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EFFECT OF SOIL CONTAMINATION WITH CADMIUM AND APPLICATION OF NEUTRALIZING SUBSTANCES ON THE YIELD OF OAT (*AVENA SATIVA* L.) AND THE UPTAKE OF CADMIUM BY THIS CROP

Elżbieta Rolka

Chair of Environmental Chemistry
University of Warmia and Mazury in Olsztyn

Abstract

Cadmium emitted to the natural environment due to anthropogenic pressure can easily move through the trophic chain, thus posing a threat to human and animal health. Soil contamination with cadmium can cause disorders in the growth and development of plants, and therefore may have an adverse effect on the volume and quality of yields. The purpose of this study has been to evaluate the effect of soil contamination with incremental doses of cadmium together with the application of neutralizing substances on the yield of oat (*Avena sativa* L.) and on the content, uptake and distribution of cadmium in oat plants. The research was based on a pot experiment conducted on cv. Dragon oat, grown on soil with the grain-size composition of loamy sand. Cadmium was introduced to soil in the form of cadmium chloride, in doses equal 0, 10, 20, 30 and 40 mg Cd kg^{-1}. In order to alleviate the negative effect of soil contamination with cadmium, neutralizing substances were used, such as compost, lime and brown coal. The statistical analysis of the results demonstrated the presence of a negative correlation between the cadmium doses and the volume of oat yields. The lowest cadmium dose (10 mg Cd kg^{-1} of soil) significantly decreased the yield of oat straw and roots; regarding the grain yield, it was significantly depressed by the two highest cadmium doses (30 and 40 mg Cd kg^{-1} of soil). Of the three neutralizing substances applied, compost had a positive effect on the quantity of grain yield, compost and brown coal affected positively the yield of straw, while soil liming significantly decreased the yield of roots. Soil contamination with cadmium significantly affected the content of cadmium, raising it in the separated parts of oat plants, of which roots contained the distinctly highest amounts of the pollutant. The highest cadmium uptake (1.50 mg Cd pot^{-1}) was detected in oat straw, which on average accumulated 58% of this xenobiotic. All the applied substances neutralizing the soil contamination with cadmium significantly decreased the content and the uptake of this element by oat grain, straw and roots, with lime producing the strongest impact.

Keywords: cadmium, soil, neutralizing substances, oat, uptake, distribution.

dr inż. Elżbieta Rolka, Chair of Environmental Chemistry, University of Warmia and Mazury in Olsztyn, Pl. Łódzki 4, 10-727 Olsztyn, Poland, e-mail: elzbieta.rolka@uwm.edu.pl

INTRODUCTION

Cadmium is a trace element, characterized by severe toxicity towards live organisms and high mobility in the natural environment. The Directive 2006/11/EC of the European Parliament and Council, approved on 15 February 2006, mentions cadmium and cadmium compounds in Annex I, where they are classified among substances characterized by high toxicity, persistence and tendency towards bioaccumulation (*Directive 2006/11/EC*). Soils polluted with cadmium are a potential source of contamination of plants, groundwater, food and animals feeds, even at low levels of pollution in soil (QUINN et al. 2011). Many plant species are quite sensitive to this xenobiotic element and respond with lower yields even to a slightly elevated amount of cadmium in soil (SU, WONG 2004, WYSZKOWSKI, WYSZKOWSKA 2004, WRÓBEL, DĘBOWSKI 2010). SCHÜTZENDÜBEL and POLLE (2002) claim that physiological effects of excess cadmium in plants include disruptions in the processes of photosynthesis, respiration and transpiration. Although cadmium does not play any physiological function in plants (TRAN, POPOWA 2013), it is readily absorbed by the root system (CIEĆKO et al. 2001, TRAN, POPOWA 2013) and then transported to the other parts of plants (CIEĆKO et al. 2004, 2005). The highest levels of cadmium are recorded in the root system, with less cadmium detected in aerial organs of plants (GONDEK 2007, RIVELI et al. 2014). The content of cadmium in plants can be modified by a variety of factors, including soil properties, e.g. the soil abundance of nutrients (KRZEBIETKE 2011). The mobility of cadmium, and hence its phytoavailability, can be reduced by the pH of soil (YOUNG et al. 2000, BLADE, GOULDING 2002, BASTA et al. 2005, PUSCHENREITER et al. 2005, WYSZKOWSKA et al. 2013). Regular soil liming stimulated the process of cadmium binding into compounds less easily accessible to plants (WRÓBEL, DĘBOWSKI 2010). Many authors (CIEĆKO et al. 2001, GONDEK 2010, KWIATKOWSKA-MALINA, MACIEJEWSKA 2011, WYSZKOWSKA et al. 2013) emphasize the positive role of organic matter in the process of reducing the phytoavailable forms of cadmium in soil.

The purpose of this study has been to analyze the effect of increasing doses of cadmium and the application of substances neutralizing the effect of metal on yields of oat, and on the content, uptake and translocation of Cd in plants.

MATERIAL AND METHODS

The analysis was based on results obtained from a pot experiment conducted in a greenhouse located at the University of Warmia and Mazury in Olsztyn. The experiment involved two factors: 1) increasing level of soil contamination with cadmium, and 2) substances neutralizing the negative effect of cadmium on plants. Cadmium was incorporated into the soil as aqueous solution of cadmium chloride ($CdCl_2$), in doses of 0, 10, 20, 30 and 40 mg Cd kg^{-1} of soil. The substances applied to soil in order to neutralize cadmium pollution were lime in the amount of 1 hydrolitic acidity (Hh) as well as compost and brown coal in amounts corresponding to 4% of the soil mass in a pot. Also, mineral fertilization was applied, such as urea, triple superphosphate and potassium salt, the amounts of 100 mg N, 43.6 mg P and 99.6 mg K kg^{-1} of soil. The substrate for growing plants consisted of brown soil, 10 kg in each pot, taken from the arable and humic horizon, with the texture of loamy sand. The soil possessed the following chemical properties: pH in 1 mol KCl dm^{-3} – 4.50, Hh – 32.6 mmol(+) kg^{-1} d.m., C-organic content – 5.3 g kg^{-1} d.m., N-total content – 0.65 g kg^{-1} d.m., the content of available forms of P – 49.0, K – 88.0 and Mg – 33.0 mg kg^{-1} d.m. The soil selected for the trial contained small quantities of cadmium – 0.17 mg kg^{-1} d.m. In turn, the neutralizing substances contained the following amounts of macronutrients: P – 2.41, K – 1.58, Mg – 1.56, Ca – 16.0 in compost; P – 0.13, K – 0.19, Mg – 4.63, Ca – 31.52 in brown coal; P – 0.10, K – 0.77, Mg – 2.65, Ca – 347.99 mg g^{-1} d.m. in lime. The content of cadmium in the same substances was: 0.39 in compost, 0.04 in brown coal and 0.27 mg kg^{-1} d.m. in lime.

All the component substances (cadmium chloride, compost, brown coal, lime and fertilizers), according to the design of the experiment, were carefully mixed with the soil and then transferred to Kick-Brauckmann pots, in four replications. The experiment plant was the cultivar of oat called Dragon, which was sown in batches of 30 kernels in each pot, leaving 20 emerged plants per pot. During the vegetation of oat plants, the moisture content of soil was kept on the level of 60% of capillary water capacity. The oat plants were harvested in the full grain ripeness phase, i.e. after 103 days of growth; harvested plants were divided into grain, straw and roots. At harvest, the yield of individual plant organs from each pot was determined, and afterwards the plant material was aggregated into experimental variants, dried at 60°C and homogenized. Then, the plant material was submitted to the following determinations: cadmium concentration by the ASA method on a Unicam 939 Solar spectrophotometer, having first performed wet mineralization in a mixture of perchloric acid and nitric acid.

Based on the results of determinations of the cadmium content in plants, its uptake with yield was calculated, and its distribution in the distinguished organs of plants was analyzed. The results pertaining to the oat yield as well as the uptake and distribution of cadmium in the oat parts were submitted to statistical analysis with the Anova test at the level of significance α=0.5, using the software Statistica 9.0 (StatSoft 2009). The correlation coefficient r between the analyzed factors was calculated with the help of the application Microsoft Excel (Microsoft 2002). In addition, the tolerance index (T_i), which indicates the amount of cadmium in soil toxic to plants was calculated too (Baran et al. 2008). The value of T_i is derived from the ratio of yield obtained by plants grown in cadmium polluted soil to the yield harvested from the control object (without cadmium in soil). The value of $T_i < 1$ indicates retardation of the plant growth, T_i = 1 means that the elevated content of cadmium in soil has no effect on plant yields and T_i > 1 suggests a positive effect of this xenobiotic on the growth of plants.

RESULTS AND DISCUSSION

The factors analyzed in this experiment affected the yields of grain, straw and roots of oat (Table 1). Depending on a series, the average oat yield (g d.m. pot^{-1}) ranged from 24.70-29.86 of grain, 21.17-26.24 of straw and 3.53--5.01 of roots, with the lowest yields determined in pots holding limed soil.

Table 1

Yield of oat grain, straw and roots (g d.m. pot^{-1})

Cd dose (mg kg^{-1} of soil)	Objects				Average
	without amendments	compost	brown coal	lime (CaO)	
Grain					
0	30.06	25.52	27.36	27.89	27.71
10	27.65	32.89	28.94	26.33	28.95
20	30.03	32.47	27.27	23.21	28.25
30	18.91	30.48	25.38	26.21	25.25
40	18.16	27.96	16.62	19.84	20.65
Average	24.96	29.86	25.11	24.70	26.16
r	-0.73**	n.s.	-0.69**	n.s.	-0.44**
LSD α = 0.05 for Cd soil pollution = 2.885; for amendments = 2.580; for interaction = 5.770					
Straw					
0	29.97	26.71	28.53	27.19	28.10
10	24.48	26.37	27.27	21.21	24.83
20	24.62	25.85	23.64	20.45	23.64
30	17.58	25.87	24.41	18.85	21.68
40	18.97	23.22	27.36	18.14	21.92
Average	23.12	25.60	26.24	21.17	24,03
r	-0.84**	n.s.	n.s.	-0.59*	-0.48**
LSD α = 0.05 for Cd soil pollution = 2.332; for amendments = 2.086; for interaction = 4.664					
Roots					
0	4.40	5.89	5.05	3.02	4.59
10	4.78	4.55	3.54	2.59	3.87
20	5.38	3.88	4.66	4.85	4.69
30	4.67	3.81	4.32	3.42	4.06
40	5.82	5.28	4.62	3.78	4.88
Average	5.01	4.68	4.44	3.53	4.42
r	n.s.	n.s.	n.s.	n.s.	n.s.
LSD α = 0.05 for Cd soil pollution = 0.684; for amendments = 0.612; for interaction = 1.369					

* correlation coefficient *r* significant for α = 0.05;
** correlation coefficient *r* significant for α = 0.01, n.s. – not significant

The statistical analysis of the results proved the presence of a negative and highly significant correlation between doses of cadmium and the volume of grain and straw yields. The grain yield of oat was lowered significantly by the two highest doses of cadmium (30 and 40 mg Cd kg^{-1} of soil), whereas the yield straw was significantly smaller in response to even the lowest cadmium dose (10 mg Cd kg^{-1} of soil). Regarding the mass of roots produced by oat plants, the dose of cadmium equal 10 mg kg^{-1} of soil significantly decreased its volume, while that of 40 mg caused its increase. In another study on cv. Borowik oat (Wyszkowski, Wyszkowska 2004), the negative influence of cadmium on the yield of aerial biomass was documented at a dose as low as 20 mg kg^{-1} of soil. In turn, an experiment on another oat cultivar called Akt (Gregorczyk et al. 2010), showed that the plant growth was inhibited when the dose of cadmium reached as much as 100 mg Cd kg^{-1} of soil. Negative correlation between crop yields and soil pollution with cadmium is also verified by research on white cabbage (Bączek-Kwinta et al. 2011), linseed, vetch, mustard and pea (Baran et al. 2008). The results presented in table 1 indicate a tendency to yield reduction under the applied neutralizing substances. These differences are generally not statistically proven (with the exception of the effect of lime on the mass of roots – objects without cadmium pollution). It could be a result of the increase in sorption processes caused by compost, brown coal and lime, which bounded cadmium and, in relation to Cd, also partly bounded macro- and micronutrients necessary for plants. However, compost added to soil positively affected the volume of average grain yields; positive correlations were also demonstrated between the soil application of compost or brown coal and yields of straw. On the other hand, soil liming caused a decrease in the volume of oat roots harvested. Similar data are reported by Gondek (2007), who noticed a tendency towards increasing oat yields owing to soil enrichment with compost. In turn, Kwiatkowska-Malina and Maciejewska (2011) proved that brown coal significantly increased yields of mustard and Chinese cabbage. A positive effect on plant yields produced by organic substance added to soil was also confirmed by Ciećko et al. (2001) and Żołnowski et al. (2013). The calculated values of the tolerance index for oat in 50% of the pots were higher than or equal to 1 (Table 2). These values were within a rather broad range of 0.68-1.38 (grain), 0.78-1.20 (straw) and 0.63-1.78 (roots), and the most beneficial results

Table 2

Tolerance index for oats

Cd dose (mg kg^{-1} of soil)	Objects											
	without amendments			compost			brown coal			lime (CaO)		
	grain	straw	roots	grain	straw	roots	grain	straw	roots	grain	straw	roots
10	0.96	1.09	1.27	1.38	1.20	0.86	1.07	0.95	0.63	1.00	0.96	1.00
20	1.08	1.18	1.36	1.33	1.20	0.79	1.03	1.04	0.88	0.86	0.78	1.56
30	0.68	0.93	1.64	1.25	1.16	0.79	0.94	0.92	0.75	0.97	0.84	1.44
40	0.68	0.86	1.73	1.19	1.13	1.21	0.68	0.88	0.75	0.72	0.79	1.78
Average	0.85	1.01	1.50	1.29	1.14	0.91	0.93	0.95	0.75	0.89	0.84	1.44

Table 3

Cadmium content in oat grain, straw and roots (mg Cd kg^{-1}d.m.)

Cd dose (mg kg^{-1} of soil)	Objects				Average
	without amendments	compost	brown coal	lime (CaO)	
Grain					
0	1.32	2.72	0.72	3.20	1.99
10	15.63	13.58	12.81	7.97	12.50
20	23.63	21.82	14.01	13.12	18.15
30	53.92	20.77	17.70	13.29	26.42
40	45.94	27.09	17.49	12.95	25.87
Average	28.09	17.20	12.55	10.11	16.98
r	0.93**	0,94**	0.87**	0.88**	0.66**
LSD a = 0.05 for Cd soil pollution = 0.397; for amendments = 0.355; for interaction = 0.794					
Straw					
0	8.10	1.68	1.58	5.49	4.21
10	58.68	37.97	37.70	22.20	39.14
20	102.51	70.65	54.38	47.79	68.83
30	230.40	106.75	63.44	45.49	111.52
40	200.10	138.53	66.01	49.91	113.64
Average	119.96	71.12	44.62	34.18	67.47
r	0.94**	1.00**	0.92**	0.91**	0.68**
LSD a = 0.05 for Cd soil pollution = 1.314; for amendments = 1.175; for interaction = 2.628					
Roots					
0	16.40	6.23	23.31	25.32	17.82
10	77.40	33.19	42.16	53.20	51.49
20	181.67	126.46	81.83	76.11	116.52
30	208.16	184.65	133.30	80.35	151.62
40	325.17	236.99	151.25	87.96	200.34
Average	161.76	117.50	86.37	64.59	107.56
r	0.98**	0.99**	0.98**	0.93**	0.79**
LSD a = 0.05 for Cd soil pollution = 11.218; for amendments = 10.034; for interaction = 22.436					

** correlation coefficient *r* significant for a = 0.01

were noted in the series with compost and in pots without these soil additives. Wróbel and Dębowski (2010) performed an experiment on spring wheat grown in soil polluted with cadmium, and demonstrated the Ti values within 0.71-0.74 (grain) and 0.67-0.77 (straw). In their investigations, the negative effect of cadmium on wheat plants was inhibited by the concurrent application of peat and elevated doses of superphosphate.

The average content of cadmium in oat grain ranged from 10.11 to 28.09 mg, in straw – from 34.18 to 119.96 mg and in roots – from 64.59 to 161.76 mg Cd kg^{-1}d.m., with the lowest concentration found in the series with lime and the highest – in pots without any neutralizing substance (Table 3). The content of cadmium in grain, straw and roots of oat tended to increase as the soil pollution with cadmium increased. The doses of Cd 10, 20 and 30 mg kg^{-1} of soil significantly raised the content of this xenobiotic in oat grain and straw; in roots, this relationship was verified up to the highest dose of the metal. However, TUMA et al. (2014) reported a significant increase in the content of cadmium in aerial parts and roots of oat of the cultivar Atego only at the dose of cadmium equal 20 mg kg^{-1} of soil, with the oat roots containing the highest level of this metal. Higher accumulation of cadmium in roots than in aerial parts was also demonstrated in experiments on oat (GONDEK 2007), wheat (ARDUINI et al. 2014) and sunflower (MARIA et al. 2013). HREBELNA et al. (2008) revealed a significant increase in the content of cadmium in roots of spring barley growing in soil with doses of 3, 15 and 30 mg Cd kg^{-1}. In our experiment, the soil application of substances neutralizing cadmium contamination significantly reduced the content of Cd in oat grain, straw and roots. Irrespective of the experimental series, the calculated correlation coefficient *r* was positive and highly significant, ranging from 0.87 to 1.00. The strongest reducing impact on the content of Cd in oat was produced by lime, next by brown coal and finally by compost. KWIATKOWSKA-MALINA and MACIEJEWSKA (2011) reported a decrease in the content of cadmium in mustard and Chinese cabbage under the influence of organic matter from Rekulter, a preparation made from brown coal. On the other hand, soil liming resulted in a decrease in the cadmium content in grain of winter wheat and spring barley (KANIUCZAK et al. 2011).

The average uptake of cadmium was within the following ranges: 0.24-0.61 mg (grain), 0.67-2.41 mg (straw) and 0.24-0.86 mg Cd pot^{-1} (roots) – Table 4, Figure 1. The highest mean uptake of cadmium in all parts of oat was noted in the series without any neutralizing substances, whilst the lo-

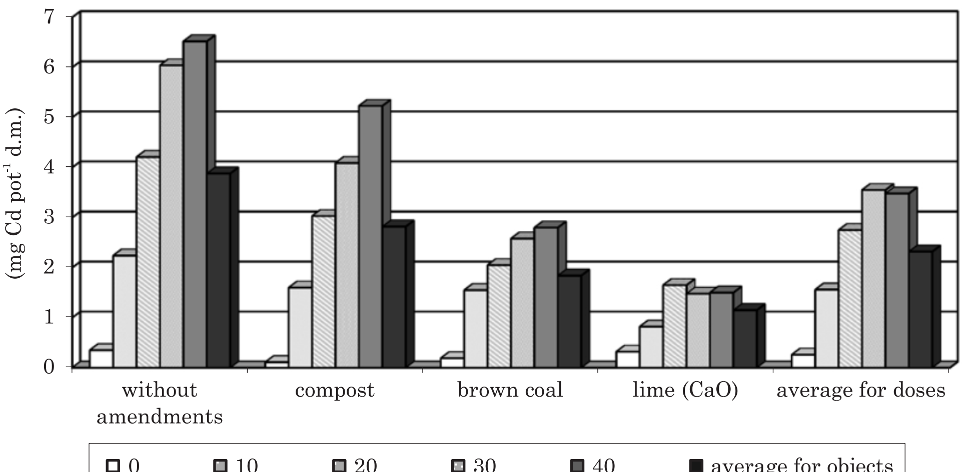

Fig. 1. Impact of neutralizing substances on upatake of cadmium by oat

Table 4

Cadmium uptake by oat grain, straw and roots (mg Cd pot^{-1}d.m.)

Cd dose (mg kg^{-1} of soil)	Objects				Average
	without amendments	compost	brown coal	lime (CaO)	
Grain					
0	0.04	0.07	0.02	0.09	0.06
10	0.43	0.45	0.37	0.21	0.37
20	0.71	0.71	0.38	0.30	0.53
30	1.02	0.63	0.45	0.35	0.61
40	0.83	0.76	0.29	0.26	0.54
Average	0.61	0.52	0.30	0.24	0.42
r	0.90**	0.88**	n.s.	0.75*	0.62**
LSD a = 0.05 for Cd soil pollution = 0.008; for amendments = 0.007; for interaction = 0.017					
Straw					
0	0.24	0.04	0.05	0.15	0.12
10	1.44	1.00	1.03	0.47	0.99
20	2.52	1.83	1.29	0.98	1.66
30	4.05	2.76	1.55	0.86	2.31
40	3.80	3.22	1.81	0.91	2.44
Average	2.41	1.77	1.15	0.67	1.50
r	0.96**	0.99**	0.94**	0.85**	0.71**
LSD a = 0.05 for Cd soil pollution = 0.029; for amendments = 0.026; for interaction = 0.058					
Roots					
0	0.07	0.04	0.12	0.08	0.08
10	0.37	0.15	0.15	0.14	0.20
20	0.98	0.49	0.38	0.37	0.56
30	0.97	0.70	0.58	0.27	0.63
40	1.89	1.25	0.70	0.33	1.04
Average	0.86	0.53	0.39	0.24	0.50
r	0.96**	0.97**	0.97**	0.80*	0.72**
LSD a = 0.05 for Cd soil pollution = 0.053; for amendments = 0.048; for interaction = 0.107					

* correlation coefficient *r* significant for a = 0.05;
** correlation coefficient *r* significant for a = 0.01, n.s. – not significant

west one occurred in the series with lime. All the tested doses of the xenobiotic metal had a significant effect on the uptake of cadmium by oat straw and roots. However, a significant increase in the cadmium uptake by oat grain appeared only to the dose of cadmium in soil equal 30 mg kg^{-1}. At the highest dose of cadmium, a significant decrease in the uptake of this metal by oat grain was recorded. In the investigations reported by BĄCZEK-KWINTA et al. (2011), at the soil contamination equal 40 mg Cd kg^{-1} of soil, the uptake of cadmium by two cultivars of head cabbage was from 260- to 560-fold higher. In our study, the soil application of the substances intended to neutralize cadmium in soil caused a significant decline in the uptake of this element by oat grain, straw and roots. Other authors, too, observed a lower uptake of cadmium by the aerial mass of maize owing to the application of organic matter, in the form of manure or sewage sludge (GONDEK 2010), and decreased accumulation of cadmium in the aerial biomass of maize in response to the application of wastewater sludge (JASIEWICZ et al. 2010). In the experiment conducted by KWIATKOWSKA-MALINA and MACIEJEWSKA (2011), following the application of Rekulter, the tested plants such as mustard and Chinese cabbage were observed to absorb less cadmium from soil.

Cadmium taken up by oat plants from the substrate mostly accumulated in straw, while roots and grain gathered much lower quantities of this metal (Table 5). On average, cadmium accumulated in oat grain was within the range of 20%, in roots – 22% and in straw – 58% of the whole amount. The translocation of cadmium to oat grain was negatively correlated with the increasing doses of the pollutant, and the correlation coefficient was signifi-

Table 5

Distribution of cadmium in oat plants (%)

Cd dose (mg kg^{-1} of soil)	Objects				Average
	without amendments	compost	brown coal	lime (CaO)	
Grain					
0	11.28	46.03	10.79	28.32	24.11
10	19.32	27.94	23.95	25.65	24.22
20	16.86	23.42	18.64	18.45	19.34
30	16.87	15.45	17.45	23.53	18.33
40	12.79	14.50	10.41	17.19	13.72
Average	15.42	25.47	16.25	22.63	19.94
r	n.s.	-0.93**	n.s.	-0.79*	-0.47**
LSD a = 0.05 for Cd soil pollution = 0.979; for amendments = 0.876; for interaction = 1.959					
Straw					
0	68.42	29.67	24.73	47.41	42.56
10	64.23	62.62	66.41	57.52	62.70
20	59.93	60.37	62.75	59.20	60.56
30	67.04	67.40	60.19	57.94	63.14
40	58.20	61.57	64.64	60.57	61.25
Average	63.56	56.33	55.74	56.53	58.04
r	n.s.	0.72*	n.s.	0.79*	0.47**
LSD a = 0.05 for Cd soil pollution = 1.340; for amendments = 1.199; for interaction = 2.680					
Roots					
0	20.30	24.30	64.48	24.27	33.34
10	16.44	9.44	9.64	16.83	13.09
20	23.21	16.21	18.61	22.35	20.10
30	16.09	17.16	22.36	18.52	18.53
40	29.01	23.93	24.95	22.24	25.03
Average	21.01	18.21	28.01	20.84	22.02
r	n.s.	n.s.	n.s.	n.s.	n.s.
LSD a = 0.05 for Cd soil pollution = 1.476; for amendments = 1.320; for interaction = 2.952					

* correlation coefficient *r* significant for a = 0.05;
** correlation coefficient *r* significant for a = 0.01, n.s. – not significant

cantly negative (-0.47). The translocation of cadmium to oat straw was more intensive in plants growing in cadmium polluted soil (where the correlation coefficient reached 0.47). With respect to roots, a statistically significant linear dependence between the analyzed characteristics was not proven. The study by GONDEK (2007) also confirms lesser accumulation of cadmium in oat aerial organs than in roots. In the current experiment, the neutralizing substances applied to soil stimulated the translocation of cadmium to grain, although the effect was statistically proven only in the case of compost and lime. The distribution of cadmium in oat straw was depressed as a result of the soil application of neutralizing substances. Regarding oat roots, compost added to soil had a significant effect, inhibiting the translocation of Cd to this part of oat plants, whereas brown coal led to the increase in the value of this quality. Smaller accumulation of cadmium in hulls and seeds of mustard or in aerial biomass of Chinese cabbage owing to the soil application of Rekulter was also noticed in the experiment by KWIATKOWSKA-MALINA and MACIEJEWSKA (2011). JASIEWICZ et al. (2010) reported a decreased accumulation of cadmium in aerial biomass of maize in response to the soil incorporation of wastewater sludge.

CONCLUSIONS

1. The volume of oat grain and straw yields was highly significantly and negatively correlated with the degree of soil contamination by cadmium. Significantly lower oat grain yields were due to the application of the two highest cadmium doses (30 and 40 mg Cd kg^{-1} of soil). The volume of straw and root yields was significantly depressed by the lowest cadmium dose (10 mg Cd kg^{-1} of soil). Out of the three tested neutralizing substances, compost positively affected the volume of grain yields, both compost and brown coal had positive influence on straw yield, while soil liming significantly decreased the volume of root yield.

2. The highest average content of cadmium was found in oat roots (107.56 mg), far less cadmium was detected in straw (67.47 mg) and grain had the lowest cadmium concentration (16.98 mg kg^{-1} d.m.). The Cd doses of 10, 20 and 30 mg kg^{-1} of soil significantly rose the content of this metal in oat grain and straw; regarding oat roots, an analogous increase was observed up to the highest cadmium dose. The application of the neutralizing substances significantly decreased the content of cadmium in grain, straw and roots of oat.

3. The highest cadmium uptake (1.50 mg Cd pot^{-1}) was attributed to oat straw, which at the same time was the organ that received 58% of this metal translocated into oat plants. The cadmium uptake by roots was three-fold lower, while that by grain was 3.6-fold lower. In these two parts of oat, the share of cadmium was 22 and 20%, respectively, of the whole amount of Cd

taken up by oat. All the substances applied in order to immobilize cadmium in soil resulted in a lower uptake of this metal by the three plant parts. The soil application of lime was demonstrably the most effective, although – same as compost – it significantly increased the translocation of cadmium to grain.

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