

THE EFFECT OF COMPOST MADE WITH SEWAGE SLUDGE ON HEAVY METAL CONTENT IN SOIL AND IN *LOLIUM MULTIFLORUM* LAM.

Elżbieta Malinowska¹

¹ Department of Grassland and Green Areas Creation, Siedlce University of Natural Sciences and Humanities, Faculty of Natural Science, Institute of Agronomy, 08-110 Siedlce, Poland, e-mail: malinowskae@uph.edu.pl

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ABSTRACT

The aim of this paper is to assess the effects of different doses of sewage sludge compost mixed with wheat straw on heavy metal content in Italian ryegrass and in soil. A two year experiment with the Italian ryegrass was set up in autumn 2012. The experimental design consisted of a control plot, a plot with NPK fertiliser and three plots with three different doses of municipal sewage sludge compost (5, 10 and 15 Mg of fresh matter·ha⁻¹). Those different compost doses contained the amounts of Nitrogen equivalent to 60, 120 and 180 kg·N·ha⁻¹. The two lower doses of compost were supplemented with nitrogen fertiliser so that the amount of this chemical element introduced to the soil of all plots with compost stood at 180 kg·ha⁻¹. During 2013 and 2014 seasons the grass was cut three times a year after about a 30-day growing period. After dry mineralisation, the content of Zn, Cu, Ni, Pb and Cd in the plant samples was measured with the ICP-AES method. The fertilisers applied significantly diversified the content of chemical elements in the grass and in the soil. The highest dose of compost resulted in the highest concentration of Zn, Cu and Cd in the grass while the highest concentration of Ni and Pb was in the soil and the grass from the plot where the mid dose of compost had been applied. Cadmium concentration in the soil was the highest in the plot where the mid dose was applied. The experiment proved that compost made with sewage sludge and wheat straw is beneficial for plants.

Keywords: heavy metals, compost, *Lolium multiflorum*, soil

INTRODUCTION

It seems that because of economic growth, rising standard of living and legal restrictions the amount of waste will continue to rise in the future. Now when European Union member states have agreed to adhere to regulations on hazardous waste treatment, attempts are being made to find the best ways of their storage and disposal [Ministry of Economy Regulation of 2007, Directive 2008, Waste Management Act of 2012]. High prices of mineral fertilisers, the falling number of farm animals as well as the falling amount of manure are the reason why organic waste is used in agriculture. According to many publications [Speir et al. 2003, Skowrońska 2005, Harrison et al. 2006, Debosz et al. 2012]

sewage sludge application to agricultural land contributes to rising amounts of nutrient in soil. Sewage sludge contains a high amount of organic substances and nutrients but also macroelements and microelements [Malinowska et al. 2015]. However, it also contains a high amount of heavy metals, most of them being accumulated in plants [Behel et al. 1983, Álvarez et al. 2002, Kalembasa, Malinowska 2013]. That is why the rising use of sewage sludge or compost made with it should be closely monitored in the soil-plant system [Shrivastava, Banerjee 2004, Yürük, Bozkurt 2006].

The aim of this paper is to assess the effect of different doses of compost made with sewage sludge and wheat straw on heavy metal content in soil and in Italian ryegrass.

MATERIALS AND METHODS

The experiment was carried out at the experimental station of the University of Natural Sciences and Humanities in Siedlce (52°17'N, 22°28'E). Loam soil, with neutral pH_{KCl} of 6.75, containing $37.0 \text{ g}\cdot\text{kg}^{-1}$ of organic carbon and $1.75 \text{ g}\cdot\text{kg}^{-1}$ of total nitrogen, was taken from the plough layer (0–25 cm). The average concentration of available phosphorus and potassium determined with the Egner-Rhiem method stood at $39.9 \text{ mg}\cdot\text{kg}^{-1}$ and $128 \text{ mg}\cdot\text{kg}^{-1}$, respectively. Before the experiment was set up, the total amount of heavy metals in the soil was measured and it was as follows ($\text{mg}\cdot\text{kg}^{-1}$): Pb – 5.03; Cd – 0.550; Cr – 3.09; Cu – 3.20; Zn – 16.56; Ni – 2.96. Those results were lower than the limits for municipal sewage sludge applied to light soil imposed by the Minister of the Environment Regulation of 2010. The concentration of some other chemical elements was as follows ($\text{g}\cdot\text{kg}^{-1}$): P – 1.05; K – 1.00; Ca – 2.40; Mg – 1.25; S – 0.508; Na – 0.312. The Kroto variety of Italian ryegrass was used in the randomised experiment set up in the autumn of 2012 and replicated three times. The experimental area was divided into the following 2.5 m^2 plots: control plot with no fertilisers, a plot with NPK fertilisers applied with the ratio of 1:0.3:0.8 and plots with three different doses of compost based on sewage sludge: 15, 10 and $5 \text{ Mg}\cdot\text{ha}^{-1}$ of fresh matter, each containing the amount of nitrogen equivalent to 180, 120 and $60 \text{ kg}\cdot\text{N}\cdot\text{ha}^{-1}$, respectively. Nitrogen fertilisers were applied three times a year: in early spring before the growing season, and after the first and second cut, while phosphorus and potassium fertilisers were used only once, before sowing. With the application of ammonium sulphate the amount of nitrogen applied was supplemented to $180 \text{ kg}\cdot\text{ha}^{-1}$ on those plots where the rate of nitrogen introduced with the compost was lower than that. We use the following indications: I dose of compost – $15 \text{ Mg}\cdot\text{ha}^{-1}+\text{N}_{0}$, II dose of compost – $10 \text{ Mg}\cdot\text{ha}^{-1}+\text{N}_{60}$, III dose of compost – $5 \text{ Mg}\cdot\text{ha}^{-1}+\text{N}_{120}$. This way there was the same amount of nitrogen applied to each plot. The same kinds of inorganic fertilisers were used each year. As said above, the compost contained

municipal sewage sludge and 15% of wheat straw (in relation to dry mass), with the composting process lasting six months. The compost obtained this way was of neutral pH (Table 1). Like in the case of soil, the total concentration of heavy metals in the compost did not exceed the limits of Fertilisers and Fertilisation Act of 10th July 2007 and Waste Management Act of 2012.

In each growing season of the 2013 and 2014 the grass was cut three times every 30 days, on average. After each cut grass samples were taken and total concentration of Zn, Cu, Ni, Pb and Cd was measured with the ICP – AES method, after dry mineralisation in a muffle furnace at the temperature of $450 \text{ }^{\circ}\text{C}$. Then, 5 ml of hydrochloric acid solution (1:1) was added and the porcelain crucible was put into a sand bath to decompose carbonates and to isolate silica. Next, the contents of the crucible, after adding 10 ml of 10% of hydrochloric acid, were put into a 100 ml conic flask. Additionally, after each year of the experiment soil samples were taken and heavy metal content was determined with the ICP–AES method.

The results were processed statistically to analyse means with the analysis of variance (using the Statistica programme, Version 10.0 StatSoft). Tukey's test was used to calculate the $\text{LSD}_{0.05}$ value.

RESULTS AND DISCUSSION

The average concentration of zinc in the biomass of Italian ryegrass was $59.05 \text{ g}\cdot\text{kg}^{-1}$ D.M. and was significantly differentiated under the influence of experimental factors and their interaction (Table 2). Zinc concentration in fodder should range from 50 to $100 \text{ mg}\cdot\text{kg}^{-1}$ D.M. [Regulation 2007] and, according to Bednarek et al. [2008], the average content of zinc in non-contaminated plants ranges from 10 to $70 \text{ mg}\cdot\text{kg}^{-1}$ D.M. In the present experiment zinc concentration did not exceed $100 \text{ mg}\cdot\text{kg}^{-1}$ DM. The highest amount of zinc (mean of 2 years) was found in the biomass of the first cutting ($60.63 \text{ mg}\cdot\text{kg}^{-1}$ D.M.), and the lowest in the biomass of the third cut-

Table 1. Physico-chemical characteristics of the compost made with sewage sludge

pH	DM	Organic matter	N_{tot}	C_{org}	Pb	Cd	Ni	Zn	Cu	Cr	Co	Hg	Fe	Mn	Mo
	%	% s.m.	$\text{g}\cdot\text{kg}^{-1}$		$\text{mg}\cdot\text{kg}^{-1}$										
6.8	27	51	45.0	352	72.3	0.55	2.96	879.0	85.4	24.1	2.12	0.99	6541	311	2.08

Table 2. Total zinc concentration ($\text{mg} \cdot \text{kg}^{-1}$ D.M.) in Italian ryegrass

Fertilization variants	Cuts – means of 2 years			Years – means of 3 cuts		Means of years
	I	II	III	2013	2014	
Control object	31.23	30.29	29.98	30.10	30.90	30.50
NPK	33.01	30.14	30.99	32.96	29.80	31.38
I dose +N ₀	94.14	92.38	90.12	93.55	90.88	92.21
II dose +N ₆₀	78.21	69.09	73.65	76.09	71.21	73.65
III dose +N ₁₂₀	66.57	70.12	65.89	71.67	63.38	67.53
Mean	60.63	58.40	58.13	60.88	57.23	59.05
LSD _{0.05} for: fertilization (F) - 0.804; cuts (C) - 0.532; years (Y) - 0.362; FxC - 1.39; CxF - 1.19; FxY - 1.39; YxF - 0.990; CxY - 0.752; YxC - 0.626						

I – dose of compost – 15 $\text{Mg} \cdot \text{ha}^{-1}$ +N₀, II – dose of compost – 10 $\text{Mg} \cdot \text{ha}^{-1}$ +N₆₀, III – dose of compost – 5 $\text{Mg} \cdot \text{ha}^{-1}$ +N₁₂₀

ting ($58.13 \text{ mg} \cdot \text{kg}^{-1}$ D.M.). Analysing the effects of different compost doses on the content of this chemical element it was found that the highest dose of compost resulted in threefold increase in the amount of zinc when compared to the control plot and the plot with mineral fertiliser NPK. The falling amount of this metal in the grass of the second and third cutting means that zinc introduced with municipal waste quickly changes to soluble forms [Jakubus, Czekala 2001, Czekala et al. 2012]. Balcer, Wołoszyk [2012] found zinc concentration to be much lower in the biomass of *Festulolium* fertilised with compost made with biodegradable waste.

Copper concentration in Italian ryegrass was dependent on the dose of fertilisers and on the cutting (Table 3). The highest amount of this metals was found in the grass of the first cutting ($8.38 \text{ mg} \cdot \text{kg}^{-1}$ D.M.) while in the grass of the second cutting the amount of copper was 11.2%, lower than in the first one. In turn in the grass of the third cutting it was 5.7% lower than in the grass of the second cutting. The average copper concentration out of all years and cuttings was 7.90

$\text{mg} \cdot \text{kg}^{-1}$ D.M.. According to Baran et al. [2007] copper concentration in the fodder grass should ranged from 7.1 to $10 \text{ mg} \cdot \text{kg}^{-1}$ D.M.. The highest copper concentration was in grass with the highest dose of compost (on average $9.20 \text{ mg} \cdot \text{kg}^{-1}$), and the lowest in the control plot and in the plot with NPK fertiliser (5.91 and $7.58 \text{ mg} \cdot \text{kg}^{-1}$, respectively). The average copper concentration in grass is $5.5 \text{ mg} \cdot \text{kg}^{-1}$, in non-contaminated areas while in the areas with copper processing industry it is $12.25 \text{ mg} \cdot \text{kg}^{-1}$ [Rosada 2007]. According to Framework Guidelines for Agriculture [1993] the concentration of this metal should not exceed $25 \text{ mg} \cdot \text{kg}^{-1}$.

The total concentration of nickel in the biomass of Italian ryegrass was $2.32 \text{ mg} \cdot \text{kg}^{-1}$ and was significantly dependent on fertilisation and cutting (Table 4). Like in the case of copper, nickel concentration did not differ significantly by year. The highest concentration of nickel was in ryegrass of the first cutting. In the second and third cuttings the concentration of this metal was lower than in the first one, 16.3% and 19.7%, respectively. The mid dose of compost ($10 \text{ Mg} \cdot \text{ha}^{-1}$)

Table 3. Total copper concentration ($\text{mg} \cdot \text{kg}^{-1}$ D.M.) in Italian ryegrass

Fertilization variants	Cuts – means of 2 years			Years – means of 3 cuts		Means of years
	I	II	III	2013	2014	
Control object	6.55	5.17	6.01	5.97	5.85	5.91
NPK	8.10	7.08	7.56	7.89	7.27	7.58
I dose +N ₀	9.78	8.70	9.11	8.99	9.41	9.20
II dose +N ₆₀	9.01	9.26	8.47	8.71	9.12	8.91
III dose +N ₁₂₀	8.45	7.01	8.30	8.01	7.83	7.92
Mean	8.38	7.44	7.89	7.91	7.90	7.90
LSD _{0.05} for: fertilization (F) - 0.442; cuts (C) - 0.292; years (Y) - n.s.; FxC - 0.765; CxF - 0.654; FxY - 0.756; YxF - 0.544; CxY - n.s.; YxC - n.s.						

I – dose of compost – 15 $\text{Mg} \cdot \text{ha}^{-1}$ +N₀, II – dose of compost – 10 $\text{Mg} \cdot \text{ha}^{-1}$ +N₆₀, III – dose of compost – 5 $\text{Mg} \cdot \text{ha}^{-1}$ +N₁₂₀, n.s. – not significant difference

Table 4. Total nickel concentration ($\text{mg} \cdot \text{kg}^{-1}\text{D.M.}$) in Italian ryegrass

Fertilization variants	Cuts – means of 2 years			Years – means of 3 cuts		Means of years
	I	II	III	2013	2014	
Control object	1.81	1.54	1.68	1.81	1.54	1.68
NPK	1.97	1.60	1.74	2.04	1.50	1.77
I dose +N ₀	2.70	2.64	2.08	2.35	2.59	2.47
II dose +N ₆₀	3.74	2.41	2.89	2.71	3.32	3.01
III dose +N ₁₂₀	3.01	2.87	2.19	2.47	2.91	2.69
Mean	2.64	2.21	2.12	2.28	2.37	2.32
LSD _{0.05} for: fertilization (F) - 0.324; cuts (C) - 0.214; years (Y) – n.s.; FxC - 0.561; CxF - 0.480; FxY - 0.561; YxF - 0.399; CXY - n.s.; YxC - n.s.						

I – dose of compost – $15 \text{ Mg} \cdot \text{ha}^{-1} + \text{N}_0$, II – dose of compost – $10 \text{ Mg} \cdot \text{ha}^{-1} + \text{N}_{60}$, III – dose of compost – $5 \text{ Mg} \cdot \text{ha}^{-1} + \text{N}_{120}$, n.s. – not significant difference

resulted in an increase in nickel concentration in Italian ryegrass by 44.2% compared to the control plot and by 41.2% compared to the plot with NPK fertiliser.

According to Kabata-Pendias, Pendias [1999] lead concentration in plants from non-polluted areas should not exceed $3 \text{ mg} \cdot \text{kg}^{-1}$. In the present experiment concentration of this metal ranged from 0.634 to $2.22 \text{ mg} \cdot \text{kg}^{-1}$, being on average $1.22 \text{ mg} \cdot \text{kg}^{-1}$ (Table 5). In the grass of the first cutting there was more lead than in the grass of the second cutting. There was also significantly more of this metal in the second year than in the first year. There was twice as much lead in the grass from the plot with the mid dose of compost applied as in the grass from the plot with NPK fertiliser.

The total concentration of cadmium was $0.411 \text{ mg} \cdot \text{kg}^{-1}$ (Table 6) and it was lower than the limit of $1 \text{ mg} \cdot \text{kg}^{-1}$ for this metal content in fodder plants [Kabata-Pendias, Pendias 1999]. Symanowicz [2005] and Kalembasa, Malinowska [2010] provide a similar content of cadmium in Italian ryegrass grown on soil with sewage sludge compost applied. The highest amount of cadmi-

um was in the grass of the first cutting with the lowest amount in the grass of the second cutting. The concentration of this metal in the biomass was dependent on fertilisation and the year. There was a significant decrease of cadmium concentration in the grass in the second year, when it was 10.1% lower, on average, compared to the first year. The highest concentration of cadmium in Italian ryegrass ($0.526 \text{ mg} \cdot \text{kg}^{-1}$) was noted in the plot with the highest dose of compost, while the lowest in the plot with the lowest dose of compost and in the control plot, 0.320 and $0.366 \text{ mg} \cdot \text{kg}^{-1}$, respectively.

According to many publications heavy metal accumulation by plants is not always related to their concentration in the soil [Czekała et al. 2012]. What determines it is soil conditions, plant species but also a potential of a given element to be released from stable forms [Pavlikova et al. 2007]. Kabata-Pendias et al. [1993] put the limits of heavy metals in fodder plants in the following order: $<100 \text{ mg Zn} < 30 \text{ mg Cu} < 20 \text{ mg Cr} < 50 \text{ mg Ni} < 10 \text{ mg Pb}$ and $<0.5 \text{ mg Cd} \cdot \text{kg}^{-1} \text{ D.M.}$ Biomass with heavy metal content exceeding those limits

Table 5. Total lead concentration ($\text{mg} \cdot \text{kg}^{-1}\text{D.M.}$) in Italian ryegrass

Fertilization variants	Cuts – means of 2 years			Years – means of 3 cuts		Means of years
	I	II	III	2013	2014	
Control object	0.981	0.748	0.779	0.729	0.942	0.836
NPK	0.654	0.8,01	0.747	0.634	0.834	0.734
I dose +N ₀	1.11	1.54	1.02	1.12	1.33	1.22
II dose +N ₆₀	2.22	1.78	1.47	1.66	1.99	1.82
III dose +N ₁₂₀	1.88	1.62	1.01	1.39	1.62	1.50
Mean	1.37	1.30	1.01	1.11	1.34	1.22
LSD _{0.05} for: fertilization (F) - 0.173; cuts (C) - 0.115; years (Y) - 0.078; FxC - 0.257; CxF - 0.300; FxY - n.s.; YxF - n.s.; CXY - 0.162; YxC - 0.135						

I – dose of compost – $15 \text{ Mg} \cdot \text{ha}^{-1} + \text{N}_0$, II – dose of compost – $10 \text{ Mg} \cdot \text{ha}^{-1} + \text{N}_{60}$, III – dose of compost – $5 \text{ Mg} \cdot \text{ha}^{-1} + \text{N}_{120}$, n.s. – not significant difference

Table 6. Total cadmium concentration (mg · kg⁻¹D.M.) in Italian ryegrass

Fertilization variants	Cuts – means of 2 years			Years – means of 3 cuts		Mean of years
	I	II	III	2013	2014	
Control object	0.430	0.320	0.348	0.405	0.327	0.366
NPK	0.320	0.360	0.417	0.412	0.332	0.372
I dose +N ₀	0.540	0.501	0.536	0.563	0.489	0.526
II dose +N ₆₀	0.499	0.422	0.489	0.489	0.450	0.470
III dose +N ₁₂₀	0.322	0.356	0.252	0.309	0.331	0.320
Mean	0.422	0.392	0.418	0.436	0.392	0.411
LSD _{0.05} for: fertilization (F) - 0.451; cuts (C) - 0.198; years (Y) - 0.139; FxC - 0.209; CxF - 0.158; FxY - 0.107; YxF - 0.122; CxY - 0.111; YxC - 0.091						

I – dose of compost – 15 Mg ha⁻¹+N₀, II – dose of compost – 10 Mg ha⁻¹+N₆₀, III – dose of compost – 5 Mg ha⁻¹+N₁₂₀

should not be used to feed animals but it should be combusted or used to produce compost.

The content of Zn, Cu, Ni and Pb in the soil was significantly diversified under the influence of experimental factors (Table 7). Fertilisation significantly diversified cadmium content. With the exception of zinc and lead the total amount of heavy metals in the soil was similar in the control plot and in the one with NPK fertiliser. Compost application, in particular at the higher doses of 15 and 10 Mg ha⁻¹, increased zinc concentration in the soil three times while Ni, Pb and Cd concentration was increased two times. There was also significantly more lead and a little more cadmium

in the first year than in the second. Concentration of the other heavy metals was significantly higher in the second year than in the first year. Throughout the experiment the average concentration of heavy metals from all plots can be put in the following order (mg·kg⁻¹): Zn (36.02) < Pb (6.67) < Cu (6.28) < Ni (5.15) < Cd (1.48). Balcer and Wołoszyk [2012] found a similar content of copper but a much lower content of zinc in soil in the second year after compost made with sewage sludge was applied. The above mentioned authors say that, compared to the control, compost made with 70% of sewage sludge resulted in a higher content of microelements in plants and in soils.

Table 7. Heavy metal concentration (mg · kg⁻¹D.M.) in the soil in the first and second year of the experiment

Fertilization variants	Years	Zn	Cu	Ni	Pb	Cd
Control object	2013	15.12	5.66	3.25	5.14	1.28
	2014	20.71	5.11	2.63	4.12	0.557
	Mean	17.92	5.38	2.94	4.63	0.919
NPK	2013	11.20	4.12	2.23	6.10	0.987
	2014	12.36	5.89	2.96	5.07	1.08
	Mean	11.78	5.01	2.60	5.59	1.03
I dose +N ₀	2013	55.95	8.56	5.56	7.74	1.11
	2014	63.70	7.99	6.99	7.09	2.09
	Mean	59.83	8.28	6.28	7.42	1.60
II dose +N ₆₀	2013	51.20	7.12	7.12	8.85	2.13
	2014	56.98	6.42	8.66	8.23	2.01
	Mean	54.09	6.77	7.89	8.54	2.07
III dose +N ₁₂₀	2013	32.09	5.01	6.23	7.23	1.99
	2014	40.89	6.89	5.87	7.11	1.54
	Mean	36.49	5.95	6.05	7.17	1.77
Mean 2013		33.11	6.09	4.88	7.01	1.50
Mean 2014		38.92	6.46	5.42	6.32	1.46
Mean		36.02	6.28	5.15	6.67	1.48
LSD _{0.05} for: F - fertilization		1.06	0.444	0.524	0.649	0.201
Y - years		0.469	0.196	0.231	0.286	n.s.
FxY - interaction		1.51	0.628	0.741	n.s.	0.284
YxF - interaction		1.05	0.438	0.517	n.s.	0.198

I – dose of compost – 15 Mg ha⁻¹+N₀, II – dose of compost – 10 Mg ha⁻¹+N₆₀, III – dose of compost – 5 Mg ha⁻¹+N₁₂₀, n.s. – not significant difference

Compared to the control, changes of the concentration of heavy metals in the soil varied in all the years of the experiment (Figure 1).

The highest dose of compost did not always resulted in a higher amount of heavy metals in the soil even if there was such a relationship in the case of Zn and Cu. In turn, a mid dose of compost, supplemented with mineral nitrogen, caused the highest rise of Ni and Pb content. Like with Cd, there was a significant increase of the content of those metals in the second year of the experiment.

The use of compost made with sewage sludge led to a rise of the chemical elements content both in plants and in the soil [De Browuere, Smolders 2006, Iżewska 2009, Wołoszyk et al. 2009]. At the same time there was no accumulation of those elements in the soil-plant system [Kabata-Pendias, Pendias 1999]. Madej, Wasiak [2005] point out that nutritional value of sewage sludge is higher than the nutritional value of manure and its use results in higher yields of crops.

CONCLUSIONS

1. In the grass from the plot where compost made with sewage sludge and wheat straw was applied there was an increase in heavy metal content (Zn, Cu, Ni, Pb and Cd, as compared to the control plot and to the plot with NPK fertiliser applied).
2. Analysing the effects of different compost doses on heavy metal content it was found that the highest amount of compost ($15 \text{ Mg}\cdot\text{ha}^{-1}$) resulted in the highest accumulation of Zn, Cu and Cd, while the highest amounts of Ni and Pb were in the grass from the plot with the mid dose of compost ($10 \text{ Mg}\cdot\text{ha}^{-1}$).
3. Compared to the first year there was an increase of the amount of Zn, Cu and Ni in the soils in the second year of the experiment.
4. The experiment proved that the effects of compost made with sewage sludge and wheat straw were beneficial for plants.

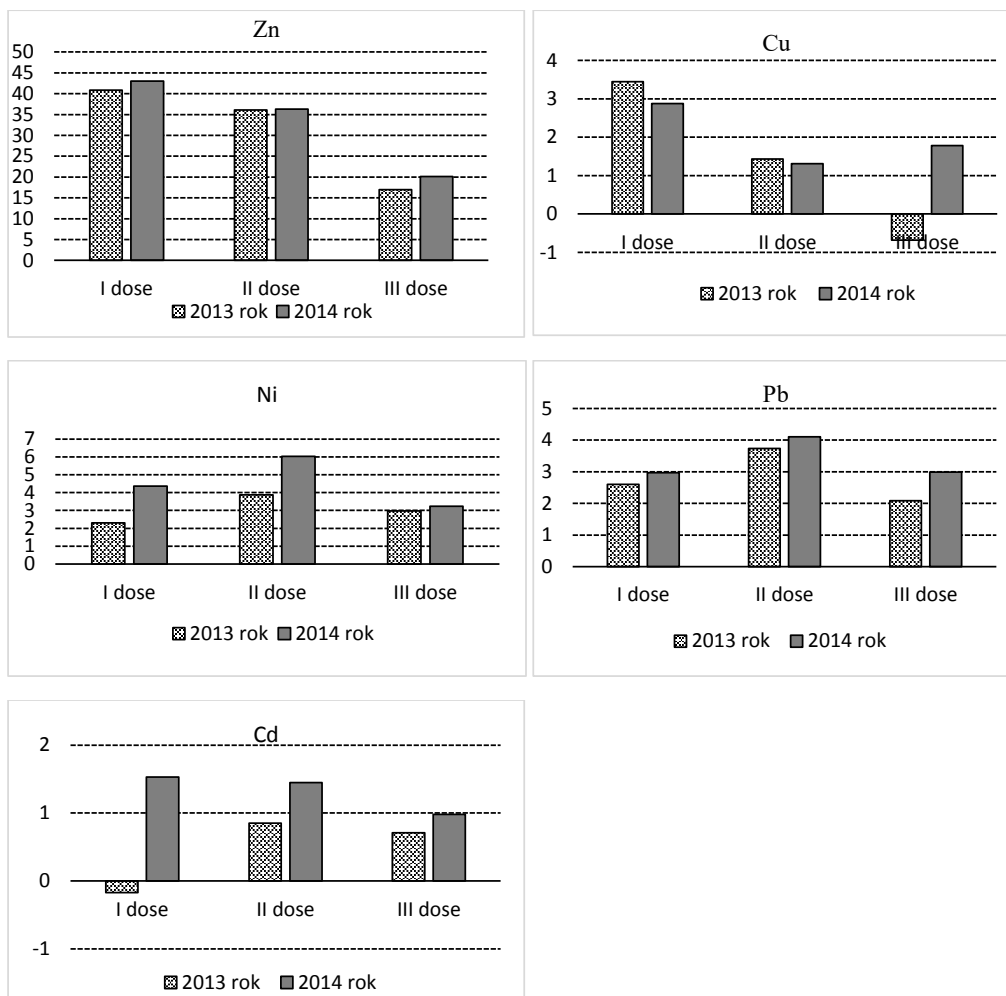


Figure 1. Changes of total concentration of heavy metals in the soil after compost application ($\text{mg}\cdot\text{kg}^{-1}$), compared to the control

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