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SOIL CONTAMINATION WITH ARSENIC VERSUS THE CONTENT OF ZINC IN PLANTS

ZANIECZYSZCZENIE GLEBY ARSENEM A ZAWARTOŚĆ CYNKU W ROŚLINACH

Abstract: The aim of the study has been to reduce the effect of soil contamination with arsenic (10, 20, 30 and 40 mg As · kg^{-1}) on the content of zinc in plants by the application of several substances (lime, natural zeolite, charcoal, loam, compost and synthetic zeolite in experiments on maize; lime, natural zeolite, charcoal, loam, compost and synthetic zeolite in tests on cocksfoot and yellow lupine; peat, pine bark, dolomite and synthetic zeolite in trials on spring barley and swede). The soil improvers which were added in order to mollify the negative effect of arsenic on plants, in addition to the plant species and organs, were determined as a factor which modified the influence of soil contamination with arsenic on the content of zinc in plants. However, the effect of arsenic in soil on the amounts of zinc in yields of the test crops was ambiguous. Both positive and negative correlations occurred, albeit limited to individual cases, between the increasing quantities of arsenic in soil and the amounts of zinc in the yields of plants. Regarding the trials where no soil improvers had been applied, negative correlation was determined for the aboveground parts and roots of maize, aboveground parts of cocksfoot, roots of yellow lupine as well as grain and straw of barley. Positive correlation was discovered in the case of aboveground parts of Swedish turnip and roots of spring barley. The influence of some of the soil improvers on the content of zinc in the crops was sometimes greater than that of arsenic. Loam, lime, charcoal and compost produced the most evident and typically negative effect on the content of zinc in plant tissues. The influence of the other soil neutralising substances on the content of zinc in plants depended on the plant species or organs.

Keywords: arsenic soil contamination, neutralising substances, crops, zinc content

Depending on the oxidation and reducing conditions prevailing in a given environment, arsenic can be present in four oxidation states: –III, 0, +III and +V. In a strongly reducing environment, elementary (0) and (–III) arsenic can occur. But the two basic forms of this element, that is (+III) and (+V), prevail in nature irrespective of the actual

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hydrogeochemical conditions [1]. Under moderately reducing conditions, arsenic (+III) becomes the dominant form while arsenic (+V) is present as a stable element mainly in strongly oxidizing environments [2]. This means that any transformation from one form of arsenic to the other is a slow process and both forms of this metalloid can be simultaneously present in soil [3]. The presence of arsenic in soil creates the risk of its uptake by plants growing on arsenic polluted soil, which means that the element will enter a food chain. Arsenic (+III) causes metabolic disorders in people and animals. Having chemical affinity for the sulfhydryl group of proteins, arsenic can easily bind with these proteins and inactivate them. This inhibits the activity of many enzymes, especially phosphatase, esterase, lipase and oxidase [4, 5]. The response of a living organism to arsenic is conditioned by the dose of this toxin, type of contact, length of exposure as well as the source and chemical form of arsenic. In the third oxidation state this element is 6-fold more harmful than in the fifth oxidation state; moreover, mineral forms of arsenic can be 100-fold more harmful than organic arsenic [6–8]. In most cases, ingestion of arsenic can lead to death. Even a brief exposure to its influence can cause sudden reactions of the body, including failure of the central nervous system, circulatory collapse, paralysis of the digestive system, with such symptoms as nausea, gastric and intestinal colic and diarrhoea, as well as damage of the kidneys [6]. Arsenic causes numerous disorders of some of macro- and microelements uptake by plants and decrease of plant growth. Arsenic and zinc are elements, which have antagonistic effect on each other [4]. Thus, it is of utmost importance that the risk of excessive uptake of arsenic by crops be eliminated.

Therefore, the aim of the present study has been to compare the effect of contamination of soil with arsenic on zinc content in some of plants and reduce the effect of soil pollution with arsenic on the content of zinc in crops by using various soil improvers.

Material and methods

The tests on soil contamination with arsenic were conducted in a design consisting of five greenhouse pot one-year experiments performed at the University of Warmia and Mazury in Olsztyn, Poland. The plants were grown on three soils, similar in their physicochemical properties, which were taken from the humic layer of proper brown soils characterised by the grain-size distribution typical of light loamy sand. The soils were either acidic or strongly acidic. The effect of soil pollution with arsenic added at 0, 10, 20, 30 and 40 mg As $\cdot$ kg^{-1} of soil was tested on yellow lupine (*Lupinus luteus* L.), Juno cv.; the other test plants, such as maize (*Zea mays* L.), Scandia cv., cocksfoot (*Dactylis glomerata* L.), Nawra cv., Swedish turnip (*Brassica napus* var. *napobrassica*), Sara cv., and spring barley (*Hordeum vulgare* L.), Ortega cv., were grown on soil contaminated with 0, 25, 50, 75 and 100 mg As $\cdot$ kg^{-1} of soil. The following soil improvers were added in the experiments involving maize to reduce the negative influence of arsenic pollution: lime, natural zeolite, charcoal, loam, compost; in the tests on cocksfoot and yellow lupine lime, natural zeolite, charcoal, loam, compost and synthetic zeolite were used, and peat, pine bark, loam, dolomite and synthetic zeolite amended the soil in the trials on spring barley and Swedish turnip. These neutralising agents were introduced to soil at a ratio of 3 % of the soil mass per pot, except lime and dolomite, which were added in the amounts balanced with 1 hydrolytic acidity (Hh). Each pot, in addition to the above, received NPK fertilization, which corresponded to the nutritional demands of the crops. Arsenic was introduced to the soils in the form of sodium arsenate, nitrogen as ammonia, phosphorus as triple superphosphate and potassium as potassium salt. All these components were carefully mixed with the soil, after which the whole mixture was placed in polyethylene pots of the capacity of 9 kg. Finally, the test crops were sown. The soil used for the maize experiments was slightly acidic (pH_{KCl} = 5.91) and moderately rich in available phosphorus, potassium and magnesium. Cocksfoot and yellow lupine were grown on acidic soil (pH_{KCl} = 4.53), moderately rich in available forms of phosphorus, potassium and magnesium. Spring barely and swede were sown to soil of very acidic reaction (pH_{KCl} = 4.16) with moderate amounts of available phosphorus and potassium, but low in available magnesium. The content of arsenic in all the test soils was very low, ranging from 2.21 to 3.58 mg As $\cdot$ kg^{-1} of soil. Also other trace elements occurred in very small contents. The experiments were carried out with the following plant stand per pot: 10 maize plants, 8 cocksfoot and yellow lupine plants, 15 spring barley plants and 3 Swedish turnips. The vegetative pot experiments were performed in 3 replications. The moisture of the soil in the pots was maintained at a level of 60 % field water capacity. The plants were harvested at the technological maturity phase.

Once the plant samples were collected during the harvest, they were fragmented, dried at 60 ^{o}C and ground. The concentration of zinc was determined (in 2 replications) using the atomic spectrophotometric absorption (ASA) method. The results of the determinations underwent statistical elaboration, using a two-factorial analysis of ANOVA variance with the Statistica software package [9]. In addition, relationships between the rate of arsenic and content of zinc in plants were determined using Pearson's simple correlations.

Results and discussion

The effect of growing rates of arsenic in soil on the content of zinc in yields of the test crops was diverse. The content of zinc in the plant material was most often positively correlated with the degree of arsenic contamination of soil. The content of zinc in plant tissues deepened on the plant species, organ and type of a substance used to neutralise arsenic (Tables 1 to 5).

The aboveground parts of maize contained slightly less zinc than its roots (Table 1). The average zinc content in maize aboveground organs and roots was 50.91 and 67.15 mg Zn $\cdot$ kg^{-1} d.m., respectively. The effect on soil pollution with arsenic on the content of zinc in maize was dependent on the plant organ. In the series without any soil improvers, arsenic depressed the maize concentration of zinc by maximum 11 % ($r = -0.871$) in aboveground parts and by 20 % ($r = -0.906$) in roots.

Table 1

Zinc content in aboveground parts and roots of maize (*Zea mays* L.) [mg · kg^{-1} d.m.]

Arsenic dose [mg As · kg^{-1} of soil]	Kind of neutralising substance						Average
	without additions	compost	charcoal	loam	lime	natural zeolite	
Aboveground parts							
0	58.29	48.93	43.97	38.08	53.35	41.59	47.37
25	59.55	44.76	51.01	39.39	54.03	51.37	50.02
50	52.80	44.22	54.90	44.80	57.90	59.70	52.39
75	52.00	44.40	57.40	54.00	59.70	56.20	53.95
100	51.80	44.20	43.70	52.20	65.60	47.40	50.82
Average	54.89	45.30	50.20	45.69	58.12	51.25	50.91
r	–0.871**	–0.761**	0.148	0.935**	0.964**	0.364	0.688*
LSD	a – 3.79**; b – 3.46**; a · b – 8.47**						
Roots							
0	79.20	69.65	67.40	70.25	95.25	87.20	78.16
25	75.30	59.35	62.50	52.95	82.35	88.05	70.08
50	76.90	53.55	44.35	53.75	79.65	90.50	66.45
75	63.65	49.90	40.55	54.75	78.10	77.45	60.73
100	62.97	49.80	40.45	55.75	76.70	76.25	60.32
Average	71.60	56.45	51.05	57.49	82.41	83.89	67.15
r	–0.906**	–0.932**	–0.929**	–0.596	–0.874**	–0.784**	–0.964**
LSD	a – 4.50**; b – 4.11**; a · b – 10.06**						

LSD for: a – kind of additions, b – arsenic contamination; r – simple correlation coefficient; significant level: * p = 0.05, ** p = 0.01; n = 10.

In most of the experimental series, the aboveground parts of maize contained elevated levels of zinc under the effect of arsenic, whereas the roots of maize from all the objects were found to contain less zinc. Nevertheless, the highest arsenic contamination rate also depressed the content of zinc in the aboveground parts of maize. The largest decrease in the zinc content in maize roots, reaching 40 % (r = –0.929) was observed in the objects amended with charcoal. Clearly, the substances added to soil in order to neutralise arsenic affected the content of zinc in both aboveground and underground organs of maize. Regarding the aboveground parts of maize, the highest concentrations of zinc was determined in the objects receiving lime, whereas the lowest ones occurred in the combinations involving compost and loam. In turn, the roots contained the highest amounts of zinc when grown on soil amended with natural zeolite and lime; the lowest levels of zinc in maize roots were found in the case of charcoal amended soil.

The content of zinc in aboveground parts of cocksfoot was slightly lower than in the roots of this plant: 57.54 mg and 66.84 mg Zn · kg^{-1} d.m. (Table 2).

Table 2

Zinc content in aboveground parts and roots of cocksfoot (*Dactylis glomerata* L.) [mg · kg^{-1} d.m.]

Arsenic dose [mg As · kg^{-1} of soil]	Kind of neutralising substance							Average
	without additions	natural zeolite	lime	charcoal	loam	compost	synthetic zeolite	
Aboveground parts								
0	74.80	61.90	54.59	62.36	60.06	61.73	64.52	62.85
25	74.01	50.00	56.25	64.01	60.08	62.05	58.50	60.70
50	57.51	46.23	52.93	67.72	63.71	62.03	56.57	58.10
75	53.00	44.50	46.10	66.80	63.95	72.65	50.60	56.80
100	52.25	36.52	45.19	40.00	52.10	73.18	45.60	49.26
Average	62.31	47.83	51.01	60.18	59.98	66.33	55.16	57.54
r	–0.931**	–0.959**	–0.907**	–0.577	–0.398	0.880**	–0.991**	–0.948**
LSD	a – 3.81**; b – 3.36**; a · b – 8.52**							
Roots								
0	65.02	54.96	59.04	73.12	96.72	56.81	58.40	66.30
25	73.28	70.05	61.80	78.25	86.70	58.49	60.06	69.80
50	70.41	71.25	61.75	78.56	78.00	57.35	66.75	69.15
75	68.25	74.45	60.03	71.50	76.25	54.50	69.70	67.81
100	51.55	74.95	57.05	63.60	53.95	49.25	77.55	61.13
Average	65.70	69.13	59.93	73.01	78.32	55.28	66.49	66.84
r	–0.597	0.857**	–0.456	–0.668*	–0.957**	–0.823**	0.980**	–0.563
LSD	a – 5.53**; b – 4.89**; a · b – 12.38**							

LSD for: a – kind of additions, b – arsenic contamination; r – simple correlation coefficient; significant level: * p = 0.05, ** p = 0.01; n = 10.

Soil contamination with arsenic usually tended to result in depressed zinc concentrations in aboveground parts of the grass and higher levels of this metal in the roots (particularly when the rate of the contaminant was low). The largest decrease in the amount of zinc found in the aboveground parts of cocksfoot (41 %, r = –0.959) was determined in the series with natural zeolite, and in the roots (44 %, r = –0.957) when soil was amended with loam. At the same time, cocksfoot growing on soil treated with natural zeolite accumulated the highest level of zinc in the roots (36 %, r = 0.857). In the series where no soil improvers were applied, the highest arsenic contamination dose caused depressed concentrations of zinc in plants, reaching 30 % (r = –0.931) in aboveground parts and 21 % (r = –0.597) in roots of cocksfoot. The substances used in our experiment to neutralise soil pollution with arsenic produced an evident effect on the concentration of zinc in cocksfoot. Noteworthy is the fact that higher concentrations of zinc were observed in the roots of cocksfoot plants growing on soil amended with loam and charcoal. On the other hand, natural zeolite, lime and synthetic zeolite added to soil caused decrease the zinc in aboveground parts of the grass whereas compost produced an analogous effect in its roots.

The contents of zinc determined in aboveground parts and roots of yellow lupine were approximately identical, reaching on average 71.61 and 76.54 mg Zn · kg^{-1} d.m. (Table 3). Contamination of substrate soil with arsenic caused higher levels of zinc in yellow lupine, with an increase being larger in aboveground parts rather than roots of this crop. When 30 mg As · kg^{-1} of soil was added, the highest increase in zinc content (82 %, r = 0.787) was determined in the objects with compost; regarding the roots of yellow lupine, such an effect occurred in the object neutralised with synthetic zeolite (25 %, r = 0.955), compost (23 %, r = 0.729) and loam (21 %, r = 0.862).

Table 3

Zinc (Zn) content in aboveground parts and roots of yellow lupine (*Lupinus luteus* L.) [mg · kg^{-1} d.m.]

Arsenic dose [mg As · kg^{-1} of soil]	Kind of neutralising substance							Average
	without additions	charcoal	natural zeolite	synthetic zeolite	loam	compost	lime	
Aboveground parts								
0	61.65	86.59	68.32	71.15	55.55	53.43	54.09	64.40
10	79.50	76.91	65.57	70.42	59.61	79.64	62.00	70.52
20	93.53	74.43	66.23	69.32	68.12	94.22	62.95	75.54
30	103.75	68.11	66.44	67.87	69.12	97.19	62.40	76.41
40	110.14	63.81	58.60	55.00	70.60	88.54	54.53	71.60
Average	89.71	73.97	65.03	66.75	64.60	82.60	59.19	71.70
r	0.983**	–0.983**	–0.786**	–0.824**	0.945**	0.787**	0.045	0.670*
LSD	a – 2.95**; b – 2.49**; a · b – 6.59**							
Roots								
0	83.59	75.48	78.44	70.29	72.91	71.60	67.19	74.21
10	82.91	77.48	78.41	77.72	72.23	69.98	66.67	75.06
20	81.15	77.11	78.95	78.28	76.01	70.15	65.47	75.30
30	76.12	87.45	77.95	87.64	88.37	88.00	65.55	81.58
40	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Average	80.94	79.38	78.44	78.48	77.38	74.93	66.22	76.54
r	–0.924**	0.842**	–0.294	0.955**	0.862**	0.729*	–0.932**	0.850**
LSD	a – 2.44**; b – 2.06**; a · b – 5.46**							

LSD for: a – kind of additions, b – arsenic contamination; r – simple correlation coefficient; significant level: * p = 0.05, ** p = 0.01; n = 10; n.a. – not analysed because of an insufficient amount of plant material.

For comparison, the dose of 40 mg As · kg^{-1} of soil caused the largest increment of zinc in yellow lupine aboveground parts (79 %, r = 0.983) in the series without any neutralising substances, in contrast to the soil amended with charcoal (r = –0.983), natural zeolite (r = –0.786) and synthetic zeolite (r = –0.824). The highest concentration of zinc in both aboveground and underground parts of yellow lupine occurred in the series without soil neutralising agents. The application of any of the neutralising substances caused a large decline in the content of zinc in plants compared to the analogous series without these agents, with the differences being larger in aboveground parts than in roots of yellow lupine. Particularly big changes in zinc contents occurred in aboveground parts of this plant under the effect of lime (on average 34 %), natural and synthetic zeolite and loam (26–28 %) and in the roots – as a result of liming (18 %).

The content of zinc in leaves of swede was on average 88.86 mg, and in the roots of this crop – 26.27 mg Zn · kg^{-1} d.m., which means that three-fold more zinc was present in leaves than in roots (Table 4). Soil contamination with arsenic had some influence on the content of zinc in swede, with the actual effect being correlated with the type of a neutralising agent applied. In some series, arsenic in soil contributed to a higher level of zinc in the plant tissues, but in some other treatments the same pollutant resulted in depressed zinc concentrations in swede. The content of zinc rose rather clearly in the leaves of swede growing on soil without the neutralising agents (r = 0.890) and in the roots of this plant on soil neutralised with synthetic zeolite (r = 0.967).

Table 4

Zinc content in aboveground parts and roots of swede (*Brassica napus* L. var. *napobrassica* (L.) Rchb.) [mg · kg^{-1} d.m.]

Arsenic dose [mg As · kg^{-1} of soil]	Kind of neutralising substance						Average
	without additions	peat	bark	loam	dolomite	synthetic zeolite	
Aboveground parts							
0	81.45	85.85	111.65	76.85	101.35	98.85	92.67
25	94.95	74.80	97.40	71.90	98.00	111.40	91.41
50	94.20	67.10	90.90	67.20	96.55	122.25	89.70
75	95.90	65.65	87.30	64.40	95.80	112.25	86.88
100	102.55	64.55	88.45	50.35	94.70	101.25	83.64
Average	93.81	71.59	95.14	66.14	97.28	109.20	88.86
r	0.890**	–0.917**	–0.891**	–0.955**	–0.953**	0.095	–0.982**
LSD	a – 6.19; b – 5.65; a · b – 13.84						
Roots							
0	25.75	36.95	31.50	21.53	22.00	21.18	26.49
25	25.50	36.25	23.80	20.75	24.25	23.10	25.61
50	24.90	34.25	21.75	19.30	27.25	31.75	26.53
75	24.45	34.00	21.95	19.10	25.75	33.40	26.44
100	23.50	33.45	20.90	18.60	24.70	36.45	26.27
Average	24.82	34.98	23.98	19.86	24.79	29.18	26.27
r	–0.979**	–0.958**	–0.841**	–0.965**	0.562	0.967**	0.164
LSD	a – 2.22**; b – n.s.; a · b – 4.95*						

LSD for: a – kind of additions, b – arsenic contamination; r – simple correlation coefficient; significant level: * p = 0.05, ** p = 0.01; n.s. – differences non-significant; n = 10.

A reverse relationship, ie depressed levels of zinc under the effect of arsenic in soil, occurred most evidently in the case of leaves in the series treated with peat (r = –0.917) and in roots – in the object neutralised with pine bark (r = –0.841). The substances used to neutralise arsenic pollution of soil differentiated rather extensively the content of zinc in Swedish turnip. The lowest content of zinc in leaves and roots of this crop was found in the series with loam and the highest one – in the series amended with synthetic zeolite (leaves) or peat (roots).

Spring barley grain and straw contained on average 30 % less zinc than its roots (Table 5).

Table 5

Zinc content in grain, straw and roots of spring barley (*Hordeum vulgare* L.) [mg · kg^{-1} d.m.]

Arsenic dose [mg As · kg^{-1} of soil]	Kind of neutralising substance						Average
	without additions	peat	bark	loam	dolomite	synthetic zeolite	
Grain							
0	45.44	47.65	57.86	20.61	25.29	35.17	38.67
25	39.28	31.12	37.31	20.05	25.95	33.29	31.17
50	31.78	29.21	37.32	20.91	28.18	29.17	29.43
75	29.20	28.00	32.12	28.29	29.16	29.38	29.36
100	30.33	28.77	31.28	31.70	30.97	28.93	30.33
Average	35.21	32.95	39.18	24.31	27.91	31.19	31.79
r	–0.918**	–0.779**	–0.853**	0.902**	0.989**	–0.906**	–0.746*
LSD	a – 4.74**; b – 2.32**; a · b – 10.59						
Straw							
0	40.41	43.00	51.89	30.47	28.60	27.92	37.05
25	38.37	38.67	53.25	28.81	29.41	34.40	37.15
50	33.59	36.95	47.13	24.90	30.46	39.24	35.38
75	33.21	36.49	37.42	22.84	34.48	41.68	34.35
100	31.36	29.63	36.24	21.20	44.22	49.48	35.36
Average	35.39	36.95	45.19	25.64	33.43	38.54	35.86
r	–0.963**	–0.947**	–0.935**	–0.989**	0.892**	0.989**	–0.810**
LSD	a – 9.69**; b – n.s.; a · b – n.s.						
Roots							
0	39.88	37.63	47.40	26.65	42.93	44.44	39.82
25	40.20	38.14	53.30	27.08	44.90	55.29	43.15
50	41.26	41.24	88.83	36.30	45.18	55.90	51.45
75	44.03	50.71	96.59	41.23	46.48	56.14	55.86
100	69.63	47.96	94.56	51.78	66.52	62.07	65.42
Average	47.00	43.14	76.14	36.61	49.20	54.77	51.14
r	0.785**	0.890**	0.914**	0.969**	0.790**	0.893**	0.988**
LSD	a – 5.76**; b – 5.25**; a · b – 12.87**						

LSD for: a – kind of additions, b – arsenic contamination; r – simple correlation coefficient; significant level: * p = 0.05, ** p = 0.01; n.s. – differences non-significant.

Arsenic contamination of soil depressed the content of zinc in grain and straw of spring barley in most of the experimental series; in contrast, the concentration of zinc in roots of spring barley increased in most of the treatments. The biggest decrease in the content of zinc in grain occurred in the series with pine bark and peat – on average the level of zinc dropped by 46 % (r = –0.853) and 40 % (r = –0.779). Regarding the straw, the maximum decline in the zinc content was determined in the series with loam (r = –0.989), pine bark (r = –0.935) and peat (r = –0.947), where it dropped on average by 30–31 %. The increase in zinc concentration in spring barley roots under the effect of 40 mg As · kg^{-1} oscillated from 28 % (r = 0.890) in the peat amended objects up to 99 % (r = 0.914) in the series with pine bark. Comparison of all the neutralising substances showed that pine bark caused the occurrence of higher levels of zinc in both aboveground and underground parts of spring barley. On the other hand, the lowest content of zinc was determined in the objects neutralised with loam.

Likewise in the present study, Kabata-Pendias and Pendias [4] as well as Paivoke and Simola [10] reported that increasing contamination of soil with arsenic caused increased levels of zinc in plant tissues. However, it should be added that the content of zinc in the analysed plant organs tended to be negatively correlated with the level of soil contamination with arsenic.

The differences in the uptake of zinc by particular species of plants as well as its transfer to plant organs are substantial. According to Lubben [11], carrot, maize and pea seeds are characterised by a low rate of zinc uptake, in contrast to leaves of spinach, roots of radish and other plants, which take up large amounts of zinc. Addition of various substances to soil modifies the content of zinc in plants. Our own results can partly support the results obtained by other authors. Jasic et al [12] showed that the highest levels of zinc occurred in cucumber growing on humus amended soil; the lowest one – when soil received fine-fraction charcoal. Tlustos et al. [13] demonstrated that zinc in spinach declined by 25 % after the soil had been neutralised with straw. Lime contributed to depressed uptake of heavy metals by plants [14], with its effect on zinc possibly larger than on other heavy metals [15]. The actual effect depends also on a plant species. According to Brune [16], levels of zinc in barley grain observed under the effect of soil liming could be depressed by as much as 50 %; Tlustos et al [13] reported than an analogous decrease in spinach could be as high as 75 %. Similar dependences were found by Wallace [17] in the case of maize. Zeolites [18] as well as modified loams [19] seem to be effective too. In a study carried out by Ciecko et al [20], lignite, lime and bentonite in particular were found to have depressed the content of zinc in plants, especially in yellow lupine and radish.

Conclusions

1. The substances added to soil in order to alleviate the negative influence of arsenic pollution as well as the species and organs of plants tested modified the effect of soil contamination with arsenic on the content of zinc in plants.

2. It was not possible to demonstrate an unambiguous effect of soil pollution with arsenic on the content of zinc in yields of the test plants. There were single cases of

either positive or negative correlation between increasing rates of arsenic added to soil and the content of zinc in the analysed organs of plants. As regards the objects not amended with soil improvers, negative correlation between the two factors mentioned above was observed in aboveground parts and roots of maize, aboveground parts of cocksfoot, roots of yellow lupine as well as grain and roots of barley; positive correlation was noticed in aboveground parts of yellow lupine, Swedish turnip and roots of spring barley.

3. The effect of some of the soil additives neutralising the effect of arsenic pollution was even greater than that exerted by arsenic itself. The most unambiguous and typically negative influence on the content of zinc in plants was produced by loam, lime, charcoal and compost. The other soil improvers produced diverse effects on zinc in plants, varying between the plant species or even the plant organs tested.

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ZANIECZYSZCZENIE GLEBY ARSENEM A ZAWARTOŚĆ CYNKU W ROŚLINACH

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Abstrakt: Celem przeprowadzonych badań było zmniejszenie oddziaływania zanieczyszczenia gleby arsenem (10, 20, 30 i 40 mg As $\cdot$ kg^{-1}) na zawartość cynku w roślinach przez stosowanie różnych substancji (wapno, zeolit naturalny, węgiel drzewny, ił, kompost w doświadczeniu z kukurydzą; wapno, zeolit naturalny, węgiel drzewny, ił, kompost i zeolit syntetyczny w badaniach z kupkówką i łubinem żółtym oraz torf, kora sosnowa, ił, dolomit i zeolit syntetyczny w doświadczeniach z jęczmieniem jarym i brukwią pastewną). Substancje zastosowane do złagodzenia wpływu arsenu na rośliny oraz ich gatunek i organ modyfikowały wpływ zanieczyszczenia gleby tym metalem na zawartość cynku w roślinach. Nie wykazano jednoznacznego oddziaływania zanieczyszczenia gleby arsenem na zawartość cynku w plonach badanych roślin. Odnotowano w pojedynczych przypadkach zarówno ujemne, jak i dodatnie korelacje pomiędzy rosnącym zanieczyszczeniem gleby arsenem a zawartością cynku w badanych organach roślin. W obiektach bez dodatków stwierdzono ujemną zależność dla zawartości cynku w częściach nadziemnych i korzeniach kukurydzy, częściach nadziemnych kupkówki, korzeniach łubinu żółtego oraz w ziarnie i słomie jęczmienia, a dodatnią w częściach nadziemnych brukwi pastewnej i korzeniach jęczmienia jarego. Wpływ niektórych dodatków neutralizujących na zawartość cynku był nawet większy niż arsenu. Najbardziej jednoznacznie i na ogół ujemnie na zawartość cynku w roślinach działały ił, wapno, węgiel drzewny i kompost. Wpływ pozostałych dodatków na zawartość cynku był często odmienny u różnych gatunków, a nawet organów testowanych roślin.

Słowa kluczowe: zanieczyszczenie arsenem, substancje neutralizujące, rośliny, zawartość cynku