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COMPARISON OF THE EFFECT OF LIMING AND MAGNESIUM TREATMENT OF HEAVY METAL CONTAMINATED SOIL ON THE CONTENT OF MAGNESIUM, CALCIUM AND IRON IN BROAD BEANS (*VCIA FABA* L. SSP. *MAIOR*)

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Abstract

Tests have been conducted to determine the effect of liming and magnesium treatment on the content of magnesium, calcium and iron in broad bean plants growing on soil polluted with such heavy metals as cadmium, lead, nickel, copper and zinc.

In 2005, an experiment was conducted in the village Zagaje Stradowskie (Œwiêtokrzyskie Province) on degraded Chernozem formed from loess, acid in reaction and containing 1.13% of organic carbon. Analyses were performed on aerial parts of cv. White Windsor broad bean (*Vicia faba* L. ssp. *maior)*, cultivated in three series: on limed soil, on soil receiving magnesium fertilizers; on unlimed soil without magnesium fertilization. In each series, the plants were cultivated on the following objects: unpolluted soil with a natural content of heavy metals (control); unpolluted soil with a natural content of heavy metals and mineral fertilization (control+NPK); soil polluted with a cadmium dose 4 $mg \cdot kg^{-1}$ d.m.; soil polluted with a dose of 530 $mg \cdot kg^{-1}$ of lead; soil contaminated with a copper dose 85 $mg \cdot kg^{-1}$ d.m., soil contaminated with a dose of 1000 $mg \cdot kg^{-1}$ of zinc and soil polluted with a nickel dose 110 $mg \cdot kg^{-1}$ d.m. Liming was based on the analysis of hydrolytic acidity of soils from individual objects. The administered dose was established according to 1Hh. Magnesium treatments were identical in all objects. i.e. 20.4 $mg \cdot kg^{-1}$ soil d.m.

Soil contamination with zinc or nickel leads to a considerable decrease in magnesium and calcium level in broad bean aerial parts but rises iron level. Liming rather than ma-

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gnesium fertilization applied to soil polluted with heavy metals, such as zinc or nickel, contributes to balancing the content of the analyzed macronutrients in broad beans. The content of Ca, Fe and Mg in plants after liming approached the level determined in the control plants.

Key words: heavy metals, magnesium fertilization, liming, accumulation, Mg, Ca, Fe.

PORÓWNANIE ODDZIA£YWANIA WAPNOWANIA I NAWO¯ENIA MAGNEZOWEGO GLEBY SKA¯ONEJ METALAMI CIÊ¯KIMI NA ZAWARTOŒÆ MAGNEZU, WAPNIA I ¯ELAZA W ROŒLINACH BOBU (*VICIA FABA* L. SSP. *MAIOR*)

Abstrakt

Celem badañ by³o okreœlenie wp³ywu wapnowania i nawo¿enia magnezowego na zawartoœæ mangezu, wapnia i ¿elaza w roœlinach bobu rosn¹cych w warunkach gleby zanieczyszczonej pojedynczymi metalami ciê¿kimi: kadmem, o³owiem, niklem, miedzi¹ i cynkiem.

Gleba u¿yta w doœwiadczeniu to czarnoziem zdegradowany wytworzony z lessu o odczynie kwaœnym i zawartoœci wêgla organicznego 1,13%. Doœwiadczenie przeprowadzono w 2005 r., w miejscowoœci Zagaje Stradowskie (woj. œwiêtokrzyskie). Analizie poddano czêœci nadziemne bobu (*Vicia faba* L. ssp. *maior*) odm. Windsor Bia³y uprawianego w trzech seriach: na glebie wapnowanej; poddanej nawo¿eniu magnezowemu; niewapnowanej i nienawo¿onej magnezem. W ka¿dej serii roœliny uprawiano w nastêpuj¹cych obiektach: gleba niezanieczyszczona – o naturalnej zawartoœci metali ciê¿kich (kontrola); gleba niezanieczyszczona – o naturalnej zawartoœci metali ciê¿kich nawo¿ona mineralnie (kontrola + NPK); gleba zanieczyszczona kadmem w dawce 4 $mg \cdot kg^{-1}$ s.m.; gleba zanieczyszczona o³owiem w dawce 530 $mg \cdot kg^{-1}$ s.m.; gleba zanieczyszczona miedzi¹ w dawce 85 $mg \cdot kg^{-1}$ s.m.; gleba zanieczyszczona cynkiem w dawce 1000 $mg \cdot kg^{-1}$ s.m.; gleba zanieczyszczona niklem w dawce 110 $mg \cdot kg^{-1}$ s.m. Wapnowanie przeprowadzono opieraj¹c siê na analizie kwasowoœci hydrolitycznej gleby z poszczególnych obiektów. Zastosowano dawkê wed³ug 1 Hh. Na wszystkich obiektach zastosowano jednakowe nawo¿enie magnezowe: 20,4 mg $Mg \cdot kg^{-1}$ s.m. Ska¿enie gleby cynkiem lub niklem prowadzi do znacznego obni¿enia poziomu magnezu i wapnia w czêœciach nadziemnych bobu, a podwy¿sza poziom ¿elaza. Wapnowanie gleby ska¿onej metalami ciê¿kimi, takimi jak cynk lub nikiel, bardziej ni¿ nawo¿enie magnezowe przyczynia siê do zrównowa¿enia zawartoœci badanych makropierwiastków w roœlinie – zawartoœæ Ca, Fe i Mg w roœlinach po zwapnowaniu gleby zbli¿y³a siê do poziomu stwierdzonego w roœlinach kontrolnych.

S³owa kluczowe: metale ciê¿kie, wapnowanie, akumulacja, Mg, Ca, Fe.

INTRODUCTION

Liming and magnesium fertilization are usually mentioned as treatments which alleviate the unfavourable effect of heavy metals on plants (HELMISAARI et al. 1999). Calcium oxide mixed with sodium sulphide ($Na_2S/CaO=1:1$) significantly reduces availability of heavy metals, such as Zn, Cu, and Ni (WANG et al. 2008). Liming most effectively reduces the solubility and the plant uptake of Zn and Cd in pea (*Pisum arvense* L.) (KREBS at al. 1998). Liming the soil fertilized with sewage sludge reduced the heavy metal content in plant tissues of *Brassica chinensis*, which were all below the admissible levels for vegetables except Fe (Wong et al. 2001). On the other hand, magnesium in plants is crucial for proper metabolism in cells and in the whole organism. Magnesium deficiency in plants appears most frequently in crops growing on excessively acidified soils (Kabata-Pendias, Pendias 1993).

Heavy metals present in soil may variously affect the macronutrient content in plants. Copper (administered to soil at doses of 4, 40, 400 mg kg^{-1}) increased the content of calcium, sodium, magnesium and potassium, but decreased that of phosphorus in spring barley. The increased zinc content in soil (dosed as mentioned above) was accompanied by a rise in the content of calcium, magnesium, potassium and partly phosphorus and sodium in plants. High doses of zinc resulted in decreased levels of phosphorus and sodium in spring barley (Wyszkowski et al. 2006).

The investigations were conducted to determine the effect of liming and magnesium treatment on the content of magnesium, calcium and iron in broad bean plants growing on soil polluted with single heavy metals: cadmium, lead, nickel, copper or zinc.

MATERIALS AND METHODS

In 2005, a field experiment was conducted in the village Zagaje Stradowskie (Œwiêtokrzyskie Province) on degraded Chernozem soil formed from loess, acid in reaction and containing 1.13% or organic carbon. Analyses were performed on aerial parts of cv. White Windsor broad beans (*Vicia faba* L. ssp. *maior)*, cultivated in three series: on limed soil, on soil receiving magnesium fertilizers; on unlimed soil without magnesium fertilization. In each series, the plants were cultivated on the following objects: unpolluted soil with a natural content of heavy metals (control); unpolluted soil with a natural content of heavy metals and mineral fertilization (control+NPK); soil polluted with a cadmium dose 4 $mg \cdot kg^{-1}$ d.m.; soil polluted with a dose of 530 $mg \cdot kg^{-1}$of lead; soil contaminated with a copper dose 85 $mg \cdot kg^{-1}$ d.m., soil contaminated with a dose of 1000 $mg \cdot kg^{-1}$of zinc and soil polluted with a nickel dose 110 $mg \cdot kg^{-1}$ d.m. The following lime doses were administered (in mg $CaO \cdot kg^{-1}$ soil d.m.): control – 619, control + NPK – 672, soil polluted with cadmium – 630, soil polluted with lead – 596, soil polluted with copper – 798, soil polluted with zinc – 1.142, soil polluted with nickel – 818. Magnesium treatments were identical for all objects (20.4 mg $Mg \cdot kg^{-1}$ soil d.m.). Magnesium was supplemented to soil as a water solution of $MgSO_4 \cdot 7H_2O$. The method for heavy metal application, the basic fertilization, soil pH in each object as well as the methods used for soil chemical analyses have been presented in another paper (Gospodarek, Nadgórska-Socha 2007). Liming was conduced on the basis of hydrolytical acidity analysis of soils from individual objects. The administered dose was established according to 1Hh. Plant material samples for chemical analyses were collected at the seed milk maturity phase. The chemical analysis of the plant material involved determinations of iron, magnesium and calcium. Plant material was washed in tap and distilled water, dried to constant weight at 105°C, ground to fine powder, then mineralized and dissolved in 10% HNO_3. After filtration, the Mg, Ca, Fe content was measured using Flame Atomic Absorption Spectrometry (FAAS) (OSTROWSKA et al. 1991, AZCUE, MURDOCH 1994). The accuracy of the analytical procedure was controlled by using samples of the reference material in each series of analysis (Certified Reference material CTA-OTL-1 Oriental Tobacco Leaves). The data were processed using Statistica software to compute significant statistical differences between samples ($p<0.05$) according to Tukey's multiple range test.

RESULTS AND DISCUSSION

Liming caused an increase in the soil pH by *ca* 0.6-1 unit, whereas magnesium treatment did not result in any major changes in the soil pH (GOSPODAREK, NADGÓRSKA-SOCHA 2008). Soil contamination with zinc and nickel led to a significant decrease in magnesium content in broad bean aerial parts (Figure 1). Magnesium concentration in broad beans growing on copper contaminated soil was also slightly lower than in the control. In zinc contaminated soil, liming caused *ca* 13-fold increase in magnesium content, whereas magnesium fertilization led to *ca* 6-fold increase in this element. Neither liming nor magnesium treatment of nickel polluted soil had any significant influence on magnesium content. On the other hand, on soil polluted with lead or cadmium, similarly to the control soils, magnesium treatment contributed to a notable increase in magnesium content in broad bean aerial parts, whereas liming did not cause any significant changes (in the soil contaminated with Pb) or contributed to a decline in this element level in broad bean aerial parts (in control plants and in plants growing on cadmium contaminated soil). In research conducted by WYSZKOWSKI (2002), soil contamination by cadmium (10, 20, 30 and 40 mg $Cd \cdot kg^{-1}$) and magnesium fertilization (50 and 100 mg $Mg \cdot kg^{-1}$ of soil) did not cause much variation in the distribution of macronutrients in aerial organs and roots of yellow lupine.

In the case of copper polluted soil, magnesium treatment only slightly raised the plant magnesium content, while liming caused an increase in magnesium concentration in broad bean aerial parts by ca 25%. In the authors' previous research (GOSPODAREK, NADGÓRSKA-SOCHA 2008), which focused on the effect of different lime doses on magnesium content in broad bean aerial parts, a decline in this element was also observed in plants harvested

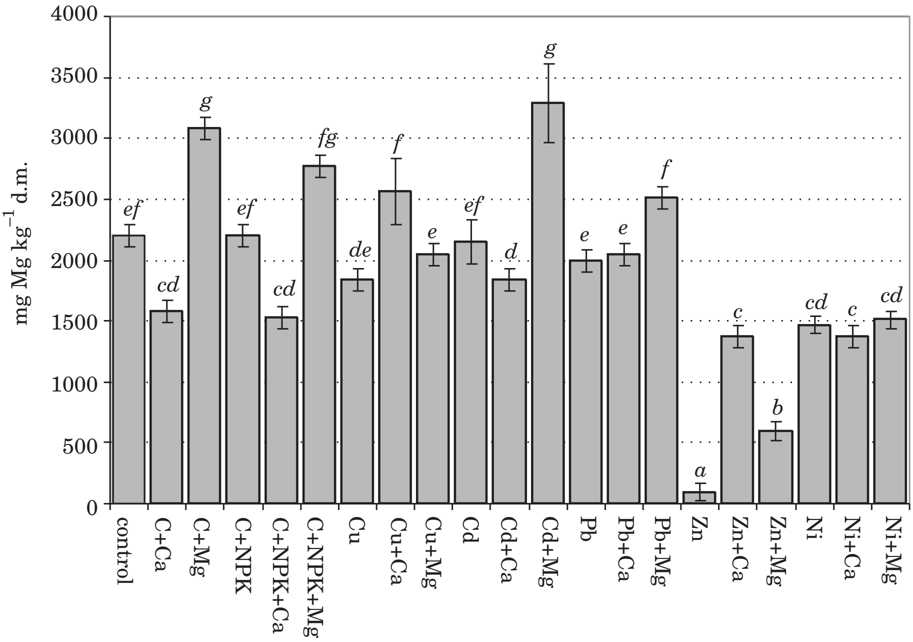

Fig. 1. Magnesium content in aerial parts of broad bean (*Vicia faba* L. ssp. *maior*) cultivated in unpolluted soil (control, NPK) and in soil contaminated with single heavy metals and after application of liming or magnesium treatment. Values marked with different letters are statistically different at $p < 0.05$

from plots with cadmium contaminated soil as a result of soil liming. On the other hand, liming of copper contaminated soil (using both the higher and lower doses) caused a slight decrease in Mg content. In nickel polluted soil, a double dose of lime diminished magnesium content in broad bean aboveground parts by about 33% in comparison with the object contaminated with this element but not limed. In contrast, in soil contaminated with zinc, liming (both when the lower and higher CaO doses were administered) led to an increase in Mg content reaching almost the level similar to that determined in plants harvested from unpolluted plots. However, liming did not affect magnesium concentrations in aerial parts of broad bean cultivated on lead polluted soil.

Soil pollution with zinc and nickel caused a very high decline (15-fold and 5-fold, respectively) in calcium content in broad bean aerial parts (Figure 2). Liming of soil contaminated with zinc caused *ca* 9-fold increase in the content of this element, whereas magnesium fertilization doubled the Ca level. In plants growing on nickel contaminated soil, liming approximately doubled the Ca content in aerial parts while magnesium treatment did not cause any notable changes in the content of this element. Similar results caused by liming on the above heavy metals were discussed in the authors' previous works (GOSPODAREK, NADGÓRSKA-SOCHA 2008). Soil contami-

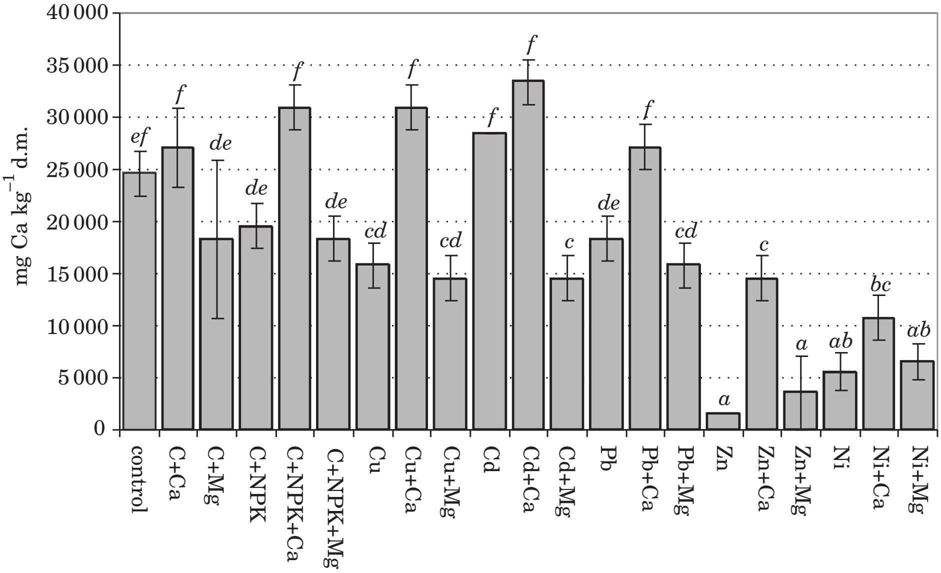

Fig. 2. Calcium content in aerial parts of broad bean (*Vicia faba* L. ssp. *maior*) cultivated in unpolluted soil (control, NPK) and in soil contaminated with single heavy metals and after application of liming or magnesium treatment. Values marked with different letters are statistically different at $p < 0.05$

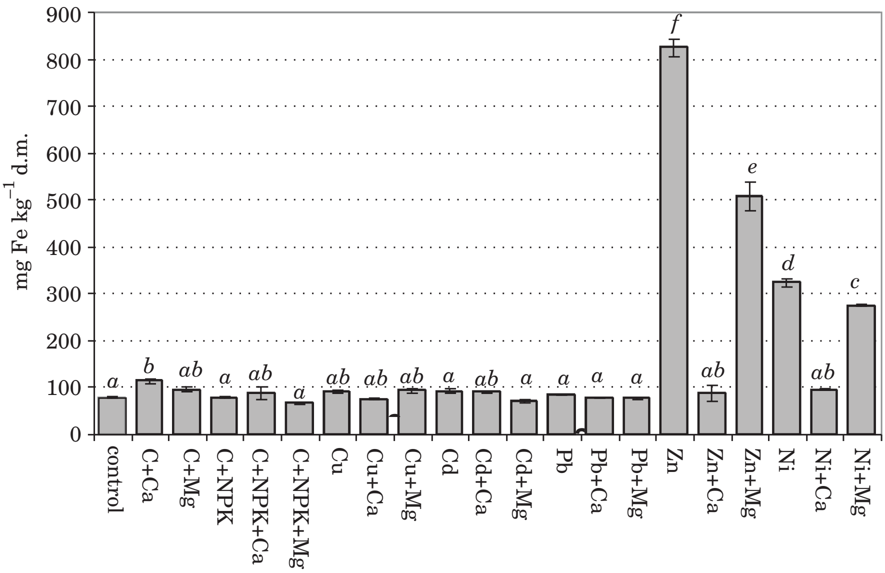

Fig. 3. Iron content in aerial parts of broad bean (*Vicia faba* L. ssp. *maior*) cultivated in unpolluted soil (control, NPK) and in soil contaminated with single heavy metals and after application of liming or magnesium treatment. Values marked with different letters are statistically different at $p < 0.05$

nation with copper or lead only slightly decreased calcium level in broad bean plants. In both cases, liming significantly raised this element in broad bean plants, whereas magnesium fertilization did not markedly affect this characteristic. On the other hand, in the case of broad bean plants grown on cadmium contaminated soil, the calcium level was even slightly higher than in the control plants. Liming caused further increase in the Ca level, while magnesium fertilization contributed to a significant (two-fold) decrease in this element in aerial parts of the plants.

Soil contamination with copper, lead and cadmium did not markedly influence the iron content in broad bean aerial parts (Figure 3). This element level ranged from 67 to 114 $mg \cdot kg^{-1}$ dry mass. According to literature (Kabata-Pendias, Pendias 1993), the iron level in legumes ranges widely (75-400 $mg \cdot kg^{-1}$ d.m.). In the case of these heavy metals, no significant changes in Fe concentrations in broad bean aerial parts were observed, either caused by liming or by magnesium fertilization. However, soil pollution with nickel and zinc caused a considerable (*ca* three-fold for Ni and eight-fold for Zn) increase in the iron content. It might have been associated with a decline in the soil pH in objects polluted with these elements (Gospodarek, Nadgórska-Socha 2007). Liming of the above soils caused a decrease in the iron content to the same level as in the control plants. Magnesium fertilization also contributed to a depression in this element, but to a smaller degree than liming. On the other hand, in the authors' previous research (Gospodarek, Nadgórska-Socha 2008) conducted on soil contaminated with nickel or zinc, only a dose of magnesium computed according to 2 Hh lowered the Fe level to the same as noticed in the control plants. The reports on the iron content in plants after liming are varied (Scheffer et. al 1978, Kotowska 1992), for example meadow plants absorbed iron best in the objects where liming was conducted (Maciejewska, Kotowska 1998). It has also been stated that calcium bioavailability improves plant resistance to deficiency or excess of iron (Kabata-Pendias, Pendias 1993).

CONCLUSIONS

1. Soil contamination with zinc or nickel leads to a considerable decrease in magnesium and calcium in broad bean aerial parts but rises the iron level.

2. Liming rather than magnesium fertilization of soil polluted with heavy metals, such as zinc or nickel, contributes more to balancing the content of the analyzed macronutrients in plants. The content of Ca, Fe and Mg in plants after liming approached the level determined in the control plants.

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