

EFFECT OF FERTILISATION WITH COMPOST FROM MUNICIPAL SOLID
WASTES ON CONCENTRATION OF SELECTED HEAVY METALS
IN SOIL AND MAIZE

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Abstract. The aim of the study was estimation of the direct and consequential effect of fertilisation with compost from municipal wastes and compost from “green” wastes and other biodegradable wastes on the content of selected heavy metals (Cr, Pb, Cd, Ni) in maize biomass and on the content of available forms those elements in soil. The nitrogen dose applied per pot (8.60 kg of air-dry soil material) in the first year of the study in fertilised treatments was 1.00 g. In the case of treatments in which the organic materials were applied, the dose of nitrogen was introduced in whole with those materials, or as a divided dose (0.50 g N with the organic material + 0.50 g N in mineral form, NH_4NO_3). For comparison, fertilisation with chemically pure mineral salts and with swine manure was applied. The largest quantity of biomass, both aboveground parts and roots, was obtained in the first year of the study, in the treatment in which fertilisation with mineral salts was applied. In the second year, significantly the highest yields of maize biomass were obtained in treatments with composts or manure. The study showed also a positive response of maize to organic fertilisation applied in conjunction with mineral fertilisation. The introduction of considerable amounts of heavy metals into the soil with the compost from non-segregated municipal wastes did not cause their excessive accumulation in maize. Higher levels of available forms of the heavy metals under study were assayed in the soil immediately after the application of the composts than in the second year.

Keywords: maize, compost, heavy metals, soil

INTRODUCTION

Soil is a non-renewable element of the natural environment and special care should be taken to protect it against contamination. Heavy metals, next to Polycyclic Aromatic Hydrocarbons and residues of pesticides, are factors that constitute a threat to the cleanliness of the soil environment (Gigliotti *et al.* 1996, Cao *et al.* 2008). Over the recent years progressing degradation of the soils of Poland is

observed, e.g. in terms of organic matter content. The necessity of searching for alternative methods of neutralisation of biodegradable wastes and the need to improve the balance of organic matter in soils lead to the consideration of the possibility of applying processed waste organic matter for soil amendment.

Compost, as a product of aerobic microbiological transformations of biomass, is usually characterised by a considerable content of fertiliser components, hence it is justified to consider its natural utilisation, including agricultural application. The material used for the production of compost is often highly diversified and hard to homogenise. It may originate from the processing of plant biomass, from a fraction of biodegradable wastes separated from the stream of municipal wastes, or from mixed municipal wastes (Ciesielczuk and Kusza 2009). The use of composts produced from waste substances for plant and soil fertilisation appears to be the most rational method of their utilisation. The problem related with the application of such materials concerns not only their content of heavy metals, but also the rate of mobilisation of those elements (Gondek 2009, Jasiewicz and Baran 2009). Based on the total content of heavy metals in composts it is hard to predict their mobility and bioavailability, i.e. the possibility of their migration of the bio-geochemical cycle, and hence the need to determine the content of those elements in their available forms (Gondek and Filipek-Mazur 2006).

Taking into account the variation of heavy metals content in composts and their varied bioavailability, a study was performed to determine the direct and consequential effect of fertilisation with composts from non-segregated municipal wastes and from green wastes and other biodegradable wastes on the content of selected heavy metals (chromium, lead, cadmium and nickel) in maize biomass and on the content of bioavailable forms of those elements in the soil.

MATERIAL AND METHOD

The study was conducted in the years 2006-2007, under conditions of a pot experiment. The design of the experiment included 8 treatments in 4 replications, as follows:

0 – soil with no fertilisation,

M – soil with an addition of mineral salts,

FYM_I – soil with an addition of manure (0.50 g N applied with manure + 0.50 g N applied in the form of NH₄NO₃),

FYM_{II} – soil with an addition of manure (1.00 g N applied with manure),

PC_I – soil with an addition of compost from green waste and other biodegradable wastes (0.50 g N applied with compost + 0.50 g N applied in the form of NH₄NO₃),

PC_{II} – soil with an addition of compost from green waste and other biodegradable wastes (1.00 g N applied with compost),

MC_I – soil with an addition of compost from non-segregated municipal waste (0.50 g N applied with compost + 0.50 g N applied in the form of NH₄NO₃),

MC_{II} – soil with an addition of compost from non-segregated municipal waste (1.00 g N applied with compost).

The study was conducted on a soil material containing 26% of the fine particle fraction (silty sandy loam). Selected properties of the soil material are presented in Table 1.

Table 1. Some properties of soil material used in the study

Assay	Unit	Value
pH KCl		5.69
Hydrolytic acidity	mmol(+) kg ⁻¹ d.m.	23.9
Organic C	g kg ⁻¹ d.m.	15.9
Total forms		
Cr		14.1
Cd		1.14
Pb		30.2
Ni	mg kg ⁻¹ d.m.	11.2
Content of available forms		
P		328
K		373

Two composts were used in the study, from composting plants operating according to different technologies and differing in the kind of composted wastes.

The compost from green wastes and other biodegradable wastes (treatments PC_I and PC_{II}) was produced in a composting plant situated in Kraków-Płaszów, operating according to the Mut-Kyberferm technology. The technology consists in composting previously fragmented, moistened and mixed components in static bioreactors in the form of concrete boxes (size: 12 m x 3 m x 3.5 m) equipped with a system of aeration and wetting of composted mass. Intensive composting in such a bioreactor lasts from 14 to 21 days. After that time, biomass is removed from the bioreactor and transported to a intermediate maturation shed, and there it is placed in prisms. Next the compost is transported to a hard-surfaced yard where it matures for a period of 1-2 months (Filipek-Mazur and Gondek 2002).

The compost from non-segregated municipal wastes (treatments MC_I and MC_{II}) was produced in a composting plant in Katowice, operating in the Mut-Dano system. The Dano technology consists in composting municipal wastes in

a biostabiliser. The biostabiliser, in the form of a rotary drum with diameter from 2 to 4 m and length of up to 45 m, is filled with wastes to 70% of its volume. The time of composting is from 1 to 3 days. Then the material after preliminary composting is screened and subjected to further composting process in prisms, for periods of 6-12 months.

As a reference for the properties analysed in the experiment, farmyard manure was applied. Selected chemical properties were assayed in the manure and the composts (Tab. 2) according to the method given in the work by Baran and Turski (1996).

Table 2. Some chemical properties of manure and composts applied in the study

Assay	Unit	Manure	Compost made of plant waste	Compost made of municipal waste
Dry matter	g kg ⁻¹	224.8	475.9	563.4
Organic matter	g kg ⁻¹ d.m.	823.3	515.8	246.1
pH H ₂ O		8.06	7.30	7.18
Electrolytic conductivity	mS cm ⁻¹	4.57	3.80	1.41
Total forms				
N		27.31	35.61	6.78
P	g kg ⁻¹ d.m.	13.09	7.17	2.29
K		23.65	25.57	11.16
Total forms				
Cr		13.13	22.58	76.61
Pb	mg kg ⁻¹ d.m.	4.28	14.66	343.7
Cd		0.61	1.51	6.28
Ni		4.93	9.67	32.87

The dose of nitrogen applied per pot (8.60 kg of air-dry soil material) in the first year of the experiment in treatments with fertilisation was 1.00 g. In the treatments with organic materials, the dose of nitrogen was applied in whole with those materials or as a divided dose (0.50 g N applied with organic material + 0.50 g N applied in mineral form, as NH₄NO₃). In all the treatments (except for the treatment with no fertilisation), phosphorus and potassium in the soil were brought to a uniform level introduced with the composts or manure – phosphorus to 0.48 g P pot⁻¹, and potassium to 1.64 g K pot⁻¹. The supplementary dose of phosphorus was applied in the form of water solution of Ca(H₂PO₄)₂·H₂O, and

that of potassium in the form of water solution of KCl. In the treatment were fertilisation with only mineral salts was applied, nitrogen was introduced in the form of NH_4NO_3 , and phosphorus and potassium in the form of water solutions of $\text{Ca}(\text{H}_2\text{PO}_4)_2 \cdot \text{H}_2\text{O}$ and KCl. In the second year of the experiment, in all treatments except for the control supplementary fertilisation with nitrogen, phosphorus and potassium was applied, in the form of the same mineral compounds as in the first year. The doses of the mineral components applied were 0.70 g N, 0.10 g P and 1.60 g K pot^{-1} , respectively.

In both years of the experiment the test plant was maize cv. "San" which was harvested in the phase of 7-9 leaves for green fodder. The yield of maize biomass was separated into the aboveground parts and the roots, then dried at temperature of 70°C in a dryer with hot air flow, and the dry matter yield was determined. The dried and fragmented plant material was dry-mineralised in a furnace (450°C for 5 hours). The ash was dissolved in diluted (1:2) nitric acid (Ostrowska *et al.* 1991). The content of chromium, lead, cadmium and nickel in the obtained solutions was assayed with the ICP-AES method on an JY 238 Ultrace apparatus, and the results obtained were converted to absolutely dry mass of the plant material.

In both years of the experiment, after the harvest, samples of soil material were taken. After drying and grinding in a porcelain mortar, the soil material was screened through a sieve with mesh size of 1 mm. Samples prepared as above were used for the following assays: pH – potentiometrically, in a suspension of the soil and water and in a suspension of the soil and KCl solution with concentration of 1 mol dm^{-3} , and the content of selected heavy metals (Cd, Pb, Cr, Ni), after extraction from the soil with a solution of HCl with concentration of 1 mol dm^{-3} (Gembarzewski *et al.* 1987). The content of chromium, lead, cadmium and nickel in the obtained extracts was assayed with the ICP-AES method on an JY 238 Ultrace apparatus, and the results obtained were converted to absolutely dry matter of the plant material.

Analyses of the material from the experiment were made in four replications, and of the initial materials (organic material, soil material) in two, adding to each series an analytical reference sample – plant sample NCS DC733448 (China National Analysis Centre for Iron & Steel) and soil sample AgroMAT AG-2 (SCP Science). The results were accepted as credible if the relative error of determination did not exceed 5%.

Based on the yields of the aboveground parts and the roots of maize, the index of tolerance (T_i) in the particular years of the experiment was calculated. The index of tolerance T_i was the quotient of plant dry matter yield in treatments fertilised with organic material and those with mineral fertilisation.

The results of the analyses were processed statistically, including two-factor analysis of variance (factors: year of experiment and fertilisation). The significance of differences between arithmetic means was estimated with the Duncan test at significance level of $\alpha = 0.05$. The statistical calculations were made using the Statistica 9.0 PL software package.

RESULTS AND DISCUSSION

The largest amount of maize biomass, both aboveground parts and roots, was harvested in the first year of the experiment, in the treatment where mineral salts were applied (M) (Tab. 3). Among the organic materials, in the first year the yield of aboveground parts of maize was the most favourably affected by manure (FYM) and by the compost of green wastes and other biodegradable wastes (PC), better yield-forming effect being achieved in those treatments where a part of the nitrogen dose was applied in the mineral form. The lowest yield was obtained in the treatment where the dose of nitrogen was applied in whole in the form of compost from municipal wastes (MC_{II}). Application of fertilisation with the compost alone may prove to be ineffective due to the time of mineralisation of the compost and to the non-availability of nutrients in the early phases of plant growth (Gil *et al.* 2008). Bazzoffi *et al.* (1998) observed in their study a decrease of maize grain yields after the application of compost from municipal wastes as compared to the mineral fertilisation applied.

Table 3. Aboveground parts and roots yields and total (two years) yield of maize biomass

Fertilisation	Aboveground parts		Roots		Total yield
	1 st year	2 nd year	1 st year	2 nd year	
	g d.m. pot ⁻¹				
0 ¹	72.21 ^{bc 2}	48.35 ^a	12.61 ^{bcdef}	8.35 ^a	141.52 ^a
M	127.91 ⁱ	76.20 ^c	17.62 ^g	11.06 ^{abc}	232.79 ^{de}
FYM _I	115.04 ^h	94.19 ^{fg}	13.47 ^{cdef}	13.74 ^{cdef}	236.43 ^f
FYM _{II}	99.00 ^g	90.05 ^{def}	15.08 ^{efg}	15.84 ^{fg}	219.96 ^{de}
PC _I	112.05 ^h	93.59 ^{fg}	13.23 ^{cdef}	11.53 ^{bcd}	230.39 ^{de}
PC _{II}	86.79 ^{de}	85.50 ^d	12.41 ^{bcde}	14.74 ^{defg}	199.43 ^c
MC _I	96.80 ^{fg}	92.65 ^{efg}	10.77 ^{abc}	13.00 ^{cdef}	213.22 ^d
MC _{II}	69.52 ^b	84.67 ^d	9.48 ^{ab}	13.55 ^{cdef}	177.22 ^b

¹– Experimental treatments as in Material and Method, ²– Mean values marked with the same letters are not significantly different acc. to Duncan test at $\alpha = 0.05$; factors: fertilisation and year.

In the second year of the experiment a distinct consequential effect of the organic materials was observed. The yield of aboveground parts of maize in those treatments varied within the range from 85.50 g d.m. pot⁻¹ to 94.19 g d.m. pot⁻¹, higher yields being obtained in those treatments where combined organic and mineral fertilisation was applied.

Significantly the highest yields of root biomass in the second year were obtained in those treatments where composts alone or manure were applied. According to many authors (Mazur *et al.* 2000, Al Zoubi *et al.* 2008, Gil *et al.* 2008, Gondek 2009), maize is a plant with high nutrition requirements, responding positively to organic fertilisation combined with mineral fertilisation. Organic fertilisers that can be applied for maize fertilisation include FYM and liquid manure, as well as organic materials of waste origin, e.g. composts and sewage sludge.

The index of tolerance (T_i) can assume values of $T_i < 1$, $T_i = 1$, $T_i > 1$. Values below 1 indicate an inhibition of plant growth, the value of 1 indicates zero effect of the organic material introduced, and values above 1 inform about a positive effect of the organic fertilisation applied on the growth and development of plants (Spiak *et al.* 2000). In the study presented here, after the first year of the experiment the value of the index of tolerance, both in the case of aboveground parts and roots, was lower than one, which indicates an unfavourable direct effect of the organic materials applied on maize yields (Fig. 1). The lowest value of T_i for the aboveground parts and for roots alike, was obtained in the treatment in which compost from non-segregated municipal wastes was applied (treatment MC_{II}). In the second year, a favourable effect of the organic materials applied on the growth and development of the plant was observed. Both in the case of aboveground parts and roots index T_i assumed values above one. An inhibition of growth of aboveground parts and roots of maize as a result of direct effect of vermicomposts applied to the soil was observed in an earlier study by Gondek and Filipek-Mazur (2003). According to those authors, that does not have to indicate any toxic effect of the materials applied, but rather insufficient availability of nutrients for the plants.

The contents of the heavy metals under study are presented as weighted means for the two years of the study, separately for the aboveground parts and for the roots. The content of chromium in the aboveground parts of maize fell within the range from 1.24 to 1.85 mg kg⁻¹ d.m. (Tab. 4), and was lower than the maximum content of that element in fodder specified as 20 mg Cr kg⁻¹ d.m. (Regulation 2010). Significantly the highest levels of that element were found in aboveground parts of maize from the treatments in which fertilisation with the composts was applied, the content of chromium being related to the compost dose. The content of Cr in the roots varied within the range from 4.85 to 7.75 mg kg⁻¹ d.m. The largest amounts of chromium were accumulated in maize roots from the treatment with no fertilisation (0), and the lowest in those from the treatment fer-

tilised with the compost from green wastes (PC_I). Also Carbonell *et al.* (2011) observed in their study a decrease in the content of chromium in fertilised maize (both with compost and with mineral fertilisers) as compared to maize with no fertilisation. In the roots even a 5-fold higher content of chromium was found than in the aboveground parts of maize, which is confirmed by the results of studies by other authors (Gigliotti *et al.* 1996, Szatanik-Kloc 2004, Jasiewicz *et al.* 2010, Carbonell *et al.* 2011), indicating the chromium absorbed by the plant gets accumulated primarily in the root system. This reduces the risk of accumulation of element in maize parts used for fodder.

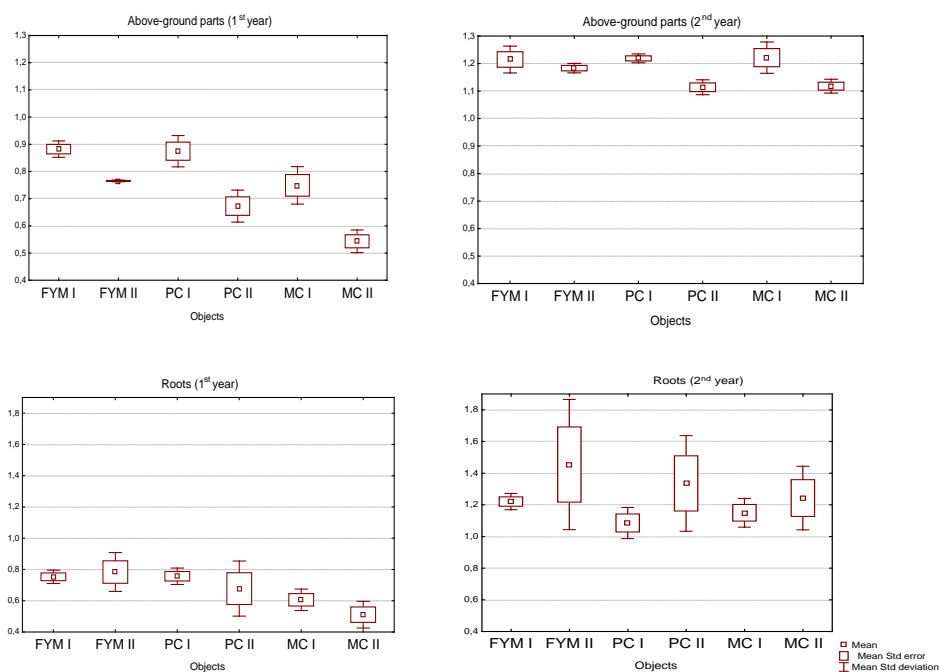


Fig. 1. Values and statistical parameters of the index of tolerance (Ti); experimental treatments as in Material and Method

Chromium, which occurs in soil mainly in the form of the cation Cr^{3+} , easily gets immobilised, thanks to which its bioavailability is limited (Gigliotti *et al.* 1996). In both years of the experiment, significantly the highest amounts of chromium were extracted, with the use of HCl solution with concentration of 1 mol dm^{-3} , from the soil with an addition of compost from non-segregated municipal wastes (MC) (Tab. 5). No significant differentiation in the content of that

form of Cr was found in the soil from the remaining treatments, which is supported by studies of Gigliotti *et al.* (1996) and Carbonell *et al.* (2011), in which the mineral and organic fertilisation applied had no effect on the level of forms of chromium extracted from the soil. Also Gondek (2004) did not observe any notable increase in the content of soluble forms of chromium after the application of tannery sediment. The solubility, in soil, of chromium introduced with wastes depends primarily on the chemical composition of the waste material, and especially on the ratio between the levels of CaO and SiO₂. Under conditions of predominance of calcium over silica, for compound CaCr₂O₄ is formed which, after oxidation, undergoes dissolution (Gondek 2004).

Table 4. Weighted means (2 years) of the content of Cr and Pb in maize biomass

Fertilisation	mg Cr kg ⁻¹ d.m.		mg Pb kg ⁻¹ d.m.	
	Aboveground parts	Roots	Aboveground parts	Roots
0 ¹	1.60 ^{cde 2}	7.75 ^b	0.45 ^{a*}	2.82 ^b
M	1.72 ^{de}	5.96 ^{ab}	0.43 ^a	2.00 ^{ab}
FYM _I	1.47 ^{abc}	5.50 ^{ab}	0.38 ^a	1.71 ^a
FYM _{II}	1.41 ^{ab}	5.95 ^{ab}	0.39 ^a	2.18 ^{ab}
PC _I	1.32 ^{ab}	4.85 ^a	0.41 ^a	1.99 ^{ab}
PC _{II}	1.85 ^e	6.41 ^{ab}	0.35 ^a	2.03 ^{ab}
MC _I	1.24 ^a	5.54 ^{ab}	0.34 ^a	2.72 ^b
MC _{II}	1.84 ^e	7.45 ^{ab}	0.40 ^a	2.79 ^b

¹– Experimental treatments as in Material and Method, ²– Mean values marked with the same letter do not differ significantly acc. to Duncan test at $\alpha = 0.05$; factors: fertilisation and year.

The fertilisation with the composts and manure did not significantly differentiate the level of lead in the aboveground parts of maize (Tab. 4) which contained from 0.34 mg to 0.45 mg Pb kg⁻¹ d.m. The roots of maize accumulated as much as 8-fold more of that element than the aboveground parts, which finds support in research results obtained by other authors (Sękara *et al.* 2005, Carbonell *et al.* 2011), indicating Pb accumulation mainly by the root system of plants. The permissible level of lead in fodders specified in the Regulation (2010) was not exceeded irrespective of the fertilisation applied. Lead uptake by plant root system is a passive process, and the amounts of Pb absorbed are proportional to the content of bioavailable forms of lead in the soil solution. Factors determining increased bioavailability of lead include acid reaction of the soil, accumulation of organic matter, and high temperature facilitating transpiration (Szatanik-Kloc 2004, Chong *et al.* 2005).

Lead is highly toxic to living organisms, but as opposed to cadmium it is characterised by low mobility in the soil environment due to strong binding of the element by organic matter, clay minerals and hydrated oxides of iron and manganese (Chong *et al.* 2005, Ingelmo *et al.* 2011). It rarely appears in the soil solution in the form of Pb^{2+} cation, whereas it forms complex compounds unavailable to plants (Chong *et al.* 2005, Ingelmo *et al.* 2011). In both years of this experiment, significantly the highest levels of lead extracted from the soil with the use of HCl solution with concentration of 1 mol dm^{-3} were found in soil with an addition of compost from non-segregated municipal wastes (treatments MC_I and MC_{II}) (Tab. 5). Differences in the level of that form of lead in the soil of the remaining treatments were not statistically significant. After the second year of the experiment, lower levels of available forms of lead were found in the soil of all the treatments. Numerous studies indicate a lack of increased solubility of lead in soil after the application of waste materials (Gondek 2004, Iżewska *et al.* 2009), which can be attributed to strong sorption of that element by the solid phase of soil. The results of studies by Gigliotti *et al.* (1996) and Smith (2009) demonstrate that lead appears in compost mainly in the residual fraction, which reduces its availability for plants.

Table 5. Content of Cr and Pb extracted from soil with HCl solution with concentration of 1 mole dm^{-3} after 1st and 2nd year of investigations

Fertilisation	Cr		Pb	
	1 st year	2 nd year	1 st year	2 nd year
	mg Cr kg^{-1} d.m. of soil		mg Pb kg^{-1} d.m. of soil	
0^1	1.56 ^{cd} ²	1.38 ^{ab}	24.86 ^b	23.64 ^{ab}
M	1.57 ^{cd}	1.37 ^{ab}	24.34 ^b	22.22 ^a
FYM _I	1.63 ^{de}	1.47 ^{bc}	24.31 ^b	22.48 ^a
FYM _{II}	1.65 ^{de}	1.35 ^a	24.93 ^b	22.38 ^a
PC _I	1.57 ^{cd}	1.43 ^{ab}	24.42 ^b	23.73 ^{ab}
PC _{II}	1.62 ^{de}	1.41 ^{ab}	24.66 ^b	22.54 ^a
MC _I	1.89 ^f	1.33 ^a	27.97 ^c	23.43 ^{ab}
MC _{II}	1.90 ^f	1.71 ^e	31.92 ^d	29.35 ^c

¹– Experimental treatments as in Material and Method, ²– Mean values marked with the same letter do not differ significantly acc. to Duncan test at $\alpha = 0.05$; factors: fertilisation and year.

The content of cadmium in the aboveground parts of maize did not limit the possibility of its use as fodder (Regulation, 2010) (Tab. 6). The highest levels of

cadmium in the aboveground parts of maize were found after the application of mineral salts (treatment M), composts and manure, higher content of the element being assayed in plants from treatments where the whole dose of nitrogen was applied in the form of those materials. Higher levels of cadmium were noted in the roots than in the aboveground parts of maize, which is conformance with research by other authors (Gondek 2004, Sądej and Namiotko 2008). Livera *et al.* (2011) attribute the limited transport of cadmium to the aboveground parts of plants and its greater accumulation in roots to the high affinity of that element to the sulphhydryl groups of proteins. Cadmium phytochelates formed are not toxic to plants. The highest levels of cadmium were assayed in the roots of plants from the treatment with zero fertilisation ($2.48 \text{ mg Cd kg}^{-1} \text{ d.m.}$), which can be attributed to the effect of dilution in the higher yield of maize in the remaining treatments. In maize roots from treatments fertilised only with organic materials higher content of cadmium was assayed than in maize from treatments where a part of the nitrogen dose was applied in mineral form. The differences, however, were not statistically significant. The organic fertilisation applied did not differentiate the values of that parameter. According to Bruwaene *et al.* (1984), the content of cadmium in plant organs decreases in the following sequence: roots > leaves > seeds > storage organs.

Cadmium displays genotoxic and cytotoxic effects towards plant and animals cells alike (Deckert 2005). The element is characterised by considerable mobility in the soil environment, due to which it can be easily included in the food chain (Livera *et al.* 2011, Carbonell *et al.* 2011). After the first year of the experiment, the level of cadmium extracted from the soil with HCl solution with concentration of 1 mol dm^{-3} did not differ statistically significantly among the particular treatments and varied from 0.95 to $1.09 \text{ mg Cd kg}^{-1} \text{ d.m.}$ of soil (Tab. 7). After the second year, in the soil from all the treatments a decrease in the level of that form of cadmium was observed, which can be attributed to the uptake of the metal by plants. Numerous studies indicate a significant effect of soil reaction on the solubility of cadmium compounds (Gondek 2004, Chong *et al.* 2005, Smith 2009). In this experiment, soil reaction facilitated the solubility of cadmium compounds, even though an increase in soil pH was noted after the application of organic materials.

The content of nickel in plant is usually within the range from 0.1 mg Ni to $5.0 \text{ mg Ni kg}^{-1} \text{ d.m.}$ (Szatanik-Kloc 2004). In the study presented here the content of that metal was within the range given above (Tab. 6). A significantly higher content of nickel was found in aboveground parts of maize from treatments fertilised with compost alone (treatments PC_{II} and MC_{II}), mineral salts, and from the treatment with no fertilisation. Maize roots contained notably higher levels of

nickel compared to the aboveground parts, as by accumulating nickel they prevented its translocation. No significant differences in nickel content in the roots were observed among the treatments, which is in conformance with the results obtained by other authors (Szatanik-Kloc 2004, Carbonell *et al.* 2011), confirming the lack of effect of both organic and mineral fertilisation on the content of nickel in plant roots. The absence of any greater variation in nickel content in maize roots can be attributed to the low concentration of that element in the organic materials applied.

Table 6. Weighted means (2 years) of the content of Cd and Ni in maize biomass

Fertilisation	Aboveground parts	Roots	Aboveground parts	Roots
	mg Cd kg ⁻¹ d.m.		mg Ni kg ⁻¹ d.m.	
0 ¹	0.17 ^{a 2}	2.48 ^c	0.76 ^{c*}	3.90 ^b
M	0.30 ^e	1.81 ^b	0.79 ^c	2.44 ^{ab}
FYM _I	0.21 ^{bc}	1.69 ^b	0.49 ^a	2.94 ^{ab}
FYM _{II}	0.25 ^{cd}	1.53 ^{ab}	0.57 ^a	3.11 ^{ab}
PC _I	0.27 ^{de}	1.71 ^b	0.59 ^{ab}	2.21 ^a
PC _{II}	0.28 ^{de}	1.69 ^b	0.82 ^c	3.30 ^{ab}
MC _I	0.21 ^{ab}	1.21 ^a	0.58 ^a	2.72 ^{ab}
MC _{II}	0.26 ^d	1.43 ^{ab}	0.72 ^{bc}	2.96 ^{ab}

¹– Experimental treatments as in Material and Method, ²– Mean values marked with the same letter do not differ significantly acc. to Duncan test at $\alpha = 0.05$; factors: fertilisation and year.

In the soil environment nickel occurs generally in forms bound by organic matter, especially in the form of mobile chelates, and soil contamination with that element is encountered rarely. Nickel is also subject to occlusion by hydrated oxides of Fe and Mn, it is sorbed by the sorptive complex of soil, and bound within the grid of clay minerals (Smith 2009). Both after the first and after the second year of the experiment non greater variation was found in the content of nickel extracted with HCl solution with concentration of 1 mol dm⁻³ among the soils from the particular treatments (Tab. 7). Whereas, Carbonell *et al.* (2011) extracted twice as much nickel from soil with mineral fertilisation as compared to control soil, based on which they concluded that Ni content in soil increased after the application of mineral fertilisers.

Table 7. Content of Cd and Ni extracted from soil with HCl solution with concentration of 1 mol dm^{-3} after 1st and 2nd year of investigations

Fertilisation	Cd		Ni	
	1 st year	2 nd year	1 st year	2 nd year
	mg Cd kg ⁻¹ d.m. of soil		mg Ni kg ⁻¹ d.m. of soil	
0 ¹	0.99 ^{cdef 2}	1.00 ^{cdefg}	2.66 ^{bcde}	2.69 ^{bcdef}
M	0.95 ^{bcde}	0.91 ^{abc}	2.62 ^{abcd}	2.61 ^{abcd}
FYM _I	1.03 ^{efg}	0.97 ^{bcdef}	2.70 ^{cdef}	2.77 ^{def}
FYM _{II}	1.03 ^{efg}	0.88 ^{ab}	2.66 ^{bcde}	2.54 ^{abc}
PC _I	1.00 ^{cdefg}	0.94 ^{bcde}	2.51 ^{ab}	2.61 ^{abcd}
PC _{II}	1.01 ^{defg}	0.93 ^{bcd}	2.53 ^{abc}	2.69 ^{bcdef}
MC _I	1.06 ^{fg}	0.82 ^a	2.82 ^{ef}	2.46 ^a
MC _{II}	1.09 ^g	1.01 ^{defg}	2.84 ^f	2.71 ^{cdef}

¹– Experimental treatments as in Material and Method, ²– Mean values marked with the same letter do not differ significantly acc. to Duncan test at $\alpha = 0.05$; factors: fertilisation and year.

CONCLUSIONS

1. In the first year of the experiment, the largest yields of maize biomass were harvested in the treatment in which mineral fertilisation was applied. In the second year, the yield of maize biomass was significantly better under the effect of fertilisation with the composts and manure as compared to mineral fertilisation.

2. The amounts of chromium, lead, cadmium and nickel introduced into the soil with the composts did not cause exceeding of the permissible levels of those elements in aboveground parts of maize used as fodder.

3. The levels of lead in the aboveground parts and in the roots of maize did not display variation among the particular treatments. The largest amounts of chromium, cadmium and nickel were assayed in aboveground parts of maize from treatments fertilised with composts alone, and in roots from the treatment with no fertilisation.

4. Higher levels of available forms of the heavy metals were assayed in the soil directly after the application of the composts than in the second year of the experiment. The solubility of the heavy metals in soil was related to the kind of element.

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NAWOŻENIE KOMPOSTAMI Z ODPADÓW KOMUNALNYCH A ZAWARTOŚĆ WYBRANYCH METALI CIĘŻKICH W GLEBIE I W KUKURYDZY

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Streszczenie. W badaniach oceniono bezpośredni i następczy wpływ nawożenia kompostem z niesegregowanych odpadów komunalnych oraz kompostem z odpadów roślinnych i innych biodegradowalnych na zawartość wybranych metali ciężkich (Cr, Pb, Cd, Ni) w biomacie kukurydzy, a także na zawartość dostępnych form tych pierwiastków w glebie. Dawka azotu zastosowana w przeliczeniu na wazon (8,60 kg powietrznie suchego materiału glebowego) w pierwszym roku badań w obiektach nawożonych wynosiła 1,00 g. W przypadku obiektów, w których zastosowano materiały organiczne dawka azotu została wprowadzona w całości z tymi materiałami lub jako dawka podzielona (0,50 g N z materiałem organicznym + 0,50 g N w formie mineralnej NH_4NO_3). Dla porównania zastosowano nawożenie czystymi chemicznie solami oraz obornikiem trzody chlewnej. Największą ilość biomasy, zarówno części nadziemnych jak i korzeni, uzyskano w pierwszym roku badań w obiekcie, w którym zastosowano nawożenie solami mineralnymi. W drugim

roku badań istotnie największe plony biomasy kukurydzy uzyskano w obiektach, w których zastosowano komposty lub obornik. Badania wykazały również pozytywną reakcję kukurydzy na nawożenie organiczne w połączeniu z mineralnym. Wprowadzenie do gleby z kompostem z niesegregowanych odpadów komunalnych znacznych ilości metali ciężkich nie spowodowało nadmiernego ich nagromadzenia w kukurydzy. Więcej przyswajalnych form badanych metali ciężkich w glebie oznaczono bezpośrednio po zastosowaniu kompostów niż w drugim roku badań.

Słowa kluczowe: kukurydza, kompost, metale ciężkie, gleba