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RESPONSE OF POTATO TO SOIL CONTAMINATION WITH MERCURY NEUTRALISED WITH SOIL IMPROVING SUBSTANCES

REAKCJA ZIEMNIAKA NA ZANIECZYSZCZENIE GLEBY RTĘCIĄ W WARUNKACH STOSOWANIA WYBRANYCH SUBSTANCJI NEUTRALIZUJĄCYCH

Abstract: Holding in mind the negative effect of mercury on environment, an experiment has been conducted in order to determine the influence of this metal on yield and chemical composition of potato grown on soil treated with various neutralizing substances.

The study consisted of a pot experiment, carried out in Kick-Brauckmann pots filled with 9 kg soil each. The soil material was subjected to simulated contamination with mercury sulphate added in the following doses: 0, 50, 100 and 150 mg Hg $\cdot$ kg^{-1}. Another experimental factor comprised application of several inactivating substances, such as zeolite, lime and bentonite. Zeolite and bentonite were added in the amounts equal 3 % of the whole soil mass in a pot whereas the dose of lime corresponded to 1 Hh of soil. All the pots received identical NPK fertilization. Edible potato of a moderately early, 'Zebra' cultivar, was the test plant.

Increasing soil contamination with mercury depressed the yield of tubers and mass of potato herbage. The largest yield decline was observed in the trials subjected to the most severe mercury contamination. As for potato tubers, a decline in their yield reached 63 % in the series with lime down to 31 % in the series with zeolite. The maximum potato herbage loss under the effect of mercury pollution was 48 % in the series with zeolite down to 23 % in the series with lime. Moreover presence of mercury in soil also affected the chemical composition of potato. Increasing rates of mercury in soil caused a rather regular depression in the content of potassium in potato tubers and herbage.

Keywords: mercury, lime, zeolite, bentonite, soil, contamination, neutralisation

Rapid technological progress alongside other transformations in the modern world are responsible for significant changes in natural environment. Heavy metals pose a particularly serious threat to nature [1–3]. Heavy metals are now found not only in heavily industrialised regions but also in natural and agricultural ecosystems [1].

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Mercury and its compounds are particularly harmful to humans. Owing to its high chemical and biological activity as well as a variety of forms it can occur in, mercury is easily involved in various chemical cycles in nature [4]. This is a dangerous phenomenon as once mercury enters a digestive system, it causes dangerous changes in living organisms [2]. More attention is now being paid to the presence of mercury in human foodstuff due to the actual risk of mercury poisoning in humans [5, 6]. It is assumed that presence of mercury should be carefully monitored in agricultural regions, where the metal can become a threat to the quality of farm produce [7]. Potatoes, next to cereals, are an important group of agricultural products in man's diet [8]. In Poland, consumption of potatoes is high, thus it is important to monitor their quality [9]. Quality control should first of all concern the presence of heavy metals in potato tubers. Another important aspect is the analysis of chemical composition of potato as a raw material.

Material and methods

The study consisted of a pot experiment carried out in a greenhouse at the University of Warmia and Mazury in Olsztyn in 2006. The experiment was established in Kick-Brauckmann pots, filled with 9 kg soil each. The soil material was collected from the arable and humus layer of soil and, regarding its grain-size distribution, represented light loamy sand. The experiment comprised two factors. Factor I consisted of substances which were to inactivate simulated mercury contamination. Depending on these neutralising substances, four series were created: without neutralising substances, with lime, bentonite or zeolite. Factor II involved increasing rates of mercury polluting the soil: 0, 50, 100 and 150 mg Hg $\cdot$ kg^{-1} of soil. Lime was introduced to soil in the amount corresponding to 1 hydrolytic acidity (Hh), whereas bentonite and zeolite were added in the quantity of 270 g per pot, which corresponded to 3 % of the soil mass per pot. Mercury was added to soil as mercury sulphate. In addition, mineral fertilizers were added: 1.2 g N, 1.2 g P_2O_5 and 1.4 g K_2O $\cdot$ pot^{-1}. Mineral fertilization was identical in all the pots. The above experimental trials were conducted with three replications. Potatoes, 'Zebra' cultivar, two tubers per pot, were planted on 28th June. They were harvested on 6th October. During the harvest, the yield of potato tubers and potato herbage was weighed, after which samples for chemical analyses were collected, dried, fragmented and mineralised in sulphuric acid. The plant material thus prepared was used for determination of: phosphorus with the vanadium-molybdenum method, potassium and calcium with the flame-photometric method and magnesium with the atomic absorption spectrophotometry.

Results

The experiment proved that both mercury as a soil contaminant and the inactivating substances added to soil (lime, bentonite, zeolite) had a large effect on the yield of potato tubers and herbage (Table 1).

Table 1

Yield of potato tubers and herbage [g f.m. · pot^{-1}]

Mercury dose [mg Hg · kg^{-1} of soil]	Neutralising substances							
	none		zeolite		lime		bentonite	
	tubers	herbage	tubers	herbage	tubers	herbage	tubers	herbage
0	378.8	124.4	325.0	129.4	218.5	94.8	263.7	93.0
50	363.9	84.2	245.6	119.4	185.2	71.7	229.3	74.9
100	230.8	83.5	128.9	117.5	117.4	72.2	185.9	61.6
150	149.1	75.6	121.0	99.1	114.3	58.8	181.3	48.2
Mean	280.7	91.9	205.1	116.3	158.9	74.4	215.1	69.4
LSD (p = 0.01)								
Tubers					Herbage			
48.13* 43.44** n.s.***					n.s.* 19.37** n.s.***			

* effect of mercury on yields, ** effect of neutralising substances on yields, *** interaction

In the control series (without the neutralising substances), the weakest mercury contamination dose depressed the tuber yield by 4 %, whereas the medium and highest rates of this heavy metal resulted in the tuber yield being 39 and 61 % lower, respectively, versus the control object, free of mercury. As for potato herbage, the three increasing rates of mercury introduced to soil depressed its yield by 32, 33 and 39 %, respectively. When comparing the control objects in each series, the yield of tubers and herbage, as a rule, decreased after introduction of the neutralising substances, except for the mass of potato herbage in the series with zeolite, where a 4 % increase occurred under the effect of the neutralising substance. Although the soil was improved with the neutralising substances, the yield of potato tubers and herbage tended to decrease as the rates of mercury in soil rose.

The highest decline in the tuber yield (63 %) was noticed in the series with zeolite, the lowest potato herbage yield, in turn, was obtained in the series with bentonite (48 %), both at the highest mercury soil pollution. Bentonite, on the other hand, had the strongest alleviating effect on the decrease in potato tuber yield caused by mercury (31 %), in the case of potato herbage yield, the most effective was zeolite (23 %). When lime was added to soil, the yield of tubers went down by 48 % and that of herbage by 38 %.

Apart from the effect produced by mercury contamination as well as the neutralising substances on yields of potato tubers and herbage, the two experimental factors also affected, in a variety of ways, the chemical composition of the plant material (Tables 2–5).

Increasing rates of mercury as a soil pollutant resulted in an increase in the content of phosphorus in potato tubers, which at the highest mercury rate reached 43 % relative to the control object in the same series. Regarding potassium and calcium, amounts of these two nutrients tended to decrease as the soil contamination with mercury became more severe. At the rate of 150 mg Hg, the respective losses were 15 and 9 %. In turn, the content of magnesium declined by an average of 39 % at 50 and 100 mg Hg per pot, but increased by 13 % versus the control when the soil was polluted with the highest mercury dose. In potato herbage, mercury contamination raised the content of phosphorus (36–86 %), potassium (21–22 %) and magnesium (25–30 %) but depressed that of calcium (40–52 %).

Table 2

Phosphorus (P) content in potato tubers and herbage [$g \cdot kg^{-1}$ d.m.]

Mercury dose [$mg\ Hg \cdot kg^{-1}$ of soil]	Neutralising substances							
	none		zeolite		lime		bentonite	
	tubers	herbage	tubers	herbage	tubers	herbage	tubers	herbage
0	3.23	2.11	3.47	2.24	3.65	2.32	3.78	2.22
50	4.35	3.62	2.84	1.90	3.10	1.74	3.55	2.63
100	3.67	2.86	3.69	2.25	2.84	2.29	3.66	2.72
150	4.61	3.93	3.10	2.51	2.88	1.95	3.80	2.59
Mean	3.97	3.13	3.28	2.23	3.12	2.08	3.70	2.54

Table 3

Potassium (K) content in potato tubers and herbage [$g \cdot kg^{-1}$ d.m.]

Mercury dose [$mg\ Hg \cdot kg^{-1}$ of soil]	Neutralising substances							
	none		zeolite		lime		bentonite	
	tubers	herbage	tubers	herbage	tubers	herbage	tubers	herbage
0	17.0	13.6	18.1	18.4	16.7	19.7	17.1	16.3
50	14.1	16.4	13.8	14.3	15.2	16.2	15.9	16.8
100	14.2	16.6	16.2	14.5	14.4	15.3	15.3	17.2
150	14.5	16.6	15.1	16.2	13.6	14.3	15.7	16.2
Mean	15.0	15.8	15.8	15.9	15.0	16.4	16.0	16.6

Table 4

Magnesium (Mg) content in potato tubers and herbage [$g \cdot kg^{-1}$ d.m.]

Mercury dose [$mg\ Hg \cdot kg^{-1}$ of soil]	Neutralising substances							
	none		zeolite		lime		bentonite	
	tubers	herbage	tubers	herbage	tubers	herbage	tubers	herbage
0	0.80	1.55	0.78	1.66	0.80	1.58	1.00	2.15
50	0.49	2.01	0.56	1.71	0.76	1.69	1.08	1.84
100	0.50	1.99	0.66	1.73	0.57	1.61	0.80	1.57
150	0.90	1.93	0.61	1.49	0.61	1.59	0.83	1.53
Mean	0.67	1.87	0.65	1.65	0.69	1.62	0.93	1.77

Table 5

Calcium (Ca) content in potato tubers and herbage [g · kg^{-1} d.m.]

Mercury dose [mg Hg · kg^{-1} of soil]	Neutralising substances							
	none		zeolite		lime		bentonite	
	tubers	herbage	tubers	herbage	tubers	herbage	tubers	herbage
0	0.64	5.56	0.53	7.24	0.56	6.05	0.59	5.67
50	0.63	3.35	0.58	4.05	0.43	4.93	0.48	4.40
100	0.63	2.93	0.64	3.27	0.53	3.47	0.49	3.82
150	0.58	2.69	0.38	3.93	0.37	3.70	0.54	3.62
Mean	0.62	3.63	0.53	4.62	0.47	4.54	0.52	4.38

Introduction of the neutralising substances to soil tended to mollify the above relationships. Besides, while analysing the mean contents of each macronutrient in all the series, it was found that all the neutralising substances had a positive effect on the accumulation of potassium, both in tubers (6–7 % increase) and herbage (4–5 % increase) as well as calcium (21–27 % increase) versus the control series (without the soil improving substances). A positive correlation was observed between the application of lime or bentonite and the content of magnesium in potato tubers (3–39 % increase). The average contents of the macronutrients indicate that the neutralising substances had a negative effect on the accumulation of phosphorus, both in tubers and in herbage, and calcium in tubers. Besides, addition of zeolite depressed the average content of magnesium in the whole potato plant while bentonite contributed to a decrease in the level of magnesium in potato herbage.

Discussion

The authors' own research has demonstrated that increasing rates of mercury have an adverse effect on yields of potato. Particularly harmful were the two highest rates of the heavy metal (100 and 150 mg Hg · kg^{-1}), which caused a 39 and 61 % decline in tuber yield, respectively. As regards the yield of potato herbage, the lowest mercury dose had a considerable effect, as it reduced the yield of herbage by 32 %. Higher doses of mercury caused a further albeit insignificantly higher depression in herbage yields. Similar results are reported by Wyszkowski and Wyszkowska [10], who showed a negative effect of mercury on yields of oats. They found out that the yield of oats was 44 % lower under the influence of 20 mg Hg · kg^{-1} of soil. The fact that mercury has a negative effect on crop yields finds further confirmation in an earlier study conducted by Ciećko et al [11], where lower yields of maize were observed as a result of soil contamination with mercury. In that case, the highest dose of mercury (150 mg Hg · kg^{-1}) caused a 27 % decrease in the yield of aerial maize organs. Also in that experiment, neutralising substances were tested, such as zeolite, lime and bentonite. They were all found to have a considerable alleviating effect on the negative influence caused by mercury on maize yields. In contrast, the present study failed to demonstrate an analogous effect of these soil improvers on potato yields, reduced by increasingly high rates of mercury in soil.

The study reported in this paper showed a considerable influence produced by the varied levels of soil contamination with mercury as well as the neutralising substances on the chemical composition of potato. Growing rates of mercury added to soil raised the content of phosphorus in potato tubers and herbage as well as potassium and magnesium in herbage but depressed the level of potassium in tubers as well as calcium in whole potato plants. The research conducted by Wyszkowski and Wyszkowska [10] also suggested that high levels of mercury in soil affected the chemical composition of oats. In their experiment, mercury raised the content of macroelements in oats, particularly that of phosphorus and calcium and, to a lesser extent, potassium and magnesium. By comparison, in a study completed by Ciećko et al [11], application of mercury to soil increased the levels of phosphorus, potassium and magnesium in maize, although the actual increase was more evident in aerial parts rather than in roots of this cereal. Soil pollution with mercury did not produce any significant effect on the content of calcium, which remained on a stable level. In the same experiment, the chemical composition of maize plants additionally depended on the type of a neutralising substance added to soil. Zeolite contributed to an increase in the content of potassium in maize, while causing a decline in the content of magnesium. In turn, liming caused a decrease in the content of phosphorus, potassium and magnesium, with calcium being an exception. In the present study, the neutralising substances also modified the chemical composition of potato. In the series with zeolite, lime and bentonite more potassium was determined in tubers and herbage and more calcium was found in herbage. In addition, bentonite and calcium had a positive effect on the content of magnesium in potato tubers. However, all the inactivating substances had a negative effect on the content of phosphorus in potato plants.

Conclusions

1. Contamination of soil with mercury had a negative effect on the yield of tubers and herbage of potatoes. The largest decrease in the tuber (69 %) and herbage yield (39 %), relative to the control, was observed at the highest mercury dose (150 mg $Hg \cdot kg^{-1}$).

2. Our analysis of the yields obtained from the control objects in the particular experimental series shows that the neutralising substances added to soil had a negative effect on the yield of potato, except zeolite, which contributed to a 4 % increase in the mass of potato herbage.

3. Application of the inactivating substances to soil did not have any larger effect on reducing the depression in potato yield caused by increasingly larger doses of mercury.

4. Potato tubers collected from mercury polluted objects contained more phosphorus but less potassium and calcium compared with the control object. On the other hand, potato herbage contained more phosphorus, potassium and magnesium but less calcium under the effect of mercury contamination of soil.

5. The neutralising substances tested in the experiment caused an increase in the concentration of potassium in tubers and herbage and that of magnesium in potato tubers. The neutralising substances had a negative effect on the accumulation of phosphorus in the whole potato plant and that of calcium in potato tubers.

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REAKCJA ZIEMNIAKA NA ZANIECZYSZCZENIE GLEBY RTĘCIĄ W WARUNKACH STOSOWANIA WYBRANYCH SUBSTANCJI NEUTRALIZUJĄCYCH

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Abstrakt: Mając na uwadze negatywne oddziaływanie rtęci na środowisko przyrodnicze, wykonano doświadczenie, którego celem było określenie wpływu tego pierwiastka na plonowanie i skład chemiczny ziemniaka uprawianego w warunkach stosowania różnych substancji neutralizujących.

Za podstawę badań przyjęto doświadczenie wazonowe, które wykonano w wazonach Kick-Brauckmanna, mieszczących 9 kg gleby. Materiał glebowy został symulacyjnie zanieczyszczony siarczanem rtęci w dawkach: 0, 50, 100 i 150 mg Hg $\cdot$ kg^{-1}. W badaniach jednocześnie uwzględniono dodatek substancji inaktywujących rtęć, takich jak: zeolit, wapno i bentonit. Zeolit oraz bentonit zastosowano w ilości 3 % w stosunku do masy gleby w wazonie, a wapno w dawce odpowiadającej 1 Hh gleby. We wszystkich obiektach doświadczenia zastosowano jednakowe nawożenie mineralne (NPK). Rośliną testową był ziemniak jadalny odmiany średnio wczesnej 'Zebra'.

Wzrastające zanieczyszczenie gleby rtęcią powodowało stopniowe zmniejszenie plonu bulw i masy łętów. Największy spadek plonu odnotowano w obiektach o największym zanieczyszczeniu gleby rtęcią. Zmniejszenie plonu bulw wynosiła od 63 % w serii z dodatkiem wapna do 31% w serii z zeolitem. Natomiast maksymalne obniżenie plonu łętów wynosiło od 48 % w serii z dodatkiem zeolitu do 23% w serii z wapnem. Ponadto rosnące zanieczyszczenie gleby rtęcią powodowało dość regularne zmniejszenie zawartości potasu w bulwach i łętach ziemniaka.

Słowa kluczowe: rtęć, wapno, zeolit, bentonit, gleba, ziemniak, zanieczyszczenie, neutralizacja