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THE EFFECT OF SOIL CONTAMINATION WITH CADMIUM ON THE PHOSPHORUS CONTENT IN PLANTS

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ABSTRACT

The aim of the experiment was to determine the effect of cadmium (10, 20, 30 and 40 mg Cd · kg^{-1} soil) on phosphorus uptake in plants. Neutralising matter, including compost, brown coal, lime and bentonite, was introduced into the soil for a basic pot experiments. Correlation between the phosphorus content and the cadmium contamination in the soil, plant yield and the macro- and microelements content in the plants were determined. The effect of soil contamination with cadmium on the phosphorus content was related to the species and the organs of plants. High cadmium concentration in the soil caused the phosphorus content in the grain and roots of oats, in maize root and in the above-ground parts of yellow lupine to increase. Such a correlation was not observed for oats straw, roots of yellow lupine and above-ground parts and roots of radish. Soil supplementation with brown coal, lime and bentonite resulted in a decrease in the phosphorus content, whereas the supplement of compost had the reverse effect and increased its content in plants. The phosphorus content was in general positively correlated with the content of macroelements (and some of the microelements) in plants.

Key words: cadmium contamination, neutralising matter, phosphorus content, yellow lupine yield, content of macro- and microelements.

INTRODUCTION

Extensive industrial production usually causes considerable emission of pollutants into the environment. Apart from polluting gases, such as sulphur and nitrogen, monoxides and carbon dioxide, the emission of large amounts of dust containing heavy metals occurs. Although the emission of pollutants has been recently significantly reduced, the local content of heavy metals may be high. Soil and bottom sediments of surface water bodies in regions where high environmental pollution has been recorded over the recent years are especially affected [9]. Heavy metals not only reduce the yield of crops but they are also related to the accumulation of xenobiotics and modify the content of other chemical elements [5, 13]. The experiments carried out so far have mainly concerned accumulation of heavy metals in plants, hence, the influence of heavy metals on the content of other elements has not yet been fully explained. Being highly mobile in the environment, cadmium happens to be one of the most dangerous metals.

The aim of the present experiment was to determine the effect of soil contamination with cadmium on the phosphorus uptake in plants. The investigation was based on a pot experiment in which soil was contaminated with cadmium and supplemented with neutralising matter such as compost, brown carbon, lime and bentonite.

MATERIALS AND METHODS

Pot experiments were carried out in a vegetation hall of the University of Warmia and Mazury in Olsztyn. Polyethylene pots were filled with 9 or 10 kg of acid soil of a grain size distributions of light clay sand. Light clay sand was characterised by pH (in 1M KCl) 4.50 in oats, maize, yellow lupine experiments and pH 4.07 in the experiment with radish. Soils used for both treatments had hydrolytic acidity (Hh) - 32.6 and 27.4 mmol (H^+) $\cdot$ kg^{-1}, and Cd content - 0.17 and 0.70 mg $\cdot$ kg^{-1}, respectively. The following increasing cadmium doses were applied to the soil: 10, 20, 30 and 40 mg Cd $\cdot$ kg^{-1} of soil. The effect of the artificial soil contamination with cadmium was determined for oats, maize, yellow lupine and radish. The oats experiment consisted of 4 series (not supplementated, supplemented with compost, brown coal and lime), while 5 series (no supplementation, supplemented with compost, brown coal, lime and bentonite) were conducted for each of the remaining experimental plants. Doses of admixtures added to the soil, namely 4% compost (0.39 mg Cd $\cdot$ kg^{-1} d.m.) and 4% brown coal (0.04 mg Cd $\cdot$ kg^{-1} d.m.), 2% bentonite bentonite (0.27 mg Cd $\cdot$ kg^{-1} d.m.) and lime (0.27 mg Cd $\cdot$ kg^{-1} d.m.) were equivalent to one hydrolytic acidity unit, which in grams of calcium per kilogram of soil corresponded to 1.51 for oats, 0.91 for maize and yellow lupine, and 1.15 for radish experiment, respectively. These organic substances were applied in order to mitigate the expected cadmium adverse effect on both the yield and chemical composition of the examined plants. All elements necessary for a proper growth and development of plants were added to all the pots by applying constant mineral fertilisation (NPK) in appropriate amounts for each species. Cadmium was applied in the form of cadmium chloride, nitrogen as urea, phosphorus in granulated trisuperphosphate, and potassium as 57% potassium salt. All the compounds and neutralising matter were thoroughly mixed with soil and introduced into the pots before the experiment began. Soil humidity over the vegetation period was maintained at 60% of the aquatic capillary capacity.

Samples of the above-ground parts and roots of the harvested plants were collected, dried, ground and disintegrated. The vanadium-molybdenum method, Kjeldahl method, atomic spectrometry of absorption (ASA) with an Unicam 939 Solar spectrometer were applied to determine phosphorus, nitrogen, and remaining micro- and macroelements contents, respectively in plant samples. Statistica software [15] was used to perform statistical calculations.

RESULTS AND DISCUSSION

The effect of heavy metals on the growth and development of plants is related to their genetic traits that determine species unique features and to the cultivar. Such traits determine plants resistance to xenobiotics [9, 13]. Certain heavy metals concentration in soil may in sensitive plants lead to a large yield reduction and modification of the chemical composition, while resistant plant crops are left unaffected [6, 7, 12, 13]. The species, plant organ and cadmium dose were the basic factors determining the content of phosphorus (Table 1 and 2). The highest content of phosphorus was reported for the above-ground parts of radish, whereas the lowest for the roots of maize. The average phosphorus content in oats grain or above-ground parts of maize and yellow lupine related to the one in the roots of respective plants was always found greater, and was increased by a factor of 2.4-2.6, 4, and nearly 2, for each plant respectively. In the analysed radish organs, differences were considerably lower and reached approximately 10%. The effect of cadmium on the content of phosphorus varied and was determined by both the species and the organ of the plant. High cadmium concentrations in soil caused an increase in the phosphorus content in oats grain and roots, contrary to the results for oats straw. A 10% increase in phosphorus content for grain was observed only up to the dose of 20 mg Cd $\cdot$ kg^{-1} of soil (r=0.28), while a 14% increase in the roots was observed up to the respective dose of 30 mg Cd$\cdot kg^{-1}$ of soil (r=0.77). On the other hand, the content of this element in the oat straw decreased by 10% (r=-0.65). However, in the case of maize the effect of cadmium on the phosphorus content in the above-ground parts was found irregular, while in the roots the content of this element increased even up to 61% (r=0.97).

Table 1. The effect of cadmium on phosphorus content in oats and maize, in g per kg of d.m.

Cd contamination ($mg \cdot kg^{-1}$ of soil)	Oats			Maize	
	grain	straw	roots	above-ground parts	roots
0	4.55	2.04	1.72	2.89	0.59
10	4.75	2.06	1.78	2.98	0.62
20	5.02	1.84	1.83	2.67	0.76
30	4.85	1.98	1.96	2.98	0.78
40	4.66	1.89	1.85	3.03	0.95
average	4.76	1.96	1.83	2.91	0.74
r	0.28	-0.65	0.77	0.31	0.97

Table 2. The effect of cadmium on phosphorus content in yellow lupine and radish, in g per kg of d.m.

Cd contamination ($mg \cdot kg^{-1}$ of soil)	Yellow lupine		Radish	
	above-ground parts	roots	above-ground parts	roots
0	1.93	1.75	5.12	4.72
10	2.21	1.36	5.36	4.67
20	2.72	1.24	5.13	4.52
30	2.79	1.62	4.72	4.31
40	2.83	1.08	4.78	4.29
average	2.49	1.41	5.02	4.50
r	0.93	-0.63	-0.78	-0.97

Contamination of soil with cadmium also caused a substantial increase of 47% (r=0.93) in phosphorus content in the above-ground parts of yellow lupine, in contrast to its roots where the content of this element decreased by 38% (r=-0.63). Moreover, substantial cadmium concentration in the soil resulted in decreasing phosphorus content in both the above-ground parts and the roots of radish. Still, the effect, when compared to other plants, was found relatively small and reached 7% (r=-0.78) and 9% (r=-0.97), respectively. It should be stressed here that for the first cadmium dose an increase in the phosphorus content in the above-ground parts of radish proved insignificant.

Admixture of neutralising organic matter into soil modified the phosphorus contents in all the experimental plants (see Table 3). Brown coal, lime and bentonite were applied to reduce the negative effect of cadmium on plants growth and development. Their presence in the soil resulted in the decrease in phosphorus content in particular plant organs. On the contrary, when compost was added to the pots, it stimulated phosphorus uptake in oats straw and roots, maize above-ground parts and yellow lupine roots. Compost inhibited the uptake of phosphorus by the above-ground parts and roots of radish. Particular attention should be paid to particularly great increase (29%) in phosphorus content for yellow lupine roots. Brown coal admixture lead to reduction of the uptake of phosphorus but varied from 5% for oats grain and maize roots to 30% for yellow lupine above-ground parts. Lime application into soil had even a greater effect on the reduction of phosphorus content. Its decreased uptake varied from 13% to 51% for the oats grain and above-ground parts of yellow lupine. Similar correlation factors were reported for application of bentonite which reduced the phosphorus uptake from 12% to 55% for roots of maize and radish and roots of yellow lupine, respectively. A 62% drop was observed for uptake by the above-ground parts of yellow lupine.

Table 3. The effect of neutralizing substances on phosphorus content in plants, in g per kg of d.m.

Organ of plant	Not supplemented	Compost	Brown coal	Lime	Bentonite	Average
Oats						
grain	5.06	4.78	4.79	4.42	-	4.76
straw	2.24	2.57	1.88	1.14	-	1.96
roots	1.86	2.02	1.61	-	-	1.83
Maize						
above-ground parts	3.58	3.75	2.63	2.20	2.40	2.91
roots	0.78	0.79	0.74	0.70	0.69	0.74
Yellow lupine						
above-ground parts	3.48	3.53	2.43	1.72	1.31	2.49
roots	1.67	2.16	1.68	1.22	0.75	1.41
Radish						
above-ground parts	5.93	5.21	5.22	4.91	4.48	5.02
roots	5.16	4.48	4.63	4.17	4.53	4.50

Based on the regression equations, correlation factors between phosphorus content and the yield of above-ground parts and the roots mass of the experimental plants were determined. The correlation between these factors was positive (Fig.1). Low phosphorus content was characteristic for lower yields and higher yielding plants had a higher phosphorus content. However, great differences were found both between plant species and particular plant organs. It should be mentioned that the phosphorus content was correlated with the content of many macro- and microelements, in particular with the content of sodium, calcium, boron, nitrogen, potassium and magnesium (Table 4). For sodium, a negative correlation was found, while for the remaining elements correlation was usually positive. A lesser degree of correlation between microelement content in plants and phosphorus content in plants was found. The greatest correlation was found in case of yellow lupine roots, in which the phosphorus content was significantly and positively correlated with the concentration of sulphur and zinc and negatively correlated with the concentration of manganese, iron, cobalt, lithium, aluminium, lead and copper. Such a system shows complex mechanisms related to the antagonism and synergism effects during the uptake of chemical elements by particular plant species.

According to Das et al. [5] soil contamination with cadmium can modify the uptake, transport and utilisation of different macroelements such as phosphorus, potassium, magnesium or calcium in plants. The results of the present experiment support the results of the previous experiments by the authors [1, 2, 3], where an increase in phosphorus content was found in the above-ground parts of the oats and maize as well as in the triticale grain, in contrast to straw in which the phosphorus content tend to decrease. In other experiments by Ciećko et al. [4] and by Narwal et al. [10] performed with maize, high cadmium concentrations in the soil did not cause significant changes in the phosphorus content in the above-ground parts of the plant. Simon [14] found no effect of cadmium on the phosphorus content in sunflower plants. It could be concluded that cadmium effect on the phosphorus content tends to vary from one plant species to another. This is supported by potato tubers experiments of Hlusek and Richter [8], who reported the effect of this metal as variable since the content of this macroelement increased in leaves. In the experiments by Navarro-Pedreno et al. [11], a similar effect of cadmium on potato leaves was also observed. Similarly, applied brown coal and lime lead to effects observed in previous experiments i.e. reduced the content of this element in the plants [1, 2, 3].

Fig. 1. Relationship between phosphorus content and plants yield

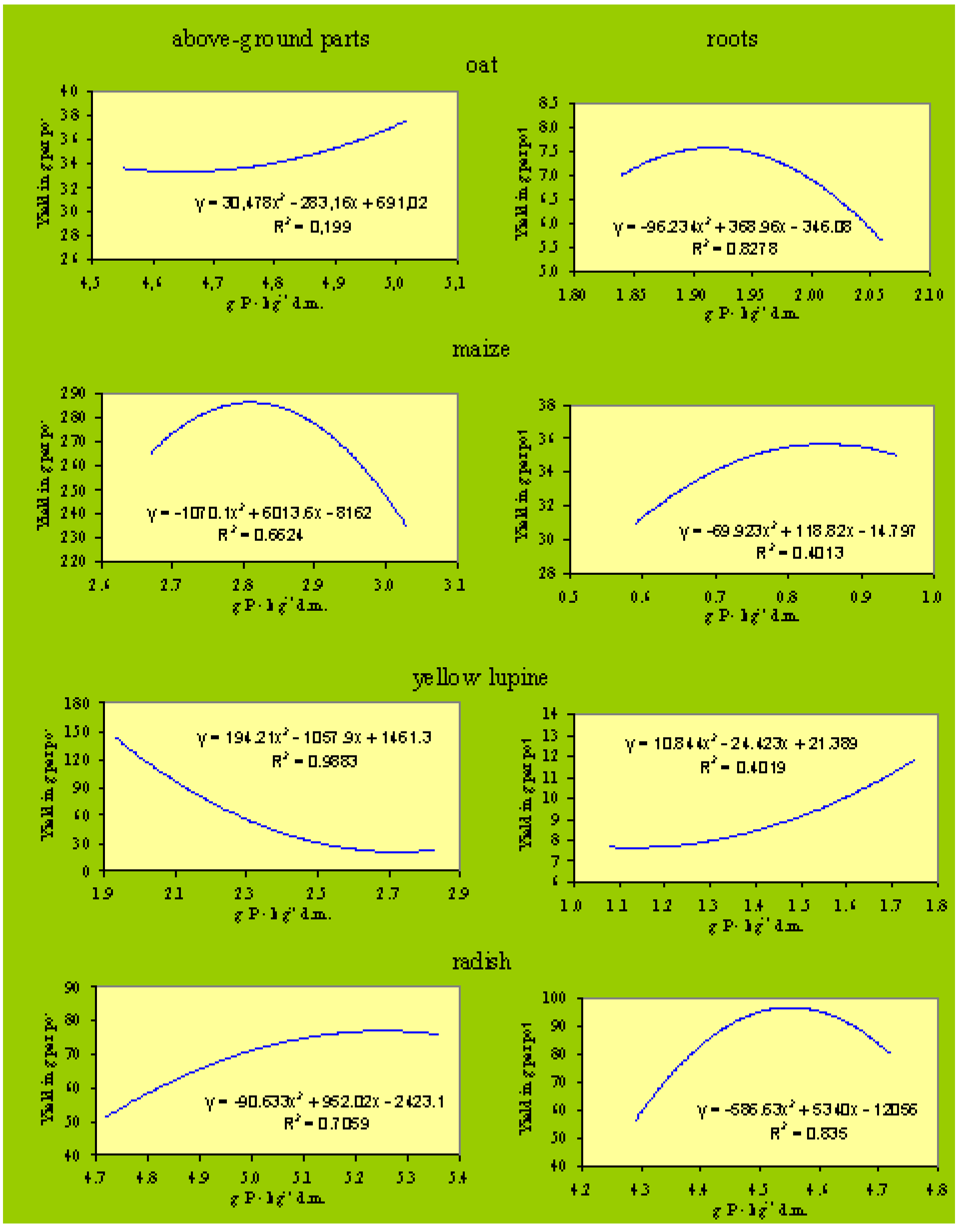

Table 4. Relationships (r) between phosphorus content and cadmium content against the content of macro- and microelements in plants

P content - Plant	Cd dose	Content in plants																
		N	K	Mg	Ca	Na	S	B	Mo	Mn	Fe	Co	Li	Al	Cd	Pb	Cu	Ni	Zn
Oats grain	0.14	0.21	-0.00	0.35*	0.11	0.19	0.29	0.06	-0.23	0.60**	-0.13	0.25	0.27	-0.06	0.64**	-0.01	-0.03	0.80**	0.67**
Oats straw	-0.10	-0.33*	0.09	-0.18	-0.77**	-0.31*	-0.23	-0.03	-0.11	0.52**	-0.04	0.26	0.47**	0.19	0.25	-0.49**	0.30	0.14	0.73**
Oats roots	0.25	0.17	0.61**	-0.08	0.11	0.24	-0.10	-0.46**	-0.40**	0.28	0.06	0.25	0.01	-0.07	0.43**	0.19	0.72**	-0.14	0.46**
Maize above-ground parts	0.06	0.61**	0.48**	0.01	0.35*	-0.36*	0.02	0.03	0.80**	-0.38**	-0.09	-0.07	-0.36*	0.37**	-0.03	0.66**	0.02	0.02	0.06
Maize roots	0.59**	0.65**	0.65**	0.72**	0.73**	0.38**	0.71**	0.42**	-0.14	-0.07	-0.14	-0.06	-0.25	0.77**	0.11	0.24	0.42**	0.44**	0.59**
Yellow lupine above-ground parts	0.34*	0.41**	0.51**	0.61**	0.70**	-0.55**	0.52**	0.22	-0.10	0.47**	0.57**	0.64**	0.72**	0.58**	0.80**	0.57**	0.33*	0.55**	0.93**
Yellow lupine roots	-0.10	0.83**	0.84**	0.29*	-0.06	-0.42**	0.31*	0.53**	0.17	-0.56**	-0.78**	-0.67**	-0.77**	-0.80**	0.40**	0.05	-0.42**	0.15	0.89**
Radish above-ground parts	-0.21	0.04	0.51**	0.44**	0.31*	-0.63**	-0.26	0.55**	0.32*	0.64**	-0.01	0.01	0.36*	-0.17	-0.24	0.53**	-0.14	0.46**	0.40**
Radish roots	-0.46**	-0.09	0.02	0.44**	0.09	0.20	0.39**	0.34*	-0.14	0.15	0.18	-0.31*	0.32*	0.22	-0.43**	0.04	0.15	0.18	0.15

* p=0.05, ** p=0.01

CONCLUSIONS

1. The phosphorus content was found to be strongly dependent both on the species and on the organ of experimental plants. Soil contamination with cadmium affected the phosphorus content and also depended on the species and particular plant organ.
2. High concentrations of cadmium in the soil caused phosphorus content in the grain and roots of oats, the roots of maize and the above-ground parts of yellow lupine to increase. The same cadmium concentration, however, caused a decrease in phosphorus content in oats straw, roots of yellow lupine and above-ground parts and roots of radish.
3. Soil supplementation with brown coal, lime and bentonite reduced the content of phosphorus while compost added to the pots proved to have rather a reverse effect.
4. Phosphorus content was usually positively correlated with the content of macro- and some microelements in the plants.

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