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EFFECT OF VARIOUS CONCENTRATIONS OF LEAD AND CADMIUM ON EARLY GROWTH OF MAIZE*

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A b s t r a c t. The experiment was conducted to measure the impact of pollution with lead and cadmium on early growth of maize. During 14 days of the laboratory experiment the daily increases of plant height, leaf area, plant mass, root length and thickness were measured. Maize was growing in water solutions of various concentrations of lead or cadmium, and in mixture of lead and cadmium. Overall maize growth was affected by lead and cadmium, however different impact of these metals according to their concentrations was observed. Lead and cadmium toxicity was the most apparent for root length, especially for thin roots. Root growth inhibition was stronger by cadmium than by lead for low heavy metals concentrations, and an inverse relation was observed for the highest concentrations.

K e y w o r d s: lead, cadmium, maize, heavy metal pollution

INTRODUCTION

Cadmium and lead are among the most widespread non-nutrient heavy metals (HM) (Seregin *et al.* 2004). The main sources of environment contamination are of anthropogenic origin, caused by mining, fossil fuels burning, fertilizers and sewages that can contain both lead and cadmium in high amounts. Very easily absorbed cadmium is one of the most toxic elements to any kind of organism (Sanita di Toppi and Gabrielli 1999). The effect of lead on root growth pattern is still far from complete (Obroucheva *et al.* 1998).

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Some plants have an ability to accumulate heavy metals to concentrations higher than that which occurs in their growth environment, which can be used to decontaminate polluted environment. For example, maize has a potential to be used as a hyper-accumulation plant in phytoremediation of polluted areas (Wójcik and Tukiendorf 2005). Different tolerance of plant species to heavy metal pollution is used to indicate the level of soil pollution (Seregin and Ivanov 2001).

Lead and cadmium enter plants via the root system. Plant metabolic disorder resulting from interactions between Cd or Pb and functional groups of proteins, nuclide acids, polysaccharides makes it difficult to distinguish direct and indirect effects (Seregin and Ivanov 2001). Mobile fractions of heavy metals in contaminated soils start affecting plant growth at the stage of a seed. However, seed germination is a process that is very resistant to heavy metals, probably as a result of low penetration of metals through seed coats (Seregin and Kozhevnikowa 2004).

The aim of the study was to investigate the effect of cadmium and lead at different concentrations on early growth of maize.

MATERIAL AND METHODS

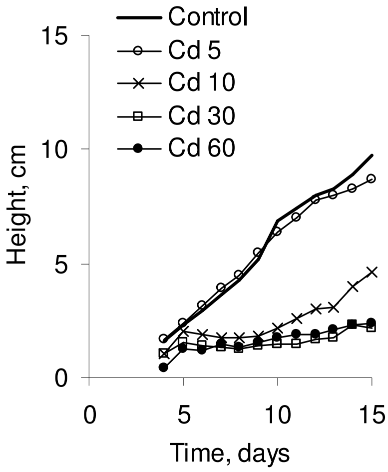
During the 14-day laboratory experiment the impact of pollution with lead and cadmium on early growth of maize roots and shoots was assessed. Maize (*Zea maize* L.) cv. San seeds were germinated in the dark on moistened filter, then the germinated plants were moved to a growth chamber with controlled day (14h) and night (10 h) temperature (18^{o}C and 24^{o}C, respectively), humidity (70%) and light (150 µmol $m^{-1}s^{-1}$). $CdCl_2$ or $Pb(NO_3)_2$ solutions were used to test the toxicity of cadmium and lead. Maize seeds were growing in 600; 300; 100; and 50 mg water solution of lead, 60; 30; 10 and 5 mg dm^{-3} water solution of cadmium, and in solution of a mixture of lead and cadmium in the following concentrations: (300 mg Pb and 30 mg Cd) dm^{-3}; (300 mg Pb and 10 mg Cd) dm^{-3}; (100 mg Pb and 30 mg Cd) dm^{-3}; (100 mg Pb and 10 mg Cd) dm^{-3} and (50 mg Pb and 5 mg Cd) dm^{-3}. The heavy metal concentrations used ranged from the levels occurring in polluted soils to the values used in the study of hyper-accumulation.

The daily increase in plant height, leaf area, fresh and dry mass, root length and thickness were measured. The procedure of root length measurements included the following steps: cutting and washing of roots, scanning of root system immersed in distilled water on glass plate with flatbed scanner using 400dpi resolution, analysis of scanned images with Scion Image NIH software with macro procedure (Kimura and Yamasaki 2003).

There were 10 replicates of each treatment; the data represent the mean values and standard deviation.

RESULTS AND DISCUSSION

The lowest concentrations of Cd (5 mg dm^{-3}) and Pb (50 mg dm^{-3}) slightly affected daily plant growth (Fig. 1), low concentrations of cadmium were reported to promote plant germination (Mel'nichuk 1990). Each higher dose of heavy metak (HM) caused a strong decrease in daily plant growth. Plant height was lowered by about 25% at the last day of the experiment by the lowest concentration mixture of Cd and Pb (5 + 50 mg dm^{-3}). Two highest concentrations of cadmium affected the growth of shoots similarly, almost completely inhibiting their growth after 5th day of the experiment. It was reported that toxicity effect of



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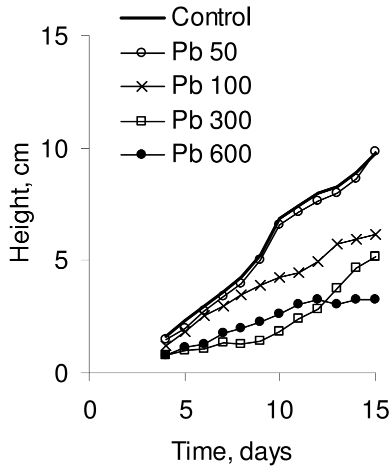

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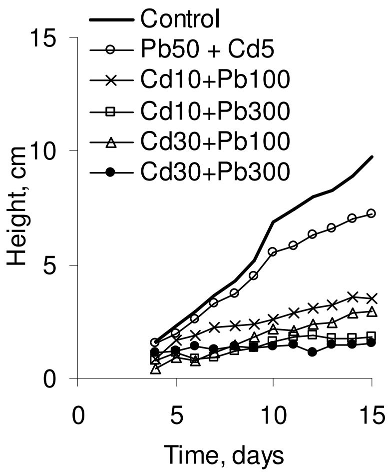

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Fig. 1. Height of plants growing in various concentrations of cadmium (A), lead (B) and mixture of cadmium and lead (C) solution (mg dm^{-3}) during experiment

lead increases with time, the lower dose of the metal the later its toxic effect appears, as heavy metals accumulate to a threshold toxic level (Obroucheva *et al.* 1998).

An overall decrease in the leaf area with increasing concentration of HM (Fig. 2) was observed. The lowest doses of HM caused a decrease in the leaf area by about 18% for both cadmium and lead and about 35% for mixture of lead and cadmium. The strongest doses of HM caused decrease in the leaf area by about 89, 77 and 94% for cadmium, lead, and mixture of lead and cadmium, respectively. This shows a stronger toxic effect of cadmium than of lead on maize shoot growth.

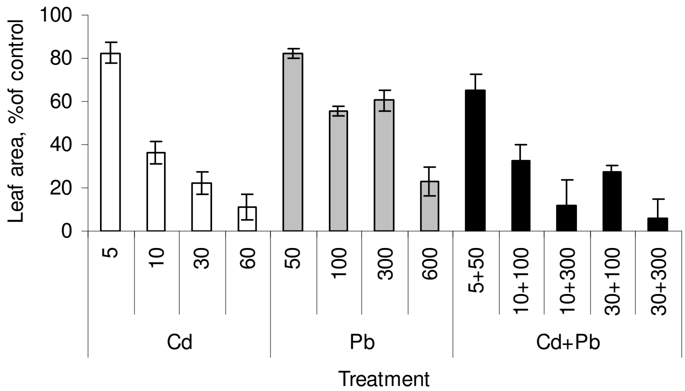


Fig. 2. Leaf area decrease as a result of various cadmium, lead and mixture of cadmium and lead concentrations (mg dm^{-3}) in comparison to control treatment

The decrease in plant mass, resulting from HM toxicity, presented in Figure 3 is stronger for fresh than for dry mass. This indicates a decrease in the amount of water stored by plants, probably as a result of reported lowering of the content of compounds maintaining turgor and cell wall plasticity by lead and cadmium (Barcelo and Poschenrieder 1990). There was stronger reduction of root mass than shoots for both HM, and this reduction was more apparent for higher concentrations of HM. Slow movement of lead toward xylem results in low content of this metal in shoots and decreasing inhibitory effect on shoot growth (Godzik 1993). Studies of Obroucheva *et al.* (1998) showed that lead affects both cell elongation and division in maize. Both highest concentrations of heavy metals and mixture of highest concentrations of lead and cadmium decreased the dry mass of roots to a similar level of 12-13% of control. Shoot dry mass varied much stronger and was the lowest for solution of 300 mg Pb and 30 mg Cd dm^{-3} and solution of 60 mg dm^{-3} Cd equalling 37 and 50%, respectively, as compared to control.

Addition of 10 mg of Cd to the 300 mg dm^{-3} solution of lead induced much stronger decrease of dry shoot mass than addition of 100 mg of Pb to the 30 mg dm^{-3}

solution of cadmium, although both 10 mg dm^{-3} solution of cadmium and 100 mg dm^{-3} solution of lead had similar effect on shoot dry mass.

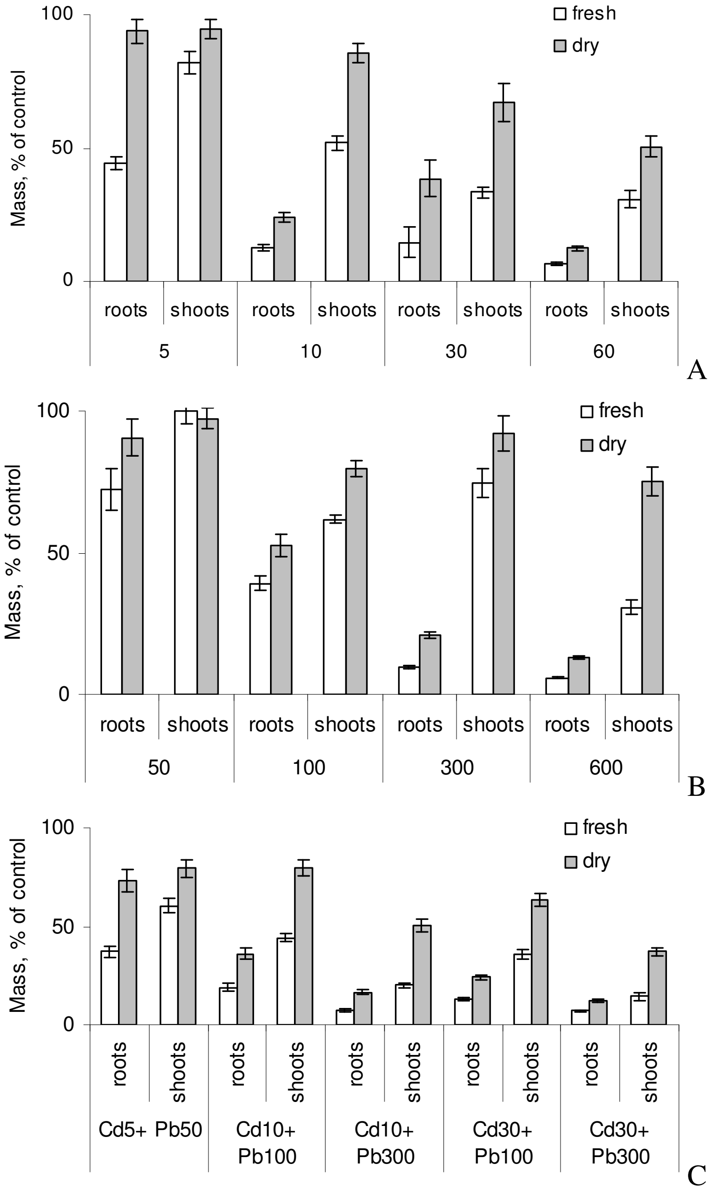


Fig. 3. Plant mass decrease as a result of various cadmium (A), lead (B) and mixture of cadmium and lead (C) concentrations (mg dm^{-3}) in comparison to control treatment

A stronger impact of HM on plant was observed in the case of root length (Fig. 4) than leaf area (Fig. 2), please note logarithmic axis in Figure 4. Generally, growth of roots is more sensitive to heavy metals than that of shoots. The effect of lead is reported to be generally stronger than that of cadmium (Karataglis 1987), however higher toxicity of cadmium than lead on maize root growth was reported by Seregin and Ivanov (2001). In our experiment stronger inhibition of root growth by cadmium than lead was observed for the lowest HM concentrations and reverse for the highest HM concentrations.

Addition of the dose of 300 mg of lead to the 10 mg dm^{-3} solution of cadmium caused stronger inhibition of root growth than addition of 30 mg of cadmium to the 100 mg dm^{-3} solution of lead, although both 30 mg Cd per dm^{-3} and 300 mg Pb per dm^{-3} solutions had similar effect on root growth (Fig. 4).

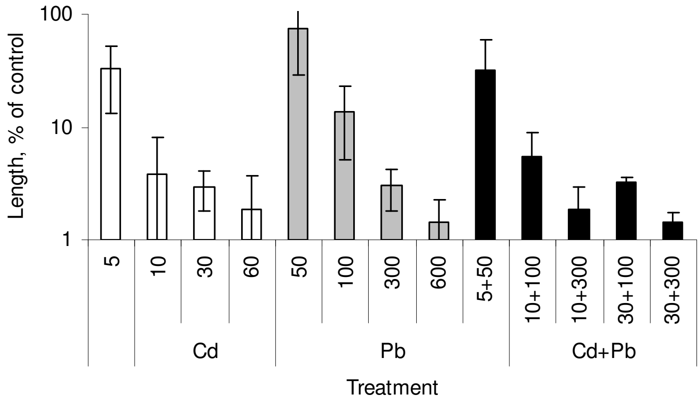
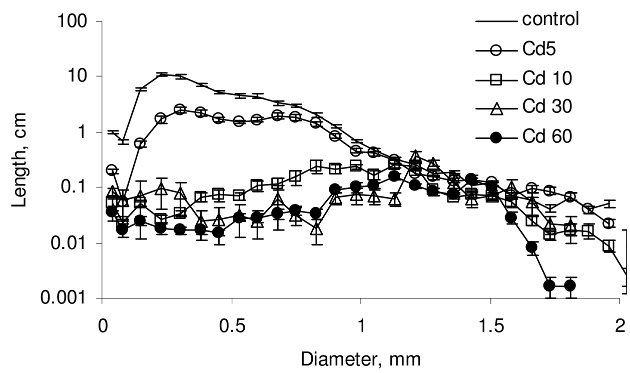


Fig. 4. Root length decrease as a result of various cadmium, lead and mixture of cadmium and lead concentrations (mg dm^{-3}) in comparison to control treatment

The decrease of root length was especially visible for thin roots (below 0.5 mm) (Fig. 5). The effect of lead toxicity on thin root length was relatively less visible; the lowest dose of 50 mg dm^{-3} of Pb only slightly decreased the length of thin roots in contrast to the lowest doses of Cd and mixture of Cd and Pb. No characteristic maximum in the range of thin roots can be seen in the Figures presenting changes of root length at specified root diameters for concentrations equal to and stronger than 10 mg Pb dm^{-3}; 100 mg Cd dm^{-3} and (10 mg Pb +100 mg Cd) dm^{-3}.

The observed effect of decrease of thin roots length probably should be attributed to overall increase of root thickness as the fraction of usually thinner, lateral roots increases with increasing lead concentration (Obroucheva *et al.* 1998). The effect of lead and cadmium toxicity on root morphology was also reported by Seregin and Ivanov (2001).



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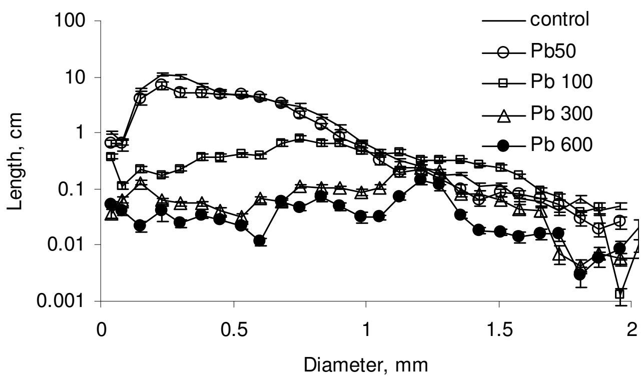

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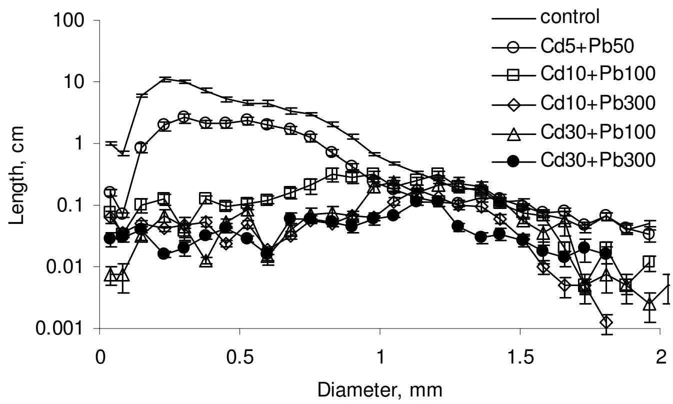

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Fig. 5. Root length in various diameter ranges for plants growing in cadmium (A), lead (B) and mixture of cadmium and lead (C) solutions (mg dm^{-3})

CONCLUSION

The impact of the studied heavy metals on plant growth varied with relation to their concentrations. Similar inhibition of leaf area observed for the lowest lead and cadmium concentrations changed with increasing concentration, and for the strongest solution of cadmium leaf area was about two-fold smaller than for the strongest lead solution. Overall, stronger reduction of root than shoot mass was the most apparent for high heavy metals concentrations. Root growth inhibition was stronger by cadmium than by lead for low heavy metals concentrations, but the reverse was observed for the highest concentrations. The growth of thin roots growth was the most affected by lead and cadmium toxicity.

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WPŁYW RÓŻNYCH STĘŻEŃ OŁOWIU I KADMU NA POCZĄTKOWY WZROST KUKURYDZY

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Streszczenie. Przeprowadzono doświadczenie mające na celu określenie wpływu różnych stężeń ołowiu i kadmu na początkowy wzrost kukurydzy. Podczas 14 dniowego doświadczenia laboratoryjnego określano przyrost wysokości, powierzchnię liści, masę, długość i grubość korzeni roślin. Rośliny wzrastały w wodnym roztworze ołowiu, kadmu i mieszaniny ołowiu i kadmu o różnych stężeniach. Zaobserwowany ogólny, ograniczający wzrost wpływ roztworów badanych metali ciężkich na wzrost roślin zależał od ich stężenia. Ograniczenie długości korzeni, w szczególności korzeni cienkich było najwyraźniejszym efektem toksyczności ołowiu i kadmu. Kadm ograniczał wzrost korzeni w wyższym stopniu niż ołów dla mniejszych stężeń metali ciężkich, odwrotna zależność zachodziła dla największych stężeń.

Słowa kluczowe: ołów, kadm, kukurydza, zanieczyszczenie metalami ciężkimi