1). Except for chromium, none of the measured heavy metals exceeded the limit values.

The pot experiment set up in spring 1996 by independent series method comprised of 6 treatments in four replications (Table 2).

The experiment was carried out on medium compact brown soil with granulometric composition of sandy and silty loam with 23% of 0.02 mm particles. The soil reaction pH was 6.45 measured in 1 mol/dm^3 KCl solution. The soil base exchange capacity (BEC) was 86.5 mmol(+)/kg and hydrolytic acidity 9.50 mmol(+)/kg. The exact characterization of soil material is summarized in Table 1.

Various amounts of organic fertilizers (applied in the first year of the experiment) were calculated on the basis of their nitrogen concentrations. Assumed nitrogen dose was 1 g N/pot. Phosphorus level was supplemented with 0.80 g P_2O_5 [$Ca(H_2PO_4)_2.H_2O$] and potassium with 1.50 g K_2O [KCl] as chemically pure solutions. For the variant treated by mineral fertilizer, the same concentrations of nutrients were added as solutions of NH_4NO_3, $Ca(H_2PO_4)_2.H_2O$ and KCl.

As indicated in Table 2 millet (cv. Gierczyckie) was cultivated first in the first year of the experiment. After emergence the plants were thinned and 15 plants per pot were left. After millet harvesting and the application of supplementary nitrogen treatment with 0.5 g N/pot white mustard (cv. Nakielska) was sown. The plants were thinned after emergence and 12 pieces per pot were left. Both plants cultivated in the first year of the experiment were harvested at their flowering phase. In the second year of the experiment and after application of equal mineral treatment (1 g N, 0.8 g

P_2O_5 and 1.3 g K_2O per pot) the following test plants were cultivated on all treatments (except the untreated control): 5 plants per pot of maize (cv. KLG 2210) and sunflower (cv. Armawijskij). Nitrogen deficiency visible as leaf yellowing and growth inhibition was spotted during maize vegetation, so mainly top nitrogen dressing dosed 0.5 g N/pot as NH_4NO_3 was applied, except the control. Maize was harvested at leaf sheaf thickening. Following the maize harvest and additional nitrogen treatment (0.5 g N/pot) sunflower seeds were sown in the amount of 5 plants per pot. The plants were harvested at their flowering phase. In the third year of the experiment the equal amount of mineral treatment was repeated on all treatments (0.8 g N, 0.6 g P_2O_5, 1.2 g K_2O) and spring triticale (cv. Gabo) was sown. After emergence 15 plants per pot were left and then harvested at full maturity. In the fourth year after the organic treatment was applied the consecutive effect of sludge, compost and vermicompost was studied using only 0.2 g N/pot on all treatments except the control. The last crop cultivated in this experiment was maize (cv. KLG 2210) 6 plants were kept per pot and harvested at the phase of leaf sheaf thickening.

The experimental plants were harvested including roots, aboveground biomass and roots were separated, dried, weighed for determination of yield and analysed for element contents.

Analytical methods

Dry mass was assessed in the organic materials (sludge, compost, vermicompost and farmyard manure) and in the plant material after drying in

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

Treatment	Millet (1st year)			White mustard (1st year)		
	tops	roots	total	tops	roots	total
Soil no fertilization	29.88	4.70	34.58	1.87	0.30	2.17
Soil + farmyard manure	32.88	4.29	37.17	18.99	2.81	21.80
Soil + mineral fertilization	43.08	5.44	48.52	16.66	2.51	19.17
Soil + sewage sludge	37.12	4.34	41.46	17.56	2.62	20.18
Soil + compost	36.63	4.75	41.38	17.73	3.22	20.95
Soil + vermicompost	38.23	5.05	43.28	17.85	3.24	20.09
$LSD_{P < 0.05}$	2.91	0.34	2.98	1.48	0.19	1.52

Treatment	Maize (2nd year)			Sunflower (2nd year)		
	tops	roots	total	tops	roots	total
Soil no fertilization	8.61	5.30	13.91	5.63	0.92	6.55
Soil + farmyard manure	44.70	16.11	60.81	32.34	5.83	38.17
Soil + mineral fertilization	39.88	18.43	58.31	23.88	4.02	27.90
Soil + sewage sludge	32.81	10.96	43.77	37.91	7.46	45.37
Soil + compost	29.32	8.26	37.58	39.17	5.38	44.55
Soil + vermicompost	31.92	8.22	40.14	42.45	6.24	48.69
$LSD_{P < 0.05}$	2.39	0.86	3.12	3.47	0.71	3.79

Treatment	Spring triticale (3rd year)				Maize (4th year)		
	grain	straw	roots	total	tops	roots	total
Soil no fertilization	3.34	5.03	0.53	5.56	15.19	3.48	18.68
Soil + farmyard manure	21.60	27.11	2.95	30.06	70.08	16.38	86.46
Soil + mineral fertilization	21.53	28.01	2.75	30.76	49.68	10.14	59.82
Soil + sewage sludge	22.21	30.08	3.66	33.74	49.32	13.98	63.30
Soil + compost	24.97	33.72	3.47	37.19	54.69	16.55	71.24
Soil + vermicompost	24.64	31.59	3.77	35.36	58.84	15.29	74.11
$LSD_{P < 0.05}$	2.15	2.84	0.62	3.92	2.47	3.68	4.82

a dryer with hot air flow (at 70°C). Total nitrogen was determined after the sample mineralization in concentrated sulphuric acid in the open system by Kjeldahl's method using automatic Kjeltec II Plus set (Tecator). Organic carbon content was determined after the sample mineralization in potassium dichromate by Tiurin's method. Ash component contents in the organic materials and plant samples were assessed after the sample mineralization in a muffle furnace (at 450°C for 5 hrs) and the ash dissolution in nitric acid. Phosphorus content was determined by vanadium and molybdenum method in Backman DU 640 spectrometer at wavelength 436 nm. Potassium, sodium and calcium were assayed by flame photometry (FES) and magnesium, chromium and the other heavy metals (only in the organic materials) were determined by atomic absorption spectrometry (AAS) in PU 9100X Phillips apparatus (Ostrowska et al. 1991).

Evaluation of the data

Based on the results of chemical analyses of the aboveground parts, which may provide a potential forage source for animals (the top parts of millet, white mustard and maize, sunflower rain and triticale straw) molar ratios P:Ca, Mg:Ca, Mg:K, Ca:K, Na:K and K:(Ca + Mg) were calculated (Czuba and Mazur 1988).

One factor analysis of variance was applied for statistical evaluation of the analytical data and the significance of differences between arithmetical means were assessed by *t*-Student test. Chemical analyses were conducted in plant material on samples prepared as weighed means from four replications (Polish Standard 83/R-04012.00). Standard deviation (*SD*) and variation coefficient (*V*%) were calculated on the basis of the results. All chemical analyses were conducted in two parallel replications. The result of the chemical analysis was considered reliable if relative standard deviation (*RSD*) assessed from two replications did not exceed 5%.

RESULTS

As evident from Table 2, the yields of aboveground parts and roots of millet and white mustard were significantly differed. In comparison with the untreated control a significant increase in yield dry matter of millet top part was found in fertilized variants. The highest yield of millet root dry mass was detected in plants variants treated by mineral fertilizer (5.44 g/pot) followed by vermicompost treatment (5.05 g/pot) receiving mineral salt treatment (5.44 g/pot).

All the after treatments led to a lower yield of millet root dry matter than obtained on the control sample (4.70 g/pot).

The total yield of the top parts and roots of millet was the highest in combinations where mineral salt fertilization was applied. The lowest total yield of the aboveground parts and roots of millet (except control) was obtained on the farmyard manure treatment.

Control yields of white mustard dry matter were considerably lower than millet yields, which was due to nutrient depletion from the untreated soil. Comparing the treatments, significantly bigger yields of the aboveground parts were found for all fertilized variants. The white mustard root system was developed best in the soil with compost and vermicompost supplement. Increases in root dry matter were significant in comparison with farmyard manure and mineral salt treatments. The total yield of the top parts and roots of white mustard did not reveal any bigger diversification among individual treatments.

In the second year of the experiment, maize was cultivated first and followed by sunflower. The yields of the plants aboveground parts and roots dry mass were presented in Table 2.

A significant decline in dry matter yields of maize top parts was detected between the variants where substances of tannery origin were applied and mineral salt treatment. Maize produced the highest yields, i.e. 44.70 g/pot of the aboveground parts on farmyard manure, which was notably higher than assessed in the variant treated by mineral fertilizer. Root dry matter yields revealed similar relationships among treatments as for the aboveground parts. The yields of maize roots were the biggest on the objects where mineral salts (18.43 g/pot) and farmyard manure (16.11 g/pot) were applied as fertilizers. A considerable decline in the yields of maize root dry matter, both compared to mineral treatment and farmyard manure was detected on the objects where tannery materials were used.

The highest yield of the sunflower top parts dry mass, which received only 0.5 g N/pot as NH_4NO_3, except the control was produced as a consecutive effect of vermicompost (42.45 g/pot). Significantly higher yields were found for all experimental treatments related to the untreated control. The increase in yields of sunflower aboveground biomass treated by tannery materials represented from 59 to 78% compared to mineral fertilizer and from 17 to 31% compared to farmyard manure treatment. Yields of the roots on all objects where tannery materials were supplied were significantly higher than the yields obtained on farmyard manure and mineral fertilizers treatments. As compared to the untreated control notably higher yields of sunflower root

Table 3. Macroelement content in top parts and roots of millet (g/kg dry matter)

Treatment	Tops						Roots					
	N	P	K	Ca	Mg	Na	N	P	K	Ca	Mg	Na
Soil no fertilization	11.6	1.3	15.2	0.6	2.2	0.8	12.3	1.1	11.7	1.4	2.3	2.4
Soil + farmyard manure	11.0	1.9	25.6	0.3	3.1	0.5	10.8	1.2	17.0	1.5	1.9	2.2
Soil + mineral fertilization	19.4	1.8	26.7	1.2	2.4	1.4	17.2	1.4	21.4	2.5	3.0	2.4
Soil + sewage sludge	12.4	1.8	38.3	0.7	3.2	1.0	12.2	1.0	19.4	1.1	3.1	4.0
Soil + compost	12.4	1.4	48.0	0.6	3.1	0.8	12.5	1.0	19.2	0.8	2.8	4.6
Soil + vermicompost	10.9	1.5	48.0	0.6	3.3	0.8	11.1	1.0	16.2	0.9	2.2	4.5
SD	2.5	0.2	12.0	0.3	0.3	0.3	2.8	0.1	4.4	0.8	0.4	1.1
V%	20	16	37	36	12	28	22	14	23	41	16	31

dry matter were found for all of the experimental treatments.

In comparison with the control, significantly higher yields of triticale grain (3.34 g/pot) were obtained for all combinations, whereas a comparison of the variants fertilized with mineral salts (21.53 g/pot) and farmyard manure (21.60 g/pot) showed an increase in grain yields for all variants fertilized by both composts and vermicompost in the first year of the experiment. Yields of straw dry matter ranged between 5.03 g/pot for the control and 33.72 g/pot for compost treatment. Similarly as for grain and straw the lowest root yield was found for the untreated control. Plants grown in the soil amended by tannery sludge, compost, and vermicompost produced significantly higher root biomass than for mineral treatments, whereas in comparison with farmyard manure treatments a notable increase in triticale root yield was found as result of consecutive effect of untreated sludge.

Dry matter yields of maize grown in the fourth year of experiment were presented in Table 2. Yield of maize aboveground parts on farmyard manure treatment was the highest and reached 70.08 g/pot, whereas on the other treatments it was notably lower. Comparing the consecutive effect of organic materials and fertilizer effect of mineral salts presented considerable increases in yields were observed on treatments with compost and vermicompost. The increases were by 10 and 18%, respectively. In comparison with the object receiving farmyard manure the consecutive effect of compost and vermicompost of tannery origin upon maize aerial parts in the fourth year of the experiment was significantly poorer. Composts or vermicompost supplement to the soil differently influenced the yields of maize root dry matter. With exception to the control, all the treatments resulted in a significantly increased yield of roots as compared to mineral fertilizer. The highest yield of the top parts and roots was obtained for farmyard manure treatment. In comparison with the farmyard manure a consecutive effect of compost and vermicompost was significantly worse in the same year.

Table 4. Macroelement content in top parts and roots of white mustard (g/kg dry matter)

Treatment	Tops						Roots					
	N	P	K	Ca	Mg	Na	N	P	K	Ca	Mg	Na
Soil no fertilization	19.7	3.1	39.4	4.6	3.2	3.5	11.6	3.5	18.5	0.8	0.8	2.0
Soil + farmyard manure	19.2	3.2	34.7	5.4	2.4	2.9	8.80	3.0	16.9	0.8	0.9	2.6
Soil + mineral fertilization	29.1	3.5	19.8	10.3	2.3	2.9	12.8	2.9	18.1	1.1	1.0	3.0
Soil + sewage sludge	27.2	3.4	32.2	7.4	2.9	10.7	11.2	3.1	17.6	1.0	1.0	3.9
Soil + compost	22.8	3.4	32.1	6.4	2.9	8.6	8.9	2.7	16.2	1.0	1.0	3.9
Soil + vermicompost	22.5	3.3	32.5	6.6	3.0	7.4	9.4	2.6	26.0	2.5	1.2	6.3
SD	3.16	0.2	5.8	1.5	0.4	2.5	1.4	0.3	2.6	0.5	0.2	1.4
V%	14	5	17	22	16	47	14	9	14	42	21	39

Table 5. Macroelement content in top parts and roots of maize (g/kg dry matter)

Treatment	Tops						Roots					
	N	P	K	Ca	Mg	Na	N	P	K	Ca	Mg	Na
Soil no fertilization	9.1	2.9	23.5	0.6	3.6	0.4	6.3	1.4	12.3	1.4	3.2	2.5
Soil + farmyard manure	17.2	2.2	21.8	0.3	2.8	0.3	10.6	1.4	11.8	1.5	2.9	1.8
Soil + mineral fertilization	16.2	2.7	24.0	1.2	2.6	0.4	8.2	1.7	10.1	2.5	1.8	0.8
Soil + sewage sludge	23.6	2.2	28.7	0.7	2.9	0.3	13.8	1.5	11.7	1.1	3.0	7.9
Soil + compost	25.4	2.4	33.5	0.6	3.2	0.2	16.8	1.7	12.2	0.8	3.9	8.0
Soil + vermicompost	21.4	1.9	29.7	0.6	3.1	0.2	16.5	1.4	12.0	0.9	3.9	7.8
SD	4.7	0.3	4.8	0.3	0.4	0.1	3.6	0.1	1.2	0.8	0.6	2.8
V%	23	15	16	36	13	24	27	10	10	41	20	75

Obtained contents of nitrogen in the cultivated crops showed its diversification depending on fertilization and plant (Tables 3–8). Immediately after organic treatment nitrogen concentrations increased in plants receiving mineral salts in comparison with plants fertilized with farmyard manure. The least amounts of nitrogen were detected in roots for the farmyard manure treatment (10.8 g/kg dry mass). The aboveground parts of white mustard were more abundant in nitrogen than millet top parts (Tables 3 and 4). This component content fluctuated from 19.2 g/kg for farmyard manure to 29.1 g/kg dry matter for mineral treatment. For all the variants receiving organic fertilizers of tannery origin nitrogen concentrations were higher than for farmyard manure. In roots was nitrogen content the highest on the variant where mineral fertilizers were applied (12.8 g/kg dry matter).

Maize and sunflower were cultivated in the first year of the subsequent effect of organic materials. Nitrogen concentrations in maize top parts were higher in plants fertilized with tannery organic materials than in crops from farmyard manure or mineral treatment (Table 5). Nitrogen concentrations in plants fertilized with organic materials from tannery tended to higher level also for sunflower at lower absolute value (Table 6). Nitrogen content in the roots of both plants revealed similar relationships, however maize roots were apparently more abundant in this component (Tables 5 and 6). Nitrogen concentrations in grain dry mass of triticale cultivated in the second year of the subsequent effect of organic materials were substantially higher than this element content in dry matter of straw and roots (Table 7). The highest content of nitrogen was typical for grain of plants fertilized with compost and vermicompost. Nitrogen content in triticale straw was between 4.4 g/kg dry matter for the control and 7.2 g/kg dry matter for sludge and compost treatments (Table 7). In triticale roots nitrogen concentration fluctuated between 5.5 and 8.2 g/kg dry matter. Nitrogen content in top parts of maize grown in the third year of subsequent effect of organic materials did not show any substantial diversification and ranged between 7.0 and 11.3 g/kg dry mass (Table 8). In the roots the element level fell

Table 6. Macroelement content in top parts and roots of sunflower (g/kg dry matter)

Treatment	Tops						Roots					
	N	P	K	Ca	Mg	Na	N	P	K	Ca	Mg	Na
Soil no fertilization	8.8	1.8	6.4	4.6	5.0	0.1	5.6	3.8	7.9	0.8	3.5	5.0
Soil + farmyard manure	6.1	2.3	5.6	5.4	4.9	0.2	6.0	3.1	5.3	0.8	2.6	3.0
Soil + mineral fertilization	8.9	2.7	6.6	10.3	4.7	0.2	6.5	2.4	4.3	1.1	2.2	2.2
Soil + sewage sludge	10.0	2.2	4.9	7.4	4.6	0.1	5.7	1.9	3.0	1.0	1.8	7.9
Soil + compost	11.0	2.0	6.1	6.4	4.5	0.9	7.0	1.6	4.0	1.0	2.5	8.2
Soil + vermicompost	12.6	1.9	6.1	6.6	4.9	0.8	6.8	1.6	3.0	2.5	1.9	7.7
SD	2.4	0.3	0.5	1.5	0.6	0.3	1.0	0.7	1.4	0.5	0.5	2.3
V%	23	14	9	22	13	79	15	37	34	42	23	51

within the range of 7.4 g/kg for farmyard manure treatment and 9.1 g/kg dry matter in the roots of plants fertilized with vermicompost.

Phosphorus content in millet top parts (the first crop cultivated in the experiment) ranged between 1.3 and 1.9 g/kg dry matter (Table 3). The highest concentration of this element was detected in plants fertilized with farmyard manure. In comparison with this treatment the phosphorus level in the top parts of the plants fertilized with tannery organic materials was lower by between 5 and 26%. Millet roots revealed a lower content of phosphorus than its top parts and the biggest amounts of this element were found in roots of plants receiving mineral fertilizers. Phosphorus content in the aboveground parts of white mustard did not differ substantially among the treatments and fluctuated between 3.1 (control) and 3.5 g/kg dry matter (variant fertilized with mineral salts) (Table 4).

Phosphorus concentration in white mustard roots was slightly lower and fluctuated from 2.6 to 3.5 g/kg dry mass (Table 4). In the second year of the experiment were cultivated maize and sunflower. The top parts of maize on the control revealed the highest content of phosphorus resulting from its high concentration in a relatively small yield (Table 5). For organic treatments this element content approximated the level assessed in the top parts of plants from farmyard manure treatment (2.2 g/kg dry matter), but it was lower than the content found after mineral fertilization (2.7 g/kg dry matter). Maize root phosphorus content revealed similar relationships at lower contents (Table 5). Similar content of phosphorus as determined in maize was also assessed in sunflower top parts (1.8–2.7 g/kg dry matter) (Table 6). The highest values concerned plants from the minerally fertilized variant. In the roots of these plants phosphorus content ranged between 1.6 and 3.8 g/kg dry mass. The highest amounts of this component was found in the roots for the control and also in the roots of sunflower fertilized with farmyard manure (3.1 g/kg dry matter) and with mineral salts (2.4 g/kg dry matter). In the third year of the experiment the consequent effect of organic tannery materials positively affected phosphorus content in spring triticale grain (Table 7). The contents were higher than determined for mineral treatment (5.3 g/kg dry matter) and farmyard manure (5.1 g/kg dry matter). Grain phosphorus concentrations were most favourably affected by fertilization with untreated sludge (10.4 g/kg dry matter) and with composted sludge (7.0 g/kg dry matter). A reverse relationship was detected in the straw of these plants.

The phosphorus content decreased in straw of plants from variants fertilized with tannery mate-

Table 7. Macroelement content in grain, straw and roots of spring triticale (g/kg dry matter)

Treatment	Grain			Straw			Roots		
	N	P	K	N	P	K	N	P	K
Soil no fertilization	16.4	5.1	6.2	4.4	2.8	9.6	5.5	2.6	0.5
Soil + farmyard manure	17.1	5.1	5.8	5.5	1.5	38.4	5.8	1.1	5.9
Soil + mineral fertilization	21.9	5.3	6.7	7.1	2.1	38.9	8.2	1.8	17.0
Soil + sewage sludge	18.8	10.4	6.2	7.2	1.4	35.6	5.3	1.3	8.0
Soil + compost	23.3	7.0	6.0	7.2	1.2	31.0	7.2	1.2	6.3
Soil + vermicompost	23.7	6.4	5.5	6.8	0.9	33.3	7.1	1.0	14.4
SD	3.1	1.5	0.5	1.0	0.6	7.9	0.8	0.4	5.4
V%	15	24	8	15	41	25	13	33	60
	Ca	Mg	Na	Ca	Mg	Na	Ca	Mg	Na
Soil no fertilization	1.2	1.3	0.4	5.3	2.9	0.9	2.6	0.3	0.42
Soil + farmyard manure	1.4	1.0	0.3	6.7	0.7	0.2	4.1	0.6	0.04
Soil + mineral fertilization	2.3	0.9	0.4	7.3	0.5	0.2	2.9	0.6	0.15
Soil + sewage sludge	1.6	0.9	0.2	7.4	0.4	0.3	4.3	0.6	0.10
Soil + compost	1.4	1.0	0.3	7.7	0.6	0.2	5.0	0.6	0.07
Soil + vermicompost	1.4	1.0	0.1	9.1	0.5	0.3	4.4	0.5	0.09
SD	0.3	0.1	0.1	1.1	0.7	0.2	1.3	0.1	2.1
V%	18	15	37	14	103	68	27	17	95

Table 8. Macroelement content in top parts and roots of maize (g/kg dry matter)

Treatment	Tops						Roots					
	N	P	K	Ca	Mg	Na	N	P	K	Ca	Mg	Na
Soil no fertilization	7.7	2.4	5.6	5.0	7.5	0.03	7.5	0.6	2.5	5.6	1.9	4.3
Soil + farmyard manure	7.0	1.2	4.0	3.9	1.8	0.02	7.4	0.5	2.4	5.2	1.0	1.7
Soil + mineral fertilization	10.8	1.6	3.5	5.3	2.3	0.02	8.2	0.6	1.6	4.9	1.1	2.3
Soil + sewage sludge	11.3	0.9	3.0	6.9	2.1	0.02	7.9	0.2	1.1	4.2	0.6	1.9
Soil + compost	9.9	0.9	3.1	6.5	2.1	0.03	8.7	0.2	1.4	5.0	0.6	1.5
Soil + vermicompost	10.8	0.5	2.9	7.2	1.7	0.02	9.1	0.2	1.2	4.7	0.7	2.0
SD	1.5	0.5	0.8	1.1	1.7	0.1	1.1	0.2	0.5	0.7	0.4	1.0
V%	16	46	2	18	73	20	15	46	30	15	47	61

rials. Triticale roots from the control and mineral salt treatment accumulated the highest quantities of phosphorus. The subsequent effect of organic materials upon phosphorus content in maize in the fourth year after organic fertilizer application was weaker than farmyard manure and mineral salt effect (Table 8). Both top parts and roots accumulated small amounts of this element and no diversification among variants was reported.

Potassium content in millet top parts (with reference to plants from the control) increased after fertilization (Table 3). Millet roots contained between 11.7 g/kg dry matter for the control and 21.4 g/kg dry mass on mineral salt treatment. In the top parts of white mustard high and equalized potassium concentration (mean 34.2 g/kg dry matter) was found except in the mineral treatment (Table 4). This elemental content in mustard roots was lower than in its top parts, but in comparison with variants fertilized by mineral salts and farmyard manure a higher content of this element was determined for vermicompost treatment. Fertilization with tannery materials increased potassium content in the top parts and roots of maize (grown in the second year of the experiment) in comparison with mineral salt treatment and farmyard manure (Table 5). A substantially lower content of potassium, with slight diversification among the variants was characteristic for sunflower biomass (Table 6). Potassium content in triticale grain (with reference to plants from farmyard manure treatment) increased slightly in plants from variants fertilized with tannery materials. Generally, potassium content in the grain of triticale fertilized with organic materials was lower than determined for the mineral salts treatment (Table 7). Triticale straw contained notably higher amounts of this element than grain (Table 7). Lower contents of potassium were found in plants fertilized with tannery materials. Triticale roots contained more potassium than grain. In the fourth year after the application of organic fertilization no subsequent

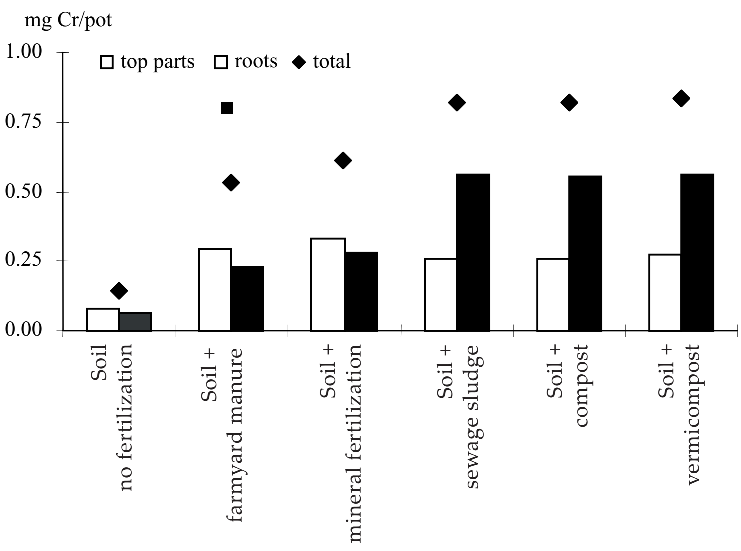

Figure 1. Chromium uptake (mg/pot) by top parts and roots of plants cultivated in pot experiment (1996–1999)

effect on maize potassium concentrations was observed (Table 8).

White mustard plants grown in the first year of the experiment on tannery material treatment were characterized by a higher content of calcium. Both in their top parts and roots in relation to plants fertilized with farmyard manure (Table 4). On the contrary, the millet top parts from the variants receiving mineral fertilizers showed higher contents of this element than in the other experimental variants. Over the subsequent two years also higher calcium content was found in plants from variants fertilized with tannery materials in comparison with plants receiving farmyard manure (Tables 5–7). In the third year of subsequent effect of organic materials (and the fourth year of the experiment) interrelationships of calcium contents in the top parts and roots of maize were similar as in the earlier years of the experiment (Table 8).

Magnesium concentrations in the top parts of millet and white mustard were similar, while millet roots were more abundant with this element other than the mustard roots (Tables 3 and 4). For organic matter treatments magnesium content in millet aboveground parts was higher than at mineral treatment. In mustard top parts the highest content of this element was found in the yield of plants from the untreated variant. It resulted from a relatively low plant yield in this case (Table 4). In the first year of the consecutive effect (and the second year of the experiment) of applied organic fertilizers maize and sunflower revealed a lower content of magnesium in their top parts for the fertilized variants in comparison with the control (Tables 5 and 6). Triticale magnesium concentrations were similar for all the experimental treatments. The contents of this element were evidently higher for the control only in the straw (Table 7). Maize cultivated in the third year of the subsequent effect of organic fertilizers (and the fourth year of the studies) contained the highest amounts of magnesium for the control. Among the treatments more of this element was detected in plants from mineral treatment (Table 8).

In the first year of the studies sodium content was the highest in the top parts of white mustard, particularly for the variants fertilized with tannery materials (Table 4). The contents ranged between 7.4 and 10.7 g/kg dry matter. In these variants were also sodium contents in millet roots the highest (between 4.0 g and 4.6 g/kg dry matter). In the top parts of plants cultivated subsequently sodium levels were generally low and no greater diversification was noticed among variants.

The roots of cultivated plants (except triticale) contained substantially more sodium than their top parts (Tables 5–8). The roots of plants fertilized with untreated sludge and its compost and vermicompost revealed the highest sodium contents.

Table 9. Molar ratios of determined elements in parts of plants cultivated in the 1st year of experiment

	Treatment	P:Ca	Mg:Ca	Mg:K	Ca:K	Na:K	K:(Ca + Mg)
Millet	soil no fertilization	2.80	6.04	0.23	0.04	0.09	3.69
	soil + farmyard manure	8.20	17.04	0.19	0.01	0.03	4.85
	soil + mineral fertilization	1.94	3.30	0.14	0.04	0.09	5.31
	soil + sewage sludge	3.33	7.54	0.13	0.02	0.04	6.57
	soil + compost	3.02	8.52	0.10	0.01	0.03	8.62
	soil + vermicompost	3.23	9.07	0.11	0.01	0.03	8.15
	SD	2.23	4.63	0.05	0.01	0.03	1.93
	V%	59	54	33	64	56	31
White mustard	soil no fertilization	0.87	1.15	0.13	0.11	0.15	4.09
	soil + farmyard manure	0.77	0.73	0.11	0.15	0.14	3.80
	soil + mineral fertilization	0.44	0.37	0.19	0.51	0.25	1.44
	soil + sewage sludge	0.59	0.65	0.14	0.22	0.57	2.71
	soil + compost	0.69	0.75	0.15	0.19	0.46	2.94
	soil + vermicompost	0.65	0.75	0.15	0.20	0.39	2.89
	SD	0.15	0.25	0.02	0.14	0.17	0.93
	V%	22	34	17	61	53	31

Table 10. Molar ratios of determined elements in parts of plants cultivated in 2nd year of experiment

	Treatment	P:Ca	Mg:Ca	Mg:K	Ca:K	Na:K	K:(Ca + Mg)
Maize	soil no fertilization	6.25	9.89	0.25	0.02	0.03	3.69
	soil + farmyard manure	9.49	15.39	0.21	0.01	0.02	4.55
	soil + mineral fertilization	2.91	3.57	0.17	0.05	0.03	4.48
	soil + sewage sludge	4.07	6.83	0.16	0.02	0.02	5.37
	soil + compost	5.18	8.79	0.15	0.02	0.01	5.84
	soil + vermicompost	4.10	8.52	0.17	0.02	0.01	5.33
	SD	2.33	3.90	0.04	0.01	0.01	0.78
	V%	44	44	19	51	41	16
Sunflower	soil no fertilization	0.51	1.79	1.26	0.70	0.03	0.51
	soil + farmyard manure	0.55	1.50	1.41	0.94	0.06	0.43
	soil + mineral fertilization	0.34	0.75	1.15	1.52	0.05	0.37
	soil + sewage sludge	0.38	1.02	1.51	1.47	0.03	0.34
	soil + compost	0.40	1.16	1.19	1.02	0.25	0.45
	soil + vermicompost	0.37	1.22	1.29	1.06	0.22	0.43
	SD	0.08	0.36	0.14	0.32	0.10	0.06
	V%	20	29	11	28	94	14

The lowest sodium content was found in the roots of plants grown on farmyard manure and in the object fertilized with mineral salts.

A relatively high concentration of chromium in tannery materials did not cause any increased content of this element in the plant top parts (Gondek and Filipek-Mazur 2002). Chromium content in plant parts which might be a potential forage source for animals was on a deficient level. The amounts of chromium taken up by the stud-

Table 11. Molar ratios of determined elements in grain and straw of spring triticale cultivated in 3rd year of experiment

	Treatment	P:Ca	Mg:Ca	Mg:K	Ca:K	Na:K	K:(Ca + Mg)
Spring triticale (grain)	soil no fertilization	5.50	1.79	0.34	0.19	0.11	1.90
	soil + farmyard manure	4.71	1.18	0.28	0.24	0.09	1.95
	soil + mineral fertilization	2.98	0.65	0.22	0.33	0.10	1.82
	soil + sewage sludge	8.41	0.93	0.23	0.25	0.05	2.06
	soil + compost	6.47	1.18	0.27	0.23	0.09	2.02
	soil + vermicompost	5.92	1.18	0.29	0.25	0.03	1.85
	SD	1.81	0.38	0.04	0.05	0.03	0.10
	V%	32	33	16	19	38	5
Spring triticale (straw)	soil no fertilization	0.68	0.90	0.49	0.54	0.16	0.98
	soil + farmyard manure	0.29	0.17	0.03	0.17	0.01	5.01
	soil + mineral fertilization	0.37	0.11	0.02	0.18	0.01	4.91
	soil + sewage sludge	0.24	0.09	0.02	0.20	0.01	4.53
	soil + compost	0.20	0.13	0.03	0.24	0.01	3.66
	soil + vermicompost	0.13	0.09	0.02	0.27	0.02	3.44
	SD	0.20	0.32	0.19	0.14	0.06	1.51
	V%	61	129	186	52	166	40

Table 12. Molar ratios of determined elements in parts of maize cultivated in 4th year of experiment

Treatment	P:Ca	Mg:Ca	Mg:K	Ca:K	Na:K	K:(Ca + Mg)
Soil no fertilization	0.62	2.47	2.15	0.87	0.01	0.33
Soil + farmyard manure	0.40	0.76	0.72	0.95	0.01	0.60
Soil + mineral fertilization	0.39	0.72	1.06	1.48	0.01	0.39
Soil + sewage sludge	0.17	0.50	1.13	2.24	0.01	0.30
Soil + compost	0.18	0.53	1.09	2.05	0.02	0.32
Soil + vermicompost	0.09	0.39	0.94	2.42	0.01	0.30
SD	0.20	0.79	0.50	0.67	0.003	0.12
V%	64	88	42	40	26	31

ied plants were evidently diversified depending mostly on the amount of plant yield and applied fertilization. Approximate amounts of this metal were found in the plant top parts fertilized both with tannery materials and traditional fertilizers (farmyard manure and mineral salts).

The total quantities of absorbed chromium were different in the subsequent years of the experiment (Figure 1). During the period from the first until the fourth year the total amount of chromium taken up by plants in the variants supplied with compost and vermicompost did not exceed 1.0 mg/pot. Plants grown on farmyard manure accumulated the lowest amount of chromium (0.53 mg/pot) followed by mineral treatment (0.61 mg/pot) and on soil no fertilization (0.15 mg/pot). A detailed interpretation of chromium content and its uptake by plants was presented in a previous publication (Gondek and Filipek-Mazur 2002).

In animal nutrition, not only contents of individual forage components play an important role but also their mutual quantitative ratios. According to Czuba and Mazur (1988) it is connected with the antagonism and synergism of elements and/or their compounds.

One of the basic criteria in the system of quantitative ratios of elements in forage is K:(Ca + Mg) ratio, which should be approximately 1.62 (Czuba and Mazur 1988). In our experiment, the closest value of this parameter was found in triticale grain (Table 11), whereas in the other plants the obtained values were too high or too low (Tables 9–12). Exceeding value 2 of the discussed ratio suggests magnesium and calcium deficiency, which may result from high potassium and nitrogen fertilization (Czuba and Mazur 1988).

Values of the other ratios were diversified and depended on the treatment (Tables 9–12). Individual crop species are characterized by different potential of nutrient uptake so it is difficult to compare the obtained results and unanimously determine fodder value of the obtained yields. Considerable quantities of calcium supplemented to the soil with doses of tannery materials might suggest much higher uptake of this element by plants, however the presence of fatty compounds in tannery materials can results in inhibited calcium uptake by plants.

DISCUSSION

The previously published investigations were predominantly concentrated on municipal sewage sludge (Burns and Boswell 1976, Zwarich and Mills 1979, Willems et al. 1981, Bidwell and Dowdy 1983, Chang et al. 1983, Elliot et al. 1990, Winiarska and Lekan 1991, Amer et al. 1997, Murillo et al. 1997). There were only a few papers focusing on industrial effluents, including tannery wastes. Thus, the discussion of the obtained results is difficult and the comparison of the results with the results of other published data is limited because of different experimental conditions (such as soil, tested plant, origin and kind of applied materials) (Mazur and Koc 1976, Czekała and Andrzejewski 1994).

The presented results demonstrated different plant responses to applied fertilization. However, it should be emphasized that compost and vermicompost treatment and untreated sludge did not limit plant yielding, as has been confirmed by higher yields of plant dry matter on these treatments in comparison with mineral fertilizers. The highest diversification in yields occurred in the first and second year of the experiment, whereas in the third and fourth year the subsequent effect of compost and vermicompost was weaker compared to our results. Filipek-Mazur (1997) obtained significantly lower yields of mustard in the first year of the experiment after the application of tannery sludge and its compost as fertilizers.

Evidently a higher yield of both top parts and roots of maize was observed on untreated and compost sludge treatments. The sunflower did not respond significantly to the kind of applied organic materials.

A considerable decrease in maize yields as a result of application of sewage sludge from chemical tannery sludge treatment plant found by Czekała et al. (1993) was confirmed by the results of this paper.

Kopeć et al. (1996) observed pot experiment showed a weaker effect of tannery sludge from chemical treatment plant on plant yield. The application of raw tannery sludge from biological treatment plant led to significant increase in yields of three crops compared to control as well as mineral fertilization. However, the application of tannery sludge from chemical treatment plant was less effective.

The mechanism of diversified plant response to sludge, compost and vermicompost of tannery origin supplied to the soil in the presented investigations could be probably mostly due to their different ability of plant species to utilize nutrients from different materials.

Nitrogen content in the experimental plants, despite of equalizing its dose to the same level on all treatments was diversified, particularly in the first year of the experiment. Expectably, the highest contents of nitrogen were detected in plants (first year of the experiment) fertilized with mineral salts. It was caused by higher bioavailability of this element supplied in mineral form than from organic materials in tannery and farmyard manure. Evidently, bioavailability of nitrogen from organic fertilizers depends on the nitrogen mineralization rate for the individual material. This statement was confirmed by increased concentrations of this element in subsequent plants at tannery material treatments and decreased content of this element in the variants receiving mineral fertilizers. Kopeć et al. (1996) detected a higher content of nitrogen in plants fertilized with sewage sludge, Lekan and Winiarska (1991) observed the same for municipal and industrial sewage sludge, and Kalembasa (1996) detected more nitrogen in plants receiving vermicomposts based on sewage sludge and meat processing wastes.

Similarly as in the experiment carried out by Kopeć et al. (1996), in the presented studies phosphorus contents depended on the plant species and applied fertilization and the consecutive effect of tannery materials on phosphorus content was comparable with farmyard manure effect but weaker than mineral treatment.

Potassium occurred at the highest level in millet, white mustard and maize in the variants fertilized with tannery materials while in the subsequently cultivated plants, except triticale straw, potassium level decreased, which confirms results obtained by Kopeć et al. (1996). Low potassium concentrations in tannery materials resulted in plant better utilization of mineral potassium applied as a supplement, which explains the fact of the gradual decline and equalizing this element level in the subsequently cultivated plants compared to mineral treatment and farmyard manure.

The studied sludge, compost and vermicompost revealed a better subsequent effect of calcium uptake than farmyard manure fertilization. Lekan and Winiarska (1991) found a higher calcium uptake by plants fertilized with municipal and industrial sewage sludge. Fertilization with vermicomposts also influenced increased calcium concentrations in yield in comparison with farmyard manure treatment, as well (Kalembasa 1996).

Similar trends were detected for sodium contents (Kopeć et al. 1996); a higher accumulation of Na was found in plants fertilized with tannery materials.

The assessment of fertilizer value of materials prepared from tannery materials should consider magnesium contents in experimental plants, as it is one of the elements determining their nutrition status. In our study, equal effect of organic materials from tannery to farmyard manure and mineral treatment on magnesium content in plants was found. Higher contents of magnesium in plants fertilized with industrial and municipal sewage and industrial wastes were found by Lekan and Winiarska (1991).

Despite a relatively high chromium content in tannery materials used for fertilization, the content of this element in the top plant parts, which may provide forage for animals remained on deficient levels. Generally, chromium retained in the plant root system as confirmed by other authors (Dudka et al. 1991, Piotrowska et al. 1991). Dudka et al. (1991) found that the content of *inter alia* chromium in oat and maize was not changed under the influence of applied sewage sludge doses. Maize contained more chromium than oats, which resulted from different uptake of this metal by various plant species. While studying the effect of the same sewage sludge on trace element concentrations in white clover and despite three-fold increasing chromium content in the soil Piotrowska et al. (1991) did not find increased chromium content in plants. Filipek-Mazur (1997) demonstrated that the chromium content in plants fertilized with organic sludge from mechanical and biological tannery treatment plant was much higher in the roots than in the top parts of the plants and depended on the applied material dose. In the top parts the author generally did not find elevated chromium concentrations.

REFERENCES

Amer A., Badawi M.A., El-Banna A.A. (1997): Effect of organic manuring on wheat plants grown in sandy soil. Annals of Agricultural Science, Cario, *42*: 107–116.

Bidwell A.M., Dowdy R.H. (1983): Cadmium and zinc availability to corn following termination of sewage sludge application. Journal of Environmental Quality, *12*: 311–316.

Burns R.E., Boswell F.C. (1976): Effect of municipal sewage on rooting of grass cittings. Agronomy Journal, *68*: 382–384.

Chang A.C., Page A.L., Warneke J.E. (1983): Accumulation of cadmium and zinc in barley grown on sludge-treated soils: A long term field study. Journal of Environmental Quality, *12*: 391–397.

Czekała J., Andrzejewski M. (1994): Fertilizer use of materials containing chromium. Proceedings of International Conference Chromium in the environment, WSI, Radom: 149–160. (In Polish)

Czekała J., Mocek A., Owczarzak W. (1993): Fertilizer activity of tannery sludge. Zeszyty Problemowe Postepów Nauk Rolniczych, *409*: 111–118. (In Polish)

Czuba R., Mazur T. (1988): Fertilization effect on yield quality. PWN, Warszawa: 1–359. (In Polish)

Dreiss S. J. (1986): Chromium migration through sludge-treated soils. Ground Water, *24*: 312–322.

Dudka S., Piotrowska M., Gałczyńska B., Bolibrzuch E. (1991): Trace metal concentrations in oat (*Avena sativa* L.) and maize (*Zea mays* L.) grown in soil with sewage sludge. In: The effect of sewage sludge treatment on trace metal concentrations in plants. IUNG, Puławy, *277*: 5–18. (In Polish)

Elliott H.A., Dempsey B.A., Maille P.J. (1990): Content and fractionation of heavy metals in water treatment sludges. Journal of Environmental Quality, *19*: 330–334.

Filipek-Mazur B. (1997): Studies on the fertilizing value of organic sludges from bio-mechanically treated tannery wastes after chromium separation. Zeszyty Naukowe Akademii Rolniczej, Kraków, 227, Rozprawy, *57*: 1–110. (In Polish)

Filipek-Mazur B., Mazur K., Gondek K. (1998): Fertilizing quality of vermicomposts of tannery sludge in pot experiment. Zeszyty Naukowe Akademii Rolniczej, Kraków, 334, Scientific Session, *58*: 75–84. (In Polish)

Filipek-Mazur B., Mazur K., Gondek K. (2000): Studies on fertilizer value of vermicomposts. Part II. The effect of vermicomposts composition of orchardgrass (*Dactylis glomerata* L.). Zeszyty Naukowe Akademii Rolniczej, Szczecin, 211, Rolnictwo, *84*: 297–302. (In Polish)

Filipek-Mazur B., Mazur K., Gondek K. (2001): The contents of heavy metal mobile forms in composts and vermicomposts based on sludge from municipal and industrial sewage treatment plants. Part I. Zinc, nickel and chromium. Zeszyty Naukowe Akademii Rolniczej, Kraków, 372, Scientific Session, *75*: 133–138. (In Polish)

Gondek K. (2002): Development of some soil properties under the influence of fertilization with composts and vermicomposts of tannery sludge. Polish Journal of Soil Science, *35*: 65–74.

Gondek K., Filipek-Mazur B. (2002): Assesment of soil mobile chromium from contents in effect of untreated and composted tannery sludge application. Acta Agrophysica, *70*: 137–148. (In Polish)

Kalembasa D. (1996): The influence of vermicomposts on the yield and chemical composition of tomato. Zeszyty Problemowe Postepów Nauk Rolniczych, *437*: 249–252. (In Polish)

Kopeć M., Mazur K., Babula J. (1996): The influence of tanner's wastes on yielding and changes of macroelements content in plants grown in a pot experiment. Zeszyty Naukowe Akademii Rolniczej, Szczecin, 172, Rolnictwo, *62*: 241–247. (In Polish)

Lekan S., Winiarska Z. (1991): Dependence of yielding, plant chemical composition and soil properties on chemical composition of sewage sludge. IUNG, Puławy, *280*: 5–28. (In Polish)

Mazur T., Koc J. (1976): Investigations of fertilizing value of tannery sludges. Part II. Effect of fertilization with tannery sludges on yield of agricultural crops. Roczniki Gleboznawcze, *27*: 113–122. (In Polish)

McLachlan M.S., Sewart A.P., Bacon J.R., Jones K.C. (1996): Persistance of PCDD/Fs in a sludge-amended soil. Environmental Science and Technology, *30*: 2567–2571.

Molina L., Diaz-Ferrero J., Coll M., Marti R., Broto-Pugi F., Comellas L., Rodriguez-Larena M.C. (2000): Study of evolution of PCDD/F in sewage sludge-amended soils for land restoration purposes. Chemosphere, *40*: 1173–1178.

Murillo J.M., Cabrera F., Lopez R. (1997): Response of clover *Trilolium fragiferum* L. cv. Salina to heavy urban compost aplication. Compost Science and Utilization, *5*: 15–23.

Oleszek-Kudlak S., Rosik-Dulewska Cz. (2002): Possibilities of sewage sludge utilization in the light of new legal regulations. Postępy Nauk Rolniczych, *5*: 47–58. (In Polish)

Ostrowska A., Gawliński A., Szczubiałka Z. (1991): Methods of soil and plant analysis and grade. Emited by Institute of Environmental Protection: 1–324. (In Polish)

Piotrowska M., Dutka S., Gałczyńska B. (1991): Trace metal concentrations in white clover (*Trifolium repens* L.) cultivated in soil with sewage sludge. In: The effect of sewage sludge treatment on trace metal concentrations in plants. IUNG, Puławy, *277*: 19–31. (In Polish)

Sommers L.E. (1977): Chemical composition of sewage sludge and analysis of their potential use as fertilizers. Journal of Environmental Quality, *6*: 225–231.

Wickliff C., Tindey D.T. (1982): Reactions of chrome tannery sludge with organic and mineral soils. Water, Air and Soil Pollution, *17*: 61–75.
Willems E., Pedersen B., Jorgensen S. (1981): Accelerated leaching of some common and trace elements from soil mixed with sewage sludge or sludge ash. Acta Agriculturae Scandinavia, *31*: 323–342.
Winiarska Z., Lekan S. (1991): The effect of composts based on urban wastes (Dano) on plant yielding and soil properties in field experiment. In: Potential use of sewage sludge and waste based compost in agriculture. IUNG, Puławy, *280*: 49–72. (In Polish)
Zwarich M.A., Mills J.G. (1979): Effects of sewage sludge application on the heavy metal content wheat and forage crops. Canadian Journal of Soil Science, *59*: 231–239.

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ABSTRAKT

Vliv aplikace čerstvého a kompostovaného koželužského kalu na výnos, výživný stav a obsah chromu u vybraných plodin

V nádobovém vegetačním pokusu byl sledován účinek aplikace koželužského kalu, a to jak neupraveného, tak i kompostovaného, na výnos, obsah makroelementů a chromu v biomase rostlin. Největší rozdíly ve výnosu rostlin byly pozorovány v prvním a druhém pokusném roce, zatímco v následujících letech nebyly zaznamenány významné rozdíly ve výnosech plodin. Rozdílná odezva pokusných rostlin na aplikaci organických hnojiv vycházela jednak z rozdílné schopnosti rostlin využívat živiny a jednak z osevního postupu a z rozdílné tolerance pokusných rostlin ke zvýšenému obsahu dodaného chromu. Obsahy dusíku v rostlinách se lišily, přestože dávka tohoto prvku byla u všech pokusných variant (kromě kontrolní) stejná. Lze předpokládat, že dusík je v aplikovaných materiálech obsažen v organické formě a jeho přijatelnost rostlinami závisí na míře mineralizace těchto materiálů. Obsah fosforu a hořčíku v rostlinách byl ovlivněn jak druhem rostliny, tak i způsobem hnojení. Draslík byl přístupnější rostlinám po aplikaci minerálních hnojiv, ale obsahy vápníku a sodíku v rostlinách se významně zvýšily po aplikaci organických hnojiv s přídavkem koželužského kalu. Obsah chromu v koželužském kalu neovlivnil významně obsah tohoto prvku v nadzemních částech rostlin a přijatý chrom byl blokován v kořenech.

Klíčová slova: koželužský kal; kompost; vermikompost; rostliny; výnos; makroelementy; chrom

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