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Letter to the Editor

# Effect of Soil Contamination by Cadmium on Potassium Uptake by Plants

**Z. Ciećko[1]*, S. Kalembasa[2], M. Wyszkowski[1], E. Rolka[1]**

[1]Department of Environmental Chemistry, University of Warmia and Mazury in Olsztyn, Plac Łódzki 4, 10-718 Olsztyn, Poland
[2]Department of Soil Science and Agricultural Chemistry, Podlaska Academy, ul. B. Prusa 14, 08-110 Siedlce, Poland

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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 the potassium uptake by oats, maize, yellow lupine and radish. The effect of organic matter on cadmium immobilization was investigated in several treatments of the experiment using non-supplemented soil and soil supplemented with compost soil, brown coal, lime or bentonite. The correlations between the potassium content and the cadmium contamination of the soil, plant yield and the content of macro- and microelements in the plants were determined. The species and organ of the plants determined the uptake of potassium and influenced the effect of cadmium on the uptake of potassium by plants. Artificial soil contamination by cadmium reduced the content of potassium in oat grains and in the above-ground parts and roots of yellow lupine and radish. A reverse effect - an increase in the concentration of potassium, was found for oat straw and roots and maize roots. The application of compost soil, brown coal, lime and bentonite reduced the potassium concentration in the particular organs of the experimental crops. The concentration of potassium was positively correlated with plant yield and the content of macroelements and some microelements in them.

**Keywords:** cadmium contamination, neutralizing materials, potassium content, plants yield, content of micro- and macroelements

## Introduction

Extensive industrial production is usually connected with the emission of various pollutants to the environment. Among the most dangerous are heavy metals which accumulate in the ground, soil and bottom sediments of seas and oceans over long periods of time and effect biotic factors of the environment. Heavy metal contamination of soil effects the quality of crops, which very often reduces and sometimes disables the production of valuable food and animal feed [1, 2, 3, 4]. Plants harvested from heavy metal polluted areas are usually tested for heavy metal concentration while the concentration of other elements is often neglected.

Cadmium is a heavy metal with a strong effect on crop quality. Moreover, it is a very mobile element in the environment. Plants can easily uptake cadmium and transfer it to other organs [1, 3]. Experiments on the effect of cadmium on contents of macroelements in plants are scarce and therefore the mechanism of its effect has not yet been fully explained.

The current pot experiment is an attempt to determine the effect of soil contamination with cadmium on the content of potassium in oats, maize, yellow lupine and radish. The experiments also involved the application of organic matter into the soil to reduce the uptake of cadmium by the experimental plants.

*Corresponding author

## Material and Methods

The experiment on the effect of soil contamination with cadmium (added at doses; 10, 20, 30 and 40 mg Cd · $kg^{-1}$ of soil as $CdCl_2 \cdot 2.5 H_2O$) on the content of potassium in the plants was carried out in polyethylene pots which were filled with 9 or 10 kg of loamy sand (pH in 1 mol · $dm^{-3}$ of KCl - 4.50 unit and hydrolic acidity Hh 32.6 mmol $(H^+) \cdot kg^{-1}$) and located in the vegetation hall of the University of Warmia and Mazury in Olsztyn. This paper presents the results of four experiments in which the following plants were tested: oats, maize, yellow lupine and radish.

To reduce the uptake of cadmium by tested plants the pots with each plant were divided in two groups:

1) without the addition of any organic materials;
2) with the addition of organic materials as follows: in the cultivation of oats - composted soil, brown coal and lime, but in the cultivation of maize, yellow lupine and radish-composted soil, brown coal, lime and bentonite.

The composted soil and brown coal were added in the amount of 4% (w/w) but bentonite at 2% (w/w) of the mass of soil and lime according to 1 unit of hydrolytic acidity. Total Cd content was in added materials as follows: in composted soil 0.39 mg · $kg^{-1}$ of D.M., brown coal 0.04 mg · $kg^{-1}$ of DM, bentonite 0.27 mg · $kg^{-1}$ of DM and lime 0.27 mg · $kg^{-1}$ of DM. To each pot in this experiment the mineral fertilizers N, P and K were added in amounts differentiated for each tested plant according the their nutritional requirements. Cadmium and mineral fertilizers were applied to the soil in the following forms: Cd - cadmium chloride, N - urea, P - granulated superphosphate and K as 57% potassium salt - potassium chloride.

Samples of the above-ground parts and roots of the harvested plants were taken, disintegrated, dried and ground. Content of the following elements in the plant samples were determinated: phosphorus content with the vanadium-molybdenum method, nitrogen with the Kjeldahl method and the content of remaining micro- and macroelements with the atomic absorption spectrometry with the use of Unicam 939 Solar spectrometer. Statistical calculations of the correlations between the cadmium dose and the content of macro- and microelements were completed with the use of Statistica software [5]. Influence of cadmium contamination of soil on Cd content in oats, maize, yellow lupine and radish was published earlier [6].

## Results and Discussion

The content of ash components in the plants is determined by several factors including species, cultivar and organ of the plant. The accumulation of potassium in the experimental plants was strongly correlated with both the species and the organ of the plant (Table 1 and 2). The greatest potassium accumulation was found in the above-ground parts (on average 51.64 g K · $kg^{-1}$ of dry matter) and the roots (57.52 g K · $kg^{-1}$ d.m.) of radish and the lowest in the roots of maize (4.96 g K · $kg^{-1}$ d.m.). The content of this element in the roots of all the plants, excluding the radish, was lower than that in their above-ground parts. Particularly great differences (9-fold) were found between the above-ground parts and the roots of maize and (about 3-fold) between the oat straw and roots. On the other hand, the content of potassium in the roots of yellow lupine was only 32% lower than that in its above-ground parts.

Plants cultivated in soil contaminated with heavy metals are subject to modification of their chemical composition not only the content of heavy metals but also other macroelements like potassium [1]. A high concentration of cadmium in the soil decreased the content of potassium in the oat grain, above-ground parts and the roots of yellow lupine, and radish, in comparison with the control plants without contaminants (Table 1 and 2). A reverse correlation, an increase in the potassium concentration, was found in the oat straw and roots and in the roots of maize. The decrease in the content of potassium in the oat grain, the above-ground parts of yellow lupine as well as in the above-ground parts and the roots of radish ranged from a few to a dozen percent. A considerably greater decrease (38%) in the content of potassium as the result of soil contamination with cadmium was stated in the roots of yellow lupine. At the same time, the increase in the potassium content in the oat straw and the roots of oat and

Table 1. Effect of cadmium on potassium content in oats and maize (in g per kg of d.m.).

| Cd contamination ($mg \cdot kg^{-1}$ of soil) | Oat | | | Maize | |
|---|---|---|---|---|---|
| | grain | straw | roots | above-ground parts | roots |
| 0 | 10.05 | 33.43 | 9.57 | 45.20 | 3.72 |
| 10 | 9.23 | 37.18 | 9.80 | 44.12 | 4.14 |
| 20 | 9.20 | 37.30 | 12.07 | 43.48 | 5.84 |
| 30 | 9.08 | 37.60 | 11.60 | 45.62 | 4.90 |
| 40 | 8.88 | 35.43 | 11.67 | 45.90 | 6.18 |
| r | $-0.88^{**}$ | $0.40^{*}$ | $0.82^{**}$ | $0.45^{*}$ | $0.85^{**}$ |

$^{*}$significant at p = 0.05, $^{**}$significant at p = 0.01

Table 2. Effect of cadmium on potassium content in yellow lupine and radish (in g per kg of d.m.).

| Cd contamination (mg·kg$^{-1}$ of soil) | Yellow lupine | | Radish | |
|---|---|---|---|---|
| | above-ground parts | roots | above-ground parts | roots |
| 0 | 10.20 | 8.66 | 55.04 | 60.46 |
| 10 | 9.70 | 7.16 | 55.84 | 58.48 |
| 20 | 9.30 | 5.88 | 47.58 | 56.53 |
| 30 | 10.80 | 6.83 | 50.10 | 57.25 |
| 40 | 9.90 | 5.37 | 49.65 | 54.88 |
| r | 0.14 | -0.86** | -0.72** | -0.93** |

*significant at p = 0.05, **significant at p = 0.01

maize was greater and equalled 12, 26 and 66%, respectively, in the oats cultivated in the soil contaminated with 20 or 30 mg Cd · kg$^{-1}$ of soil and maize roots with 40 mg Cd · kg$^{-1}$ of soil.

The application of different organic matter into the soil to reduce the effect of cadmium on the plants resulted in considerable fluctuations in the content of potassium in their particular organs (Table 3). This effect was usually negative. The application of compost soil and brown coal in comparison with the control plants (non-supplemented) caused insignificant changes in the plant roots and were usually only a few percent. The application of brown coal reduced the potassium uptake by the oat grain and the above-ground parts of yellow lupine by 15% and in the above-ground parts of radish by as much as 35%. Larger changes occurred after the application of lime and ranged between 16-22%. The maximum decrease in the content of potassium (2.5-3-fold), in comparison with the control series, was observed in the roots of maize and yellow lupine and in the above-ground parts of radish cultivated on the soil supplemented with bentonite.

Pearson's simple correlation coefficients indicate that the cadmium uptake by particular plant organs is likely to be determined by other chemical elements. This is related to the phenomena of synergism and antagonism, which may have a different course in contaminated soil than in typical cultivation soil (Table 4). In most of the experimental plant organs positive correlations were generally found between the content of potassium and the concentration of phosphorus, magnesium, nitrogen, calcium, boron, manganese, lithium, aluminium, copper and zinc and clearly negative correlations with the content of sodium. Similar correlations were found for other microelements and in some plant organs.

The considerably strong effect of soil contamination with cadmium on the content of potassium in plants for different species and organs was stated by other authors: Ciećko et al. [7] and Obata, Umebayashi [4] which clearly

Table 3. Effect of neutralization substances on potassium content in plants (in g per kg of d.m.).

| Plant organ | Without additions | Compost dirt | Brown coal | Lime | Bentonite | Average |
|---|---|---|---|---|---|---|
| Oats | | | | | | |
| Grain | 9.98 | 9.00 | 8.46 | 9.70 | - | 9.29 |
| Straw | 36.74 | 37.76 | 33.82 | 36.42 | - | 36.19 |
| Roots | 11.14 | 11.30 | 10.38 | - | - | 10.94 |
| Maize | | | | | | |
| Above-ground parts | 46.52 | 45.46 | 44.20 | 45.76 | 42.38 | 44.86 |
| Roots | 6.10 | 5.78 | 5.70 | 4.76 | 2.44 | 4.96 |
| Yellow lupine | | | | | | |
| Above-ground parts | 9.98 | 9.00 | 8.46 | 9.70 | 9.29 | 9.98 |
| Roots | 9.00 | 8.53 | 8.28 | 7.54 | 2.96 | 6.78 |
| Radish | | | | | | |
| Above-ground parts | 76.05 | 62.86 | 49.14 | 60.76 | 25.56 | 51.64 |
| Roots | 60.25 | 61.72 | 66.54 | 62.00 | 39.50 | 57.52 |

Table 4. Relationships between potassium content versus the content of cadmium and the content of macro- and microelements in plants.

| K content in plants | Cd dose | Content in plants | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N | P | Mg | Ca | Na | S | B | Mo | Mn | Fe | Co | Li | Al | Cd | Pb | Cu | Ni | Zn |
| Oat grain | -0.41** | 0.30 | -0.00 | -0.58** | 0.06 | 0.52** | -0.30 | -0.68** | 0.25 | 0.46** | -0.09 | 0.59** | 0.55** | 0.72** | 0.10 | 0.24 | 0.38* | -0.07 | -0.04 |
| Oat straw | 0.23 | 0.15 | 0.09 | -0.46** | 0.11 | 0.06 | -0.13 | -0.50** | -0.02 | 0.15 | 0.37* | 0.32* | -0.20 | 0.26 | 0.51** | 0.11 | 0.66** | 0.28 | 0.19 |
| Oat roots | 0.54** | 0.53** | 0.61** | 0.29 | 0.42** | 0.87** | 0.39* | -0.04 | -0.08 | 0.05 | -0.35* | -0.05 | -0.26 | -0.30 | 0.63** | 0.12 | 0.65** | -0.37 | 0.30 |
| Maize above-ground parts | 0.13 | 0.59** | 0.48** | -0.01 | 0.49** | -0.37** | 0.21 | -0.03 | 0.43** | 0.00 | -0.03 | -0.09 | 0.09 | 0.29* | 0.01 | 0.42** | -0.20 | 0.02 | 0.13 |
| Maize roots | 0.40** | 0.22 | 0.65** | 0.66** | 0.68** | -0.33* | 0.13 | 0.65** | 0.16 | 0.12 | 0.14 | 0.15 | -0.15 | 0.46** | 0.11 | 0.29* | 0.25 | 0.59** | 0.40** |
| Yellow lupine above-ground parts | -0.15 | 0.72** | 0.51** | 0.64** | 0.73** | -0.92** | -0.02 | 0.43** | -0.19 | 0.39** | -0.11 | -0.03 | 0.06 | -0.11 | 0.13 | 0.00 | 0.11 | -0.11 | 0.58** |
| Yellow lupine roots | -0.24 | 0.93** | 0.84** | 0.36* | 0.36* | -0.52** | 0.41** | 0.46** | 0.02 | -0.82** | -0.88** | -0.83** | -0.87** | -0.88** | 0.19 | -0.29* | -0.56** | 0.18 | 0.72** |
| Radish above-ground parts | -0.00 | 0.35* | 0.51** | 0.16 | 0.40** | -0.94** | -0.44** | 0.52** | -0.13 | 0.62** | 0.26 | -0.04 | 0.50** | 0.19 | 0.49** | 0.11 | -0.39** | 0.13 | 0.66** |
| Radish roots | -0.15 | 0.50** | 0.02 | 0.80** | 0.80** | -0.94** | 0.16 | 0.79** | 0.31* | 0.42** | -0.02 | -0.14 | -0.06 | -0.61** | 0.08 | -0.12 | 0.25 | 0.41** | 0.67** |

*significant at p = 0.05; ** significant at p = 0.01

refers to our presented results. It is usually larger in the roots. Ciećko et al. [7] observed a decrease in potassium content in triticale grains and oats grains and an increase in the content of this element in the straw from pots contaminated with cadmium. These authors also found an increase in the content of potassium in the above-ground parts of spring rape and oats [7, 8]. The experiments of Ciećko et al. [8, 9] and Jasiewicz and Antonkiewicz [10, 11] indicate a positive influence of cadmium on the accumulation of potassium in the above-ground parts of maize, and in an experiment reported by Hlusek and Richter [12], who found the same reaction for potato tubers. Jasiewicz and Antonkiewicz [11] observed an increase in the content of potassium in different organs of maize including ears, leaves, stems, roots and topinambur, in the experiment with soil contaminated with high doses of heavy metals, including cadmium (40-80 mg Cd·kg$^{-1}$ of soil). The content of potassium in the experiments of Hlusek and Richter [12] in potato leaves and in the experiments of Navarro-Pedreno et al. [13] in tomato leaves as well as in the experiments of Simon [14] in sunflower plants was not influenced by the concentration of cadmium in the soil. According to the Narwal et al. [15], the effect of high cadmium doses on the content of potassium in the roots of maize is usually negative and its effect on the above-ground parts can be connected with soil quality. They claimed that the content of this element can increase in lighter soils and decrease in heavier soils. In the experiments of Ciećko et al. [7, 16], as in the current experiment, compost soil and brown coal caused a slight decrease in the content of potassium in the above-ground parts of spring rape and maize and in the straw of spring triticale, in contrast to the triticale grain. In the current experiment, unlike in the previous experiments [8, 16], the application of lime had rather a negative effect on the content of potassium in the plants, particularly in their roots.

## Conclusions

1. The total content of potassium in the plants and the trend of its changes as the result of soil contamination with cadmium were affected mainly by plant species and organs.
2. Soil contamination with cadmium caused an increase or a decrease in the content of potassium, depending on the plant species and organ. An increase in the content of potassium was found in oat straw and roots and in the roots of maize and a decrease in the content of this element was observed in oat grains as well as in the above-ground parts and the roots of yellow lupine and radish.
3. The application of compost soil, brown coal, lime and particularly bentonite into the soil had a decreasing effect on the content of potassium in particular organs of the experimental plants.
4. The content of potassium was positively correlated with plant yield and with the content of macroelements and some microelements.

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