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EFFECT OF NEUTRALIZING SUBSTANCES IN ZINC-CONTAMINATED SOIL ON THE YIELD AND MACRONUTRIENT CONTENT OF YELLOW LUPINE (*LUPINUS LUTEUS* L.)

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Abstract

Some trace elements, for example zinc, play both a positive and a negative role in plant life, which requires their content in soil. If soil is excessively contaminated with zinc, an attempt should be made to reduce the negative effect of this element on plants and other living organisms. For this reason, a study was undertaken to determine whether it was possible to alleviate the effect of soil zinc contamination (0, 150, 300 and 600 mg Zn kg^{-1} of soil) on the yield and macronutrient content of yellow lupine (*Lupinus luteus* L.). Compost (3%), bentonite (2%) and zeolite (2% relative to soil mass) were used to reduce the effect of soil zinc contamination. Macro- and micronutrients were applied to the soil in the same amounts in all pots: 30 mg N, 30 mg P, 100 mg K, 50 mg Mg, 0.33 mg B, 5 mg Mn and 5 mg Mo per kg soil. Yellow lupine was harvested in the flowering phase and plant material samples were collected for laboratory tests. The induced soil zinc contamination reduced yellow lupine growth and development because a dose of 300 mg Zn kg^{-1} soil caused plant seedlings to wither. Compost and bentonite reduced the negative influence of soil zinc contamination on yellow lupine yield, especially on aerial parts. The most demonstrable effect of zinc on the macronutrient content of lupine plants was recorded for magnesium and calcium, whose content increased compared to the control in both the aerial parts and roots of yellow lupine. Among the neutralizing substances, the effect of zeolite on the phosphorus, magnesium and calcium content and bentonite on the sodium content in the plants was the most beneficial.

Key words: zinc contamination, compost, bentonite, zeolite, *Lupinus luteus* L., yield, macroelements.

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INTRODUCTION

Soil, water and air are the most important environmental resources (D`Emilio et al. 2012, Massas et al. 2013, Zhang et al. 2009). They are under continuous human pressure causing environmental degradation (Faiz et al. 2009, Massas et al. 2013). The main pollutant emitting sources are industry, urbanization, public utilities, mining activity, motor traffic and agriculture (Ruiz et al. 2009, Takáč 2009, Liu et al. 2012, Modrzewska, Wyszkowski 2014). Heavy metals, which accumulate in the environment, deserve special attention among these pollutants (Takáč 2009, Zhang et al. 2009, Liu et al. 2012, Sagi, Yigit 2012, Massas et al. 2013). Trace elements present in the environment have a substantial effect on soil properties and living organisms (Kucharski et al. 2011), including plants growing in soils with their increased content (Wyszkowska et al. 2013). Some trace elements (White, Brown 2010), e.g. zinc, play both a positive and a negative role in plant life, which requires their content in soil (Jacquat et al. 2009, Wyszkowska et al. 2013). The main sources of zinc are dust emissions from zinc smelters and the cosmetics, rubber, paint and pharmaceutical industries. Zinc also comes from municipal waste, coal combustion and the application of fertilizers and pesticides (Jacquat et al. 2009, Ruiz et al. 2009, White, Brown 2010, Pérez-Novo et al. 2011). Zinc in trace amounts is necessary for proper plant and animal functioning. In excessive quantities, however, it has a negative effect on living organisms (Pérez-Novo et al. 2011, D`Emilio et al. 2012). This is shown by the growth inhibition as well as decreased plant yields and their worse quality (Feng et al. 2007, Jacquat et al. 2009, White, Brown 2010, Guala et al. 2013). Zinc is characterized by high soil mobility, which affects its bioavailability for plants (Sipos et al. 2008, Ruiz et al. 2009, Trakal et al. 2012). If soil is excessively contaminated with zinc, an attempt should be made to reduce the negative effect of this element on plants and other living organisms.

For this reason, a study was undertaken to determine whether it was possible to alleviate the effect of soil zinc contamination on the yield and macronutrient content of yellow lupine (*Lupinus luteus* L.) cv. Mistral through the application of selected mineral and organic substances.

MATERIAL AND METHODS

An experiment with three replications was set up on acidic soil formed from sand. The trials were conducted in a greenhouse at the University of Warmia and Mazury in Olsztyn. The soil properties were as follows: pH at 1 mole KCl dm^{-3} – 5.32; hydrolytic acidity (HAC) – 33.6 mmol(+) kg^{-1}; total exchange bases: Ca^{++}, Mg^{++}, K^{+} and Na^{+} (TEB) – 42.1 mmol(+) kg^{-1}; cation exchange capacity (CEC) – 75.7 mmol(+) kg^{-1}; the degree of base saturation

(BS) – 55.6%; C_{org} content – 13.8 g kg^{-1}; the content of available forms of: phosphorus – 40.3 mg kg^{-1}; potassium – 11.9 mg kg^{-1} and magnesium – 33.6 mg kg^{-1}; total zinc content – 60.3 mg kg^{-1} soil. The soil was contaminated with zinc (as $ZnCl_2$) in the amounts of 0, 150, 300 and 600 mg Zn^{2+} kg^{-1} soil (1st factor). Compost (3%), bentonite (2%) and zeolite (2% relative to soil mass) were used to reduce the effect of soil zinc contamination (2nd factor). Compost was prepared from leaves, manure and peat. The content of macroelements in compost (g kg^{-1}) was as follows: 2.32 P, 1.33 K, 1.47 Mg and 15.86 Ca. Apart from zinc and the neutralizing substances, the soil (9 kg in each polyethylene pot) was enriched with macro- and micronutrients, added in the following doses, identical in all pots: 30 mg N, 30 mg P, 100 mg K, 50 mg Mg, 0.33 mg B, 5 mg Mn and 5 mg Mo per kg soil. Yellow lupine (*Lupinus luteus* L.) cv. Mistral was then sown. The experiment was conducted at a density of 8 plants per pot, maintaining the moisture content at 60% of the maximum water capacity. Yellow lupine was harvested in the flowering phase and plant material samples were collected for laboratory tests.

The plant material was dried at 60°C, milled and mineralized in concentrated sulfuric acid with an addition of hydrogen peroxide as the catalyst. Afterwards, the following determinations were made: the phosphorus (P^{5+}) content was measured colorimetrically by the vanadium-molybdenum method; the content of potassium (K^+), sodium (Na^+) and calcium (Ca^{2+}) was assayed by atomic emission spectrometry (AES) and the magnesium (Mg^{2+}) content was checked by atomic absorption spectrometry – AAS (Ostrowska et al. 1991). The following were analyzed in the soil before the experiment was established: soil pH – by the potentiometric method in aqueous KCl solution of the concentration of 1 mole dm^{-3}, hydrolytic acidity (HAC) and the total exchange bases (TEB) – by the Kappen method, the content of organic carbon (C_{org}) – by the Tiurin method, available phosphorus and potassium – by the Egner-Riehm method and available magnesium – by the Schachtschabel method (Lityński et al. 1976), total zinc – by the flame atomic absorption spectrophotometric method (FAAS) and US-EPA3051 method (1994). The test results were analyzed statistically with a Statistica package (StatSoft, Inc. 2010) using a two-factor analysis of variance (Anova).

RESULTS AND DISCUSSION

The soil zinc contamination reduced the growth and development of yellow lupine (*Lupinus luteus* L.) because a dose of 300 mg Zn kg^{-1} soil caused the plant seedlings to wither (Figure 1). The results presented in this paper indicate that the effect of soil zinc contamination on yellow lupine weight could be alleviated by an application of selected mineral (bentonite and zeolite) and organic substances (compost). Compost and bentonite had a positive effect, reducing the negative influence of soil zinc contamination on yellow

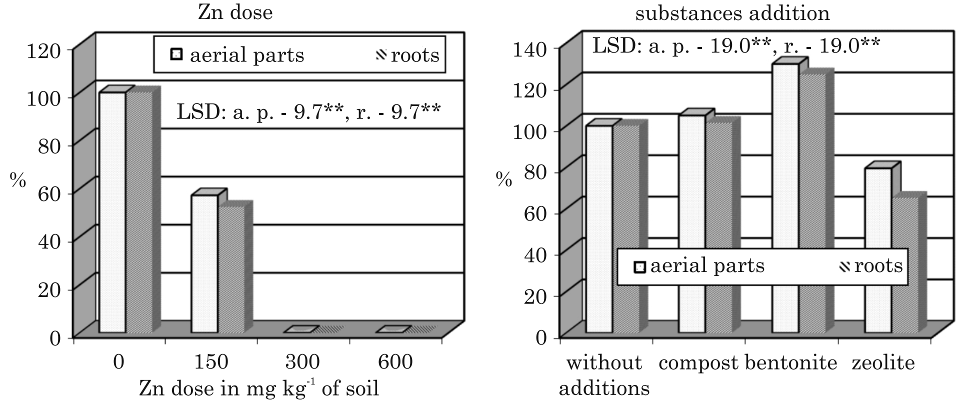

Fig. 1. The variability of the dry matter of aerial parts and roots of yellow lupine (*Lupinus luteus* L.) depending on soil contamination with zinc, in %: a.p. – aerial parts, r. – roots, differences significant for: ** – $P = 0.01$, * – $P = 0.05$

lupine yield. The average weight of the aerial parts and roots of yellow lupine was the highest in the treatments with bentonite, followed by the ones with compost, in contrast to treatments with no application of any of these substances to the soil. Bentonite had a particularly positive effect, especially on the aerial parts of the test plant.

A similar relationship was demonstrated by FENG et al. (2007) in an experiment where soil was amended with minerals such as clays, bentonite, zeolite, iron oxides and phosphatic fertilizers, which effectively restrained the action of trace elements (including zinc) on yellow lupine. This outcome was also reported by SIPOS et al. (2008), who found that organic matter, clay minerals and iron and manganese oxides added to soil caused sorption of trace elements present in the soil. Calcium and magnesium fertilization can contribute to the neutralization of the negative effect of zinc on plants (GOSPODAREK, NADGÓRSKA-SOCHA 2010). These indications were confirmed in our research because, as was observed, the average weight of the aerial parts and roots of yellow lupine was the highest in the treatments with bentonite, followed by the ones with compost, in contrast to treatments with no application of any of the substances to the soil. The positive effect of compost on plant weight was also indicated by FENG et al. (2007), who related it to a lower zinc availability for test plants after its binding to organic particles of soil. In a study on reducing the effect of oil derivatives on plant growth and development, compost and especially bentonite proved to be the most effective substances, particularly for spring oilseed rape (WYSZKOWSKI, ZIÓŁKOWSKA 2009*b*).

Both the soil zinc contamination and the application of the substances (compost, bentonite and zeolite) to the soil modified the macronutrient content in the aerial parts and roots of yellow lupine (Tables 1-2). Lupine belongs to the family of dicotyledonous plants, which have the capacity to

Table 1

Content of nitrogen, phosphorus and potassium and sodium in yellow lupine (*Lupinus luteus* L.), g kg^{-1} d.m.

Dose of zinc (mg kg^{-1} of soil)	Aerial parts					Roots				
	type of substance neutralizing effect of zinc									
	no substance	compost	bentonite	zeolite	average	no substance	compost	bentonite	zeolite	average
Nitrogen										
0	12.50	12.27	11.28	12.05	12.03	7.78	11.63	11.43	10.57	10.35
150	12.71	11.89	10.75	11.55	11.73	9.25	13.62	11.56	9.17	10.90
300	n.a.	11.31	11.05	9.97	10.78	n.a.	n.a.	11.95	7.90	9.93
600	n.a.	n.a.	11.47	n.a.	11.47	n.a.	n.a.	11.64	n.a.	11.64
Average	12.61	11.82	11.14	11.19	11.50	8.52	12.63	11.65	9.21	10.70
LSD	a - 0.41**, b - 0.41**, a·b - 0.80**					a - n.s. 0.68**, b - 0.68**, a·b - 1.36**				
Phosphorus										
0	0.470	0.497	0.394	0.460	0.455	1.619	1.539	1.809	1.589	1.639
150	0.511	0.486	0.385	0.479	0.465	1.623	1.996	1.541	1.775	1.734
300	n.a.	0.529	0.405	0.645	0.526	n.a.	n.a.	1.543	2.080	1.812
600	n.a.	n.a.	0.441	n.a.	0.441	n.a.	n.a.	1.544	n.a.	1.544
Average	0.491	0.504	0.406	0.528	0.472	1.621	1.768	1.609	1.815	1.682
LSD	a - 0.02**, b - 0.02**, a·b - 0.03**					a - 0.02**, b - 0.03**, a·b - 0.03**				
Potassium										
0	20.09	19.47	12.62	23.21	18.85	21.49	30.03	6.23	19.05	19.20
150	18.85	20.09	12.62	23.21	18.69	18.44	25.15	5.93	18.44	16.99
300	n.a.	23.52	15.42	28.50	22.48	n.a.	n.a.	5.01	12.33	8.67
600	n.a.	n.a.	18.22	n.a.	18.22	n.a.	n.a.	5.32	n.a.	5.32
Average	19.47	21.03	14.72	24.97	19.56	19.97	27.59	5.62	16.61	12.55
LSD	a - 0.73**, b - 0.73**, a·b - 1.47**					a - 1.17**, b - 1.17**, a·b - 2.33**				

n.a. – not analysed because of an insufficient amount of plant material
LSD for: a – zinc dose, b – type of neutralizing substance, a · b – interaction; significant for: ** – P = 0.01, * – P = 0.05, n.s. non-significant;
r - correlation coefficient

Table 2

Content of sodium, calcium and potassium and magnesium in yellow lupine (*Lupinus luteus* L.), g kg^{-1} d.m.

Dose of zinc (mg kg^{-1} of soil)	Aerial parts					Roots				
	type of substance neutralizing effect of zinc									
	no substance	compost	bentonite	zeolite	average	no substance	compost	bentonite	zeolite	average
Sodium										
0	0.474	0.415	2.300	0.752	0.985	1.038	1.205	2.120	1.101	1.366
150	0.534	0.574	2.320	0.812	1.060	0.934	1.121	2.161	1.080	1.324
300	n.a.	0.693	2.419	1.228	1.447	n.a.	n.a.	2.224	1.142	1.683
600	n.a.	n.a.	2.776	n.a.	2.776	n.a.	n.a.	2.286	n.a.	2.286
Average	0.504	0.561	2.454	0.931	1.567	0.986	1.163	2.198	1.108	1.665
LSD	a - 0.04**, b - 0.04**, a · b - 0.07**					a - n.s. 0.05**, b - 0.05**, a · b - n.s. 0.11**				
Calcium										
0	2.524	2.221	1.614	2.322	2.170	1.464	3.197	2.851	3.544	2.764
150	5.252	4.545	1.716	3.635	3.787	2.157	3.371	4.064	4.584	3.544
300	n.a.	6.768	2.322	8.283	5.791	n.a.	n.a.	3.024	5.971	4.498
600	n.a.	n.a.	4.040	n.a.	4.040	n.a.	n.a.	4.757	n.a.	4.757
Average	3.89	4.511	2.423	4.747	3.947	1.811	3.284	3.674	4.700	3.891
LSD	a - 0.12**, b - 0.12**, a · b - 0.25**					a - 0.26**, b - 0.26**, a · b - 0.53**				
Magnesium										
0	6.520	5.771	4.046	6.694	5.758	6.218	8.472	7.862	7.433	7.496
150	7.340	7.257	4.441	7.439	6.619	8.751	8.667	9.127	9.150	8.924
300	n.a.	8.363	4.977	10.419	7.920	n.a.	n.a.	9.047	9.683	9.365
600	n.a.	n.a.	6.854	n.a.	6.854	n.a.	n.a.	9.920	n.a.	9.920
Average	6.93	7.130	5.080	8.184	6.788	7.485	8.570	8.989	8.755	8.926
LSD	a - 0.22**, b - 0.22**, a · b - 0.44**					a - 0.32**, b - 0.32**, a · b - 0.63**				

n.a. – not analysed because of an insufficient amount of plant material
LSD for: a - zinc dose, b – kind of neutralizing substance, a · b – interaction; significant for: ** – $P = 0.01$, * – $P = 0.05$, n.s. non-significant;
r – correlation coefficient

accumulate calcium, magnesium and sodium in tissues (Grzegorczyk et al. 2013). The content of other elements, including trace elements, in individual plant parts is determined by their different mobility in the plant and distribution in soil, which results in their high variation in the aerial parts and roots of plants (Page et al. 2006). In the treatments without the application of the neutralizing substances to the soil, the most evident effect of zinc was recorded for magnesium and, even more so, for calcium, whose concentrations increased, both in the aerial organs and roots of yellow lupine, compared to the control (without Zn). An increase in the magnesium content in response to a dose of 150 mg Zn kg^{-1} soil by 13% in the aerial parts and by 41% in the roots of yellow lupine, and in the calcium content by 108 and 47%, respectively, was demonstrated. A 19% rise in the nitrogen content and a 10% decrease in the sodium content as well as a 14% decline in potassium in the roots of this plant, compared to the control, was also recorded. Changes in the content of phosphorus in roots and nitrogen, phosphorus, potassium and sodium in the aerial organs of yellow lupine were relatively, less than 10%. However, it should be noted that in the whole experiment, because of the lack of plant material in the highest contamination variant, the macronutrient content in plants was determined only in the variants with 0 and 150 mg Zn kg^{-1} soil.

The same relationship was recorded by Gospodarek and Nadgórska-Socha (2010) in their study because the application of increased zinc doses to soil caused a rise in magnesium and calcium content in dicotyledonous plants. Pérez-Novo et al. (2011) report that the translocation of trace elements in plants depends on the presence of phosphorus in soil. In their study, high doses of this macronutrient contributed to decreased zinc mobility in plants.

Among the neutralizing substances, the effect of zeolite on the phosphorus and calcium content and bentonite on the sodium content of the lupine plants was most positive (Tables 1-2). Zeolite caused an increase in the phosphorus content by 8% on average in the aerial parts and by 11% in the roots of yellow lupine, a rise in the magnesium concentration by 18% and 17%, respectively, and in calcium by 22% and 160%, compared to the pots without the neutralizing substances. Bentonite induced an average rise in the sodium content by as much as 387% in the aerial parts and by 123% in the roots of yellow lupine and a drop in potassium by 24% and 72%, respectively. The influence of bentonite and zeolite on the content of the other elements was different for the aerial parts and roots of yellow lupine. The effect of compost on the chemical composition of the aerial parts and roots of yellow lupine was weaker, although usually positive, particularly in the zinc-contaminated soil.

The results of this research were partly confirmed by other authors' experiments. Bentonite had a significant stimulating effect on sodium content (Wyszkowski, Ziółkowska 2009*a*), while its action on the concentration of trace elements depends on a plant species. According to Ciećko et al. (2004, 2005), compost and bentonite cause an increase in the magnesium content and decrease in the potassium content in most organs of the test plants. However, bentonite can have a negative effect on the magnesium content in other plant species (Wyszkowski, Ziółkowska 2009*a*). In the study by Sivitskaya and Wyszkowski (2013), bentonite, compost and zeolite reduced the phosphorus content and raised the potassium accumulation in maize. Bentonite stimulated most the sodium content, compost – the calcium content and zeolite – both calcium and magnesium in the aerial parts of maize. However, it should be noted that bentonite reduced the calcium concentration in the aerial parts of this plant.

CONCLUSIONS

1. Soil zinc contamination reduced yellow lupine growth and development because a dose of 300 mg Zn kg^{-1} soil caused plant seedlings to wither.

2. Compost, particularly bentonite, reduced the negative influence of soil zinc contamination on yellow lupine yield, especially on the aerial parts.

3. The most evident effect of zinc on the macronutrient content in lupine was recorded in the case of magnesium and, even more so, calcium, whose content increased in both the aerial parts and roots of yellow lupine, compared to the control.

4. Among the neutralizing substances, the effect of zeolite on the content of phosphorus, magnesium and calcium and bentonite on the content of sodium in lupine was the most beneficial.

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