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Effect of liming on cadmium immobilisation in the soil and content in spring wheat (*Triticum aestivum L.*)

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Abstract

The objective of the study was the determination of the efficiency of the liming process in terms of cadmium immobilisation in the soil and its uptake by spring wheat. The research was conducted on a microfield experiment established at the Experimental Station of the Institute of Agriculture in Skierniewice. The surface soil layer was contaminated with cadmium to the second degree of contamination according to Kabata-Pendias et al. (1993), i.e., 1.87 mg Cd·kg^{-1}.The soil was subject to liming with CaO (60%) at doses according to 0, 0.5, 1.5, and 2 hydrolytic acidity (Hh). In the experiment, the analysed crop was spring wheat (Mandaryn cultivar). Data showed that an increase in liming was accompanied by a decrease in the content of cadmium both in the grain and straw of wheat. The content of cadmium in wheat grain varied from 0.038 mg Cd kg^{-1} (2 Hh) to 0.351 mg Cd kg^{-1} (0 Hh). In the case of wheat straw, it ranged from 0.147 mg Cd kg^{-1} (2 Hh) to 0.554 mg Cd kg^{-1} (0 Hh). The content of cadmium in straw did not exceed the acceptable content of trace substances in fodders as stipulated in the Regulation of the Minister of Agriculture and Rural Development 2012.

1. Introduction

One of the elementary physicochemical properties of soil is its reaction, determining a number of factors such as: fertility and course of chemical and biochemical processes. They determine the ecological and phytosanitary function and is responsible for the regulation of nutrients uptake by plants. An increase in soil acidity changes the rate of a number of processes causing the release of heavy metals from the sorption complex to the soil solution (Przewocka, 2014). Soil reaction determines the form and bioavailability of heavy metals. Soil acidity affects the mobilisation or immobilisation of heavy metals (Kabata-Pendias and Pendias, 1999). In the case of very acidic and acidic soils, an increase in mobile forms of heavy metals in the soil solution occurs. This process is associated with the increase in solubility of chemical substances containing a given element, and simultaneously a decrease in their retention by soil colloids at low soil reaction (Yasir et al., 2018).

Soils with very acidic and acidic reaction are grouped to chemically degraded soils, where the biological life declines, including bacteria fulfilling an important function in the environment. The resulting gap in the ecosystem is occupied by fungi (Karczewska and Kabała, 2010).

Data reported by the Chief Inspectorate of Environmental Protection (website 1), point at the the following voivodeships as characterised by soils with the lowest pH: Mazowieckie, Świętokrzyskie, Łódzkie, Podlaskie, and Kujawsko-Pomorskie. Only soils at the Pomorskie, Lubuskie, and Lubelskie voivodeships could be classified as slightly acidic. Currently, liming is an efficient and commonly applied method for immobilising metals in the soil (Kamionka, 2010; Karczewska and Kabała, 2010; Dradrach et al. 2019). The application of calcium compounds ($CaCO_3$, and CaO) increase the negative charge of soil particles and sorptive properties of soil and precipitation of metals in the form of carbonates or hydroxides (Krzyżak, 2013).

According to information of IUNG (Monitoring chemizmu… 2018), a decrease in the application of calcium fertilisers has been observed in recent years. Calcium doses were on average 90 kg CaO ha^{-1} year^{-1}, and deviated from the actual demand of soils for the compound. The cause of the situation could have been the revoking of subsidies for liming in 2004. The amount of calcium fertilisers supplied to soils did not cover the losses resulting from the ongoing natural processes (Przewocka, 2014). In terms of anthropogenic soil acidification related among others to the application of physiologically acidic fertilisers, the liming process should be systematic (Chief Inspectorate of Environmental Protection, 2018).

The objective of the paper was the determination of the efficiency of the liming process in terms of cadmium immobilisation in the soil and limiting of its uptake by spring wheat.

2. Material and methods

The study was conducted on a microfield experiment established at the Experimental Station of the Institute of Agriculture of the Warsaw University of Life Science in Skierniewice in 2019. The analysed crop was spring wheat, the Mandaryn cultivar. Microfields were established in stoneware pipes with a height of 120 cm and diameter of 40 cm embedded in the ground, filled with soil reflecting the soil profile. The experiment was established on Luvisols (IUSS Working Group WRB, 2015) the agrotechnical properties of which are presented in Table 1. The surface soil layer (0–25 cm) was contaminated with cadmium (in the form of $CdSO_4 \cdot 8\ H_2O$ as aqueous solution) to the second degree of contamination according to Kabata-Pendias et al. (1993), i.e., 1.87 mg $Cd \cdot kg^{-1}$. A month after cadmium application, the soil was limed with calcium oxide with a 60% content of CaO in accordance with the following hydrolytic acidity: 0, 0.5, 1, 1.5, and 2 Hh. The experiment was conducted in three replications. Soil and plant samples were collected on 29.07.2019. Plant material (grain, straw) was ground on a grinder by Retsh at 5000 rounds per minute. The resulting plant material was subjected to mineralisation in a mixture of acids HNO_3 and $HClO_4$ in a volumetric ratio of 4 : 1. The content of cadmium was determined by means of the method of atomic absorption spectrometry (ASA). The soil samples after air drying were sieved through a 2 mm mesh. The content of total cadmium after dissolution of the soil in reverse aqua regia ($HCl : HNO_3$ in a ratio of 1 : 3) and content of available Cd after extraction in a solution of 1 mol dm^{-3} HCl was determined by the ASA method. Soil reaction (pH) was measured by of the potentiometric method in 1 mol dm^{-3} solution (Table 1).

The statistical processing of results applied the multi-factor analysis of variance and the linear regression method. Tukey's test was applied for determining the significance of differences between mean values at a significance level p = 0.05. The statistical analysis of results was performed with the application of Microsoft Excel and Statistica 13.1 Stat Soft Polska.

Table 1. Soil properties in experiment

Gravel	Sand	Silt	Clay	C_{org}	CEC	Ca_{ex}
%				$g \cdot kg^{-1}$	$cmol(+) \cdot kg^{-1}$	
1	68	16	15	5.59	4.20	2.38

3. Results and discussion

Soil reaction considerably affected the yield of the test crop (Table 2). An increase in the liming dose was accompanied by higher yields in spring wheat grain. The yield varied from 650.8 to 759.8 g m^{-2}. Liming also significantly affected the yield of straw. Substantially higher yields in comparison to the control were obtained on the treatment of 1.5 and 2 Hh. Similarly, according to Zhang et al. (2018), soil reaction manifested a strong effect on the phytotoxicity of heavy metals. At a higher pH, the toxic effect of cadmium decreased. Lower yields of wheat caused by heavy metals are a consequence of their phytotoxic effect. It is manifested in a lower content of chlorophyll in plant tissues, lower photosynthetic, respiration, and transpiration activity, resulting in the inhibition of their growth (Czeczot and Majewska, 2010; Vaverková and Adamcová, 2014).

The current research showed that the content of cadmium in wheat grain growing on all the contaminated treatments was lower as compared to the control. Cadmium content both in grain and straw decreased with an increase in the dose of CaO (Table 3).

Similar dependencies were obtained by Xiao et al. (2017), who evidenced that combined application of liming and phosphorus fertilisation permits a reduction of the content of cadmium in rice grain by even 85%. They simultaneously observed a decrease in the content of available forms of cadmium in the soil by more than 16% in comparison to the treatment without liming. Also Malinowska (2017) evidenced a strong decrease in availability of metals as a result of liming. Similar changes were observed by Tlustoš et al. (2006), who obtained a 50% decrease in the content of cadmium in the soil as a result of liming in comparison to the control, simultaneously observing a decrease in the content of the element both in the roots and above-ground parts (straw and grain) of wheat. Karalić et al. (2013) reported that liming caused

Table 2. Yield of spring wheat depending on liming and soil pollution by cadmium

Treatment	Grain	Straw
Hh	$g \cdot m^{-2}$	
0	653.0^a	403.0^a
0.5	650.8^a	393.6^a
1.0	691.8^a	419.0^a
1.5	758.3^b	463.0^b
2.0	759.8^b	523.6^c

a–c – mean values marked with the same letters do not differ significantly at the p = 0.05

Table 3. Cadmium content in wheat grain and straw

Treatment	Grain	Straw
Hh	mg $Cd \cdot kg^{-1}$	
0	0.351^d	0.554^d
0.5	0.227^c	0.357^c
1.0	0.094^b	0.238^b
1.5	0.092^b	0.231^b
2.0	0.038^a	0.147^a

a–d – mean values marked with the same letters do not differ significantly at the p = 0.05

the strongest effect of reduction of the content of available forms of metals (Zn, Pb, Cr, and Cd) in extremely acidic soils with the highest initial available concentrations. On the other hand, the weakest relative effect of liming on a decrease in availability of heavy metals was recorded in moderately acidic soils with the lowest initial concentrations of available heavy metals.

Chamon et al. (2005) pointed out that in addition to liming, also an addition of organic substance and iron compounds (by-product of the aluminium industry) additionally limits the content of available forms of metals such as Zn, Ni, Cd, and Cr. Research by Antonkiewicz et al. (2018) also shows that waste materials primarily containing calcium compounds supplied to the soil can reduce the mobility of heavy metals.

In this research, the content of cadmium in grain and straw did not exceed the maximum acceptable content (1 mg Cd kg^{-1}) in fodders as stipulated by the Ministry of Agriculture and Rural Development (Dz.U. poz. 203., 2012). Symanowicz et al. (2015) shows that nitrogen fertilization influenced on concentrations of the selected heavy metals (except for Pb and Cd) were within the permissible limits for trace elements in feedstuffs specified by Polish and European standards.

The showed that the content of available and total forms of cadmium significantly decreased in the entire range of liming (Table 4), which limited the occurrence of both forms of cadmium the strongest at the dose of 2 Hh. The content of total cadmium form, on all the analysed treatments did not exceed the acceptable content in the soil or ground of agricultural and forest land (3 mg Cd kg^{-1}), (Dz.U. poz. 1395., 2016). An increase in the dose of CaO was accompanied by a decrease in the soil content of forms extractable with hydrochloric acid at the concentration of 1 mol dm^{-3} The percent share of Cd extractable in 1 mol dm^{-3} HCl to total content of cadmium was varied depending on the treatment (Table 4). The highest share of the available form to total form exceeded 83% and was occurred on the treatment 1Hh. Because the share of the available form to total form varied from 53 to 83.9%, it can be concluded that 1 mol dm^{-3} HCl is a very strong extraction solution.

For the purpose of analysis of the dependency between the soil properties and yield of wheat and cadmium content in grain and straw, the correlation analysis was performed (Table 5).

The analysis showed significant correlations between the soil properties. The strongest correlation was observed between the content of cadmium in straw and soil pH (r=−0.89). Strong positive correlations were also found for the yield of straw and grain of wheat depending on soil pH, where coefficients of correlation were 0.55 and 0.58, respectively. This means, that an increase in pH in soil was accompanied with a significant increase in crop yields.

Table 4. Content of total and available forms of cadmium in soil and pH

Treatment	Total forms	Available forms	Share of available into total forms	
Hh	mg Cd·kg^{-1}		%	pH
0	1.597^{c}	1.264^{c}	79.1	5.95
0.5	1.779^{d}	1.301^{c}	73.1	6.79
1.0	1.462^{b}	1.227^{c}	83.9	7.38
1.5	1.426^{b}	0.951^{b}	66.7	7.25
2.0	1.216^{a}	0.645^{a}	53.0	7.63

a–d – mean values marked with the same letters do not differ significantly at the p = 0.05

4. Conclusions

(1) Liming increased yields of spring wheat throughout the range of CaO doses.
(2) Liming was a treatment considerably limiting the uptake of cadmium and its content both in straw and grain of wheat. The contents did not exceed the acceptable level of cadmium in fodders as stipulated by the Regulation of the Minister of Agriculture and Rural Development.
(3) Soil liming at least according to 1.5 hydrolytic acidity significantly reduces the content of available forms of cadmium in the soil by approximately 50% as compared to the unlimed treatment.

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Table 5. Simplified correlation matrix showing the relationships between the features

	pH	Available forms	Total forms	Cadmium-content in grain	Cadmium-content in straw	Grain yield	Straw yield
pH	1						
Available forms	–0.62*	1					
Total forms	–0.54*	0.65*	1				
Cadmium content in grain	–0.33	0.43	0.33	1			
Cadmium content in straw	–0.89*	0.65*	0.45	0.42	1		
Grain yield	0.55*	–0.75*	–0.79*	–0.31	–0.41	1	
Straw yield	0.58*	–0.65*	–0.46*	–0.37	–0.62*	0.63*	1

* statistically significant values

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Wpływ wapnowania na unieruchamianie kadmu w glebie oraz na jego zawartość w pszenicy jarej (*Triticum aestivum L.*)

Słowa kluczowe

Pszenica jara
Kadm
Ziarno
Słoma
Plon

Streszczenie

Celem badań było określenie skuteczności procesu wapnowania, na unieruchamianie kadmu w glebie i ograniczenia pobierania tego metalu przez pszenicę jarą. Badania prowadzono w oparciu o doświadczenie mikropoletkowe założone w Stacji Doświadczalnej Instytutu Rolnictwa w Skierniewicach. Wierzchnią warstwę gleby zanieczyszczono kadmem doprowadzając ją do II stopnia zanieczyszczenia (1.87 mg Cd·kg^{-1}) wg. Kabaty-Pendias i in. (1993). Glebę wapnowano CaO (60%) w dawkach według 0, 0,5, 1,5 oraz 2 kwasowości hydrolitycznej (Hh). W doświadczeniu badaną rośliną była pszenica jara odmiany Mandaryn. W badaniach stwierdzono, że wraz ze wzrostem wapnowania zmniejsza się zawartość kadmu zarówno w ziarnie jak i w słomie pszenicy. Zawartość kadmu w ziarnie pszenicy wahała się od 0.038 mg Cd·kg^{-1} (2 Hh) do 0.351 mg Cd·kg^{-1} (0 Hh). Zawartość kadmu w słomie pszenicy wynosiła od 0.147 mg Cd·kg^{-1} (2 Hh) do 0.554 mg Cd·kg^{-1} (0 Hh). Zawartość kadmu w słomie nie przekroczyła dopuszczalnej zawartości substancji śladowych w paszach ustanowionych Rozporządzeniem Ministra Rolnictwa i Rozwoju Wsi z 2012 roku.