Letter to the Editor

The Magnesium Content in Plants in Soil Contaminated with Cadmium

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Abstract

The aim of the experiments was to determine the effect of cadmium-contaminated soil (10, 20, 30 and 40 mg Cd · kg^{-1} soil) on the magnesium content in oats, maize, yellow lupine and radish. Compost, brown coal, lime and bentonite were added to reduce the undesirable effect of cadmium contamination on the plants. As a result of soil contamination with cadmium, the amount of magnesium increased in all the examined parts of the oats, in the above-ground parts of yellow lupine and radish as well in the roots of maize. The application of compost, lime, bentonite and especially brown coal into the soil had an overall positive effect on the magnesium content in the vegetative parts of the crops. The magnesium content in the plants was generally correlated with the accumulation of other macro- and some microelements.

Keywords: cadmium contamination, neutralizing substances, magnesium content, plant yield, macro- and microelement content

Introduction

Pollution of the environment has a principal effect on the suitability and utilization of varied crops. It can limit or even eliminate agricultural crops from consumption by people or animals. Heavy metals are one of the most dangerous groups of pollutants. Cadmium is considered to pose the greatest threat in Poland due to its toxicity and its amounts accumulated in particular components of the environment and in the biosphere. This heavy metal is able to circulate at high rates in the environment through the particular links of the trophic chain and has an effect on the intake of other elements by crops [1, 2, 3].

The aim of the experiments was to determine the effect of soil contaminated with cadmium and varied neutralizing substances on the amount of magnesium in oats, maize, yellow lupine and radish.

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Materials and Methods

The effect of cadmium contaminated soil (10, 20, 30 and 40 mg Cd · kg^{-1}) on the amount of magnesium in the crops was examined in four pot experiments carried out in the vegetation hall, University of Warmia and Mazury in Olsztyn. The experiment involved oats, maize, yellow lupine and radish. The experiment was conducted in four (oats) or five series (the remaining crops). In order to reduce the effect of cadmium on the crops, the pots containing acidic soil with a granulometric composition of light loamy sand were supplemented with neutralizing substances such as compost, brown coal, lime and bentonite (Table 1). The crops were cultivated in polyethylene pots filled with 9 or 10 kg of soil. The neutralizing substances were introduced into the soil at the beginning of the experiment in the following amounts: compost and brown coal - 4%, and bentonite - 2% of the total soil mass in the pots. Lime was applied in an amount relative to soil hydrolytic acidity (experiment with: oats - 1.51 g Ca · kg^{-1},

Table 1. Some physicochemical properties of the Eutric Cambisol light loamy sand soils used in the experiments.

Plant	pH_{KCl}	Hh mmol(+) · kg^{-1} of soil	Cd content in mg · kg^{-1}	Content of available forms in mg · kg^{-1}			
				C	P	K	Mg
Oats, maize, yellow lupine	4.50	32.6	0.17	5.30	10.77	11.10	3.51
Radish	4.07	27.4	0.07	5.62	12.60	14.73	2.93

C – organic carbon content, Hh – hydrolytic acidity

Table 2. Content of cadmium and macroelements in applied substances.

Substance	Cd content in mg · kg^{-1}	Content in g · kg^{-1} d.m.			
		P	K	Mg	Ca
Compost	0.39	2.41	1.58	1.56	16.00
Brown coal	0.04	0.13	0.19	4.63	31.52
Lime	0.27	0.10	0.77	2.65	347.99
Bentonite	0.27	0.47	2.43	5.03	26.72

Table 3. Effect of cadmium on magnesium content in oats and maize, in g per kg of dm.

Cd contamination mg · kg^{-1} of soil	Oats			Maize	
	grain	straw	roots	above-ground parts	roots
0	1.45	1.61	1.35	2.72	1.06
10	1.54	1.48	1.56	2.71	1.04
20	1.62	1.60	1.68	2.67	1.34
30	1.60	1.81	1.94	2.56	1.49
40	1.55	1.69	2.09	2.57	1.67
r	0.606**	0.632*	0.995**	-0.921**	0.970**

*significant at p=0.05, **significant at p=0.01, r - correlation coefficient

maize and yellow lupine - 0.91 g Ca · kg^{-1}, radish - 1.15 g Ca · kg^{-1} of soil). Some physicochemical properties of the applied substances are in Table 2. In all pots, the soil was enriched with the following amounts of macroelements necessary for the proper growth and development of plants (quantities expressed in mg · kg^{-1} of soil): N – 100 (50 - in experiment with yellow lupine) as $CO(NH_2)_2$, P – 43,6 as $Ca(H_2PO_4)_2$+H_3PO_4+$CaSO_4$, K - 96 as KCl. For the whole vegetation period, soil moisture was maintained at a fixed level of 60% of the capillary water holding capacity. Plant harvest was realized in the following phases of development: oats - in phase of full maturity, yellow lupine - in flowering phase, maize - after cob formation and radish - in phase of full maturity.

Samples of the above-ground parts and roots of crops were taken during harvest, then disintegrated, dried and ground. The samples were analyzed for the amounts of magnesium with the ASA technique with the use of a Unicam 939 Solar spectrometer. The results were analyzed statistically with the use of Statistica [4] software.

Results and Discussion

The qualitative crop properties, including the content of minerals, were determined for a wide variety of factors, among others, species, variety and plant parts. In the experiments the part of the crop and the plant species determined the accumulation of magnesium to a greater degree than soil contamination with cadmium (Tables 3 and 4). The greatest magnesium content was found in the above-ground parts of yellow lupine (on average 3.12 g Mg · kg^{-1} of dry matter) and radish (3.21 g Mg · kg^{-1} of d.m.), while the lowest magnesium content was reported for maize

Table 4. Effect of cadmium on magnesium content in yellow lupine and radish, in g per kg of dm.

Cd contamination $mg \cdot kg^{-1}$ of soil	Yellow lupine		Radish	
	above-ground parts	roots	above-ground parts	roots
0	2.24	2.43	3.08	1.71
10	2.75	2.40	3.10	1.64
20	3.39	2.19	3.15	1.57
30	3.60	2.47	3.56	1.53
40	3.61	2.34	3.18	1.55
r	0.941**	-0.143	0.533*	-0.909**

*significant at p=0.05, **significant at p=0.01, r - correlation coefficient

Table 5. Effect of neutralization substances on magnesium content in plants, in g per kg of dm.

Plant organ	Without additions	Compost	Brown coal	Lime	Bentonite	r
Oats						
Grain	1.49	1.47	1.79	1.46	-	0.22
Straw	1.30	1.40	2.31	1.54	-	0.45**
Roots	1.59	1.50	2.08	1.68	-	0.34*
Maize						
Above-ground parts	2.12	2.85	3.67	2.25	2.34	0.43**
Roots	1.23	1.24	1.82	1.17	1.13	0.10
Yellow lupine						
Above-ground parts	3.21	3.46	4.84	2.60	1.49	-0.05
Roots	1.75	2.19	3.16	2.05	2.30	0.32*
Radish						
Above-ground parts	1.77	3.05	5.60	2.48	2.24	0.10
Roots	1.53	1.66	2.06	1.48	1.25	-0.09

*significant at p=0.05, **significant at p=0.01, r - correlation coefficient

roots (1.32 g $Mg \cdot kg^{-1}$ of d.m.). The above-ground parts of all the crops, excluding oats, contained greater amounts of this element than the roots. The greatest differences (approximately 2-fold) were found between the above-ground parts and the roots of maize and radish, while this difference was very small in the grain, straw and roots of oats.

The intake of particular elements including heavy metals, trace elements and other macroelements is disturbed in crops cultivated within areas polluted with heavy metals [1]. In the experiments, cadmium-contaminated soil had a great effect on the amount of magnesium in the experimental plants in comparison to uncontaminated soil (control) (Tables 3 and 4). The magnesium content also varied depending on the plant species and part. Cadmium effect on yellow lupine and radish resulted in greater changes in magnesium accumulation in the above-ground parts than in the roots. Reverse correlations were observed in oats and maize. Great cadmium concentration in soil had a positive and significant effect on magnesium accumulation in all the parts of oats, the above-ground parts of yellow lupine and radish and maize roots. The greatest increase in the content of magnesium in the pots with soil contaminated with the greatest dose of cadmium (40 mg $Cd \cdot kg^{-1}$ soil), in comparison to the control soil (with no Cd), were observed in the above-ground parts of yellow lupine and the roots of maize and oats. This increase reached 61, 58 and 55%, respectively. In the oats grain and straw as well as in the above-ground parts of radish the variation of magnesium content was only below 20%. A reverse correlation, i.e. a significant decrease in magnesium content, was observed in the above-ground parts of maize and in the roots of radish. This decrease was small and did not exceed 10%.

The application of different neutralizing substances into the soil reduced the effect of cadmium on the crops and differentiated the content of magnesium in plants (significant in general). However, these fluctuations were heavily determined by the plant part (Table 5). This effect also depended on the kind of neutralizing substance added; nevertheless, it was generally positive. It should be underlined that the application of brown coal had an especially great effect and resulted in an increase in the content of magnesium in comparison to the control (with no supplements). This increase ranged from 20% in oat grains, through 30% in oat roots to 78-81% in the oat straw and the roots of yellow lupine. However, the greatest increase, i.e. 216% in the content of this element as the result of brown coal application, was found in the above-ground parts of radish. The effect of the remaining substances applied to the soil on the level of magnesium in the plants was generally lower. The application of compost resulted in an increase in the content of magnesium in the above-ground parts of radish by 72%. A lower increase in magnesium accumulation, ranging from below 20 to above 30% was found in oat straw (lime), the above-ground parts of maize (bentonite and compost), the roots of yellow lupine (lime, compost, bentonite) and in the above-ground parts of radish (bentonite and lime). As the result of the application of bentonite, the content of magnesium in the roots of radish decreased by 18% and the application of lime and bentonite caused a decrease

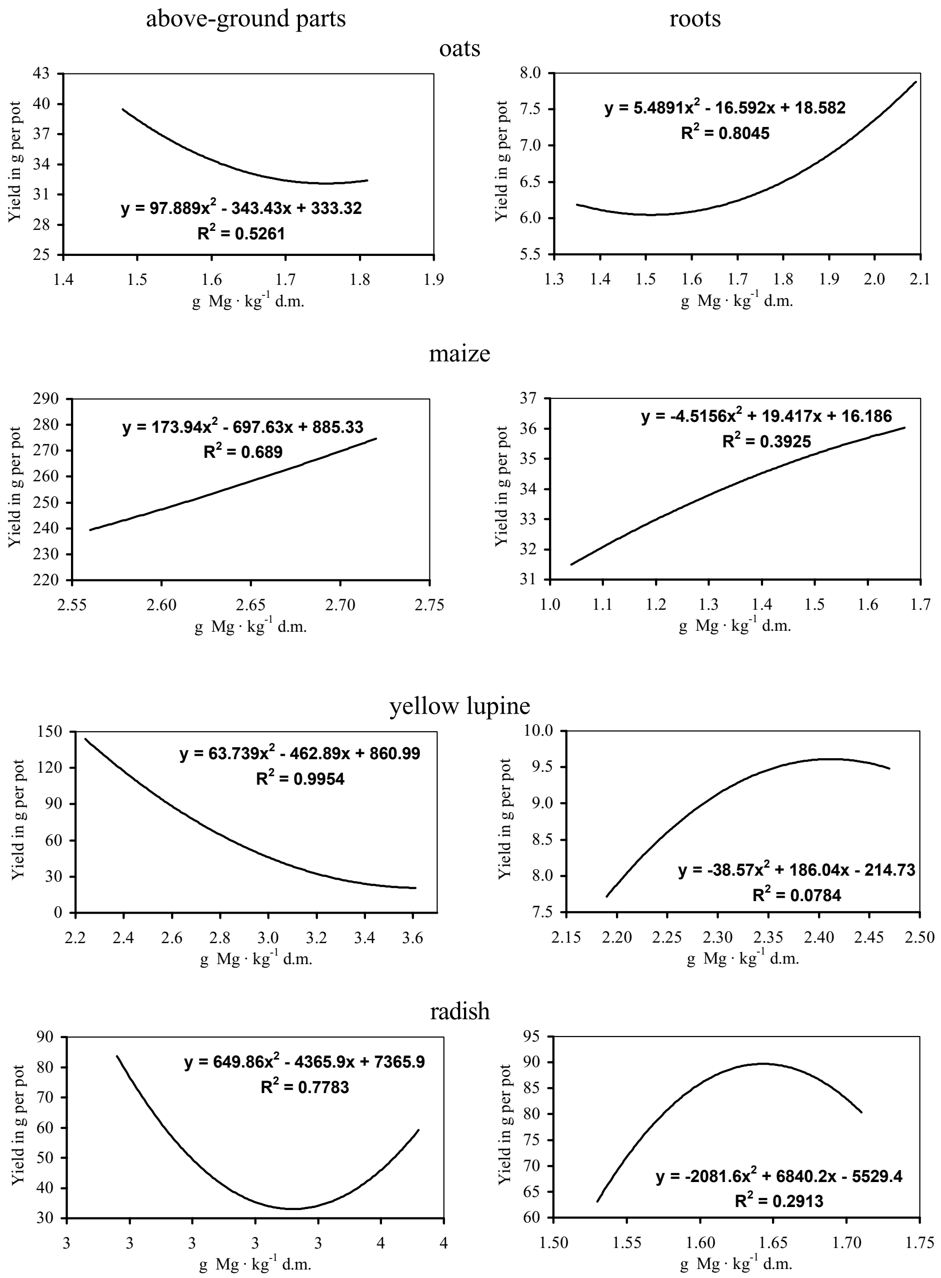

Fig. 1. Relationship between the content of magnesium and yield of plants.

in the content of magnesium in the above-ground parts of yellow lupine by 19 and 54%, respectively.

The correlations between magnesium content and crop yield obtained from the regression equations are interesting (Fig.1). The content of magnesium in the roots rather positively correlated with plant root mass and the content of this element in the above-ground parts (excluding maize) correlated rather negatively with plants' above-ground parts yield (in g per pot). This negative correlation was related to a great decrease in the yield of crops cultivated on soil heavily contaminated with cadmium and with the tendency of magnesium to increase the so-called "concentration effect". Pearson's simple correlation co-efficients were calculated in order to determine the correlation between the content of magnesium in plants and the accumulation of other elements. The coefficients indicate the correlation between the intake of Mg and its distribution over the particular plant parts and the presence of other elements (Table 6). It is likely that many phenomena of synergy and antagonism modified by high cadmium concentration in the soil, as described in the scientific literature, have taken place. The majority of the parts of the experimental plants exhibited generally positive correlations between the content of magnesium and the accumulation of nitrogen, phosphorus, calcium, sulphur, boron and partially potassium and microelements and clearly negative correlations with the accumulation of sodium and copper. It should be stressed that these correlations occurred more frequently in the roots than in the above-ground parts of the examined plants.

Soil contamination with cadmium may cause a wide range of modifications in the intake of macroelements, which was also shown in previous experiments [5, 6]. In the experiments of Ciećko et al. [5] and Wyszkowski [6], similar to the present experiment, soil contamination with cadmium caused a significant increase in the content of magnesium in particular parts of plants; however, it was relatively low. In addition, Jasiewicz and Antonkiewicz [7] indicated the possibility of an increase in the content of macroelements in plants cultivated in soil contaminated with cadmium. Other authors (Gil et al. [8], Grejtowsky and Pirc [9], Międzybrodzka et al. [10], Obata and Umebayashi [3]) do not always confirm the tendency of an increasing content of magnesium in crops harvested from soil contaminated with cadmium. In their experiments, the content of magnesium in the harvested crops was maintained at a similar level regardless of cadmium concentration in the soil. In other experiments by Gussarsson [11], the content of magnesium in the crop roots decreased. The effect of magnesium in this experiment was determined by the plant species and the cadmium content in the soil. In the experiments by Ciećko et al. [12], soil contamination with cadmium caused an increase in the content of magnesium in the above-ground parts of spring rape and a decrease in its accumulation in triticale grain and straw.

The accumulation of magnesium is greatly determined by the application of supplements cushioning the effect of cadmium on the plants. This is also confirmed by previ-

Table 6.

Mg content - Plant	Cd dose	Content in plants																
		N	P	K	Ca	Na	S	B	Mo	Mn	Fe	Co	Li	Al	Cd	Pb	Cu	Ni	Zn
Oats grain	0.23	0.09	0.35*	-0.58**	0.21	-0.13	0.18	0.93**	-0.13	-0.14	0.39**	-0.35*	-0.43**	-0.27	0.12	-0.16	-0.71**	0.20	0.04
Oats straw	0.16	0.00	-0.18	-0.46**	0.08	0.10	0.64**	0.88**	0.00	-0.40**	-0.06	-0.17	-0.41**	-0.07	-0.12	0.15	-0.60**	-0.09	-0.40**
Oats roots	0.66**	0.56**	-0.08	0.29*	0.79**	0.39**	0.94**	0.67**	-0.20	0.17	-0.05	0.08	-0.38**	-0.30	0.47**	0.08	-0.05	-0.54**	-0.07
Maize above-ground parts	-0.11	-0.23	0.01	-0.01	0.22	-0.24	0.04	0.90**	-0.15	-0.02	-0.12	-0.00	-0.22	-0.26	0.11	-0.30*	-0.10	0.03	-0.11
Maize roots	0.56**	0.39**	0.72**	0.66**	0.80**	0.12	0.65**	0.80**	-0.01	0.03	0.01	-0.02	-0.15	0.59**	0.12	0.25	0.31*	0.20	0.56**
Yellow lupine above-ground parts	0.40**	0.38**	0.61**	0.64**	0.71**	-0.59**	0.59**	0.75**	-0.04	0.02	0.22	0.20	0.26	0.24	0.37**	0.40**	-0.01	0.18	0.52**
Yellow lupine roots	-0.19	0.47**	0.29*	0.36**	0.14	0.34**	0.93**	0.69**	0.18	-0.59**	-0.55**	-0.52**	-0.52**	-0.51**	-0.13	-0.36**	-0.46**	-0.48**	0.22
Radish above-ground parts	-0.04	-0.19	0.44**	0.16	0.78**	-0.44**	0.60**	0.85**	0.33**	0.03	-0.60**	-0.04	-0.17	-0.62**	-0.11	0.12	-0.36**	0.19	0.04
Radish roots	-0.25	0.30*	0.44**	0.80**	0.73**	-0.62**	0.52**	0.93**	0.20	0.26	0.06	-0.24	0.08	-0.38**	-0.19	-0.19	0.38**	0.44**	0.49**

*significant at p=0.05, **significant at p=0.01, r - correlation coefficient ous experiments by Ciećko et al. [12, 13] and Csizinszky [14]. Their effect is generally positive (which is related to a greater availability of magnesium forms easy to assimilate) which is in the soil and originates from these neutralizing substances and partially from mineralized organic substances, e.g. from compost [15]. The result of the latter experiment indicate an increase in the content of magnesium in the particular parts of triticale, spring rape, maize [12, 13] and other crops [14] after the application of compost, brown coal and partially of lime. In maize, the application of lime had an antagonistic effect on the content of magnesium exhibited by a decrease in the magnesium content in the crops cultivated in the pots supplemented with lime.

Conclusions

1. The effect of soil contaminated with cadmium on the content of magnesium in plants was determined by the plant species and part.
2. A positive effect of soil contamination with cadmium on the content of magnesium in the plants was observed in all the examined parts of oats, the above-ground parts of yellow lupine and radish and in the roots of maize. A negative effect, however, was found in the above-ground parts of maize and in the roots of yellow lupine and radish. This decrease in the content of magnesium was low and did not exceed 10%.
3. The application of compost, lime, bentonite and, especially brown coal into the soil resulted in an increase in the content of magnesium in the majority of the parts of the examined plants.
4. The content of magnesium in plants generally correlated with the accumulation of other macro- and some microelements.

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