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EFFECT OF MAGNESIUM FERTILISATION WITH SOIL SUPPLEMENTATION OF CADMIUM ON THE YIELD AND QUALITATIVE PARAMETERS OF POPPY (*Papaver somniferum*)

WPŁYW NAWOŻENIA MAGNEZEM I DODATKU KADMU DO GLEBY NA PLONOWANIE I PARAMETRY JAKOŚCIOWE MAKU (*Papaver somniferum*)

Summary: The objective of the pot experiment was to discover the effect of magnesium applied in the form of magnesium nitrate together with soil supplementation of cadmium on the qualitative and quantitative parameters of poppy, variety Opál. During the vegetation (stage DC 41) Mg fertilisation had a positive effect on Mg and Ca concentrations in the plant. Mg application also had a synergic effect on N uptake and increased its content in the plant. In variants where Cd was supplemented its content in the plants considerably increased. With Mg fertilisation the yields of poppy seeds increased when compared with the unfertilised variants; both in the variant with a natural Cd content and variant where it was supplemented, *ie* by 3.6 and 19.9%, respectively. We compared the yields of variants not fertilised with magnesium and found that they increased statistically significantly (by 32.1%) in the variant with a higher content of Cd. It was similar in variants where Mg was applied. We see that cadmium had a synergic effect enhancing a better utilisation of nutrients, which was reflected in higher seed yields. There were no statistical differences in the yields of poppy straw among the variants. As a result of Mg application the amount of morphine in poppy straw increased; that is both in variants with a natural and supplemented Cd content (by ca 5.4 and ca 8.6%, respectively). As expected, the content of Cd in poppy seed increased in variants where it was applied to the soil. Comparisons between variants not fertilised with magnesium and variants with a natural and increased content of Cd showed that the concentration of the heavy metal in seeds increased in the same way as in the plant matter, *ie* almost tenfold. Magnesium fertilisation reduced the content of cadmium particularly in variants where it was supplemented (by almost 50%).

Keywords: poppy, magnesium, cadmium, fertilisation, seed, straw, yield, morphine

At the present time poppy is grown in the Czech Republic for the food industry (seeds) and for pharmaceutical purposes (alkaloids) in an area of ca 58,000 ha. The enormous increase in the cultivation areas in the past years makes quite obvious especially the economic advantages of growing this crop traditional for the region of Central Europe. It is connected with the need to establish a well-elaborated and compact growing technology, an integral part of which is complex plant nutrition ensuring a good supply of available nutrients in the soil. In addition to a good supply of all biogenic elements to a great extent contributing to the production of optimal yields of seeds and poppy straw, it is necessary to concentrate attention also on the presence of substances, which decrease its quality particularly from the point of view of its use in the food industry.

One of many factors limiting the use of poppy as food is the increased content of heavy metals in seeds, in the first place of cadmium. In a number of studies [1, 2] attention has been devoted to “soil - plant” interactions in terms of the entrance of this metal into the food chain. According to Eriksson [3], Öborn et al. [4], McLaughlin et al. [5] and

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Trebichavský et al. [6] the risk of an increased content of Cd is seen in products made from crops grown on soils with a low pH value, low content of organic substances, high content of Cd in the soil and low or high content of Zn and Pb in the soil. Trebichavský et al. [6] reported that 6 mg · kg^{-1} of releasing Cd is toxic for plants and soil bacteria. Important in the contamination of the product with this element are also atmospheric deposits and mineral P fertilisers made of phosphates with high cadmium content [7].

A number of literary sources described the uptake of Cd by the plant in interaction with microelements (namely with Zn) and its distribution in tissues [8-13]. The effect of macrobiogenic elements on cadmium uptake by the plants and its utilisation has been described in literature only sporadically. Known are studies on the interaction of cadmium with phosphorus [14] and calcium [10, 15] on plant metabolism. Results of authors illustrating the magnesium - cadmium interaction coming from the nutrient medium of plants and its impact on the plant organism are very rare.

In the present study we explored the effect of Mg interacting with Cd on the contents of nutrients in poppy plants in the stage of elongations growth, on yields of poppy seeds, yields of straw (empty capsules + 15 cm of stem), content of the morphine alkaloid in the straw and concentration of Cd in the seeds.

Material and methods

A one-year pot experiment with poppy (*Papaver somniferum*), variety Opál, was established in the vegetation hall of the Department of Agrochemistry, Soil Science, Microbiology and Plant Nutrition of MUAF in Brno. Plastic pots were filled with 9.5 kg of medium heavy soil characterised as fluvial soil. Table 1 gives the agrochemical characteristics of the soil before establishment of the experiment.

Table 2 gives the variants of fertilisation used in the experiment in 4 replications.

Table 1

Agrochemical characteristics of the soil in mg · kg^{-1} d.m. soil

pH/$CaCl_2$	Content of available nutrients (Mehlich 3)				Content of Cd	
	P	K	Ca	Mg	Total (aqua regia)	Available (2 M HNO_3)
7.3	122	147	2557	144	0.108	0.100

Table 2

Treatments of experiment

	Variants of fertilization	Doses of nutrients	Fertilizers
1	no fertilizer without Cd	-	-
2	Mg without Cd	0.78 g Mg · pot^{-1}	$Mg(NO_3)_2$
3	no fertilizer with Cd	1 ppm Cd	$(CH_3COO)_2Cd \cdot 2H_2O$
4	Mg with Cd	1 ppm Cd; 0.78 g Mg · pot^{-1}	$Mg(NO_3)_2$; $(CH_3COO)_2Cd \cdot 2H_2O$

Nitrogen in the form of ammonium nitrate (34.5% N) was balanced in all variants to a uniform level of 0.9 g N per pot. After dissolution all the nutrients and cadmium were applied to the soil in the form of watering. Shallow sowing of poppy followed fertilisation (4 May 2006).

During vegetation watering was conducted on a regular basis with demineralised water to a level of 60% of the maximal water capacity, then poppy was thinned out to the final

number of 4 plants per pot; plant samples were taken for chemical analyses at stage DC 41 (22 June 2006), the pots were kept weed-free and control against beet aphid and poppy downy mildew was conducted.

The plants were harvested on 8 August 2006. Samples of plant matter taken at stage DC 41 were dried up at 60°C, ground in a mill and homogenized. This matter was then subjected to wet mineralization (H_2SO_4 and H_2O_2) [16] and the basic macrobiogenic elements (N, P, K, Ca and Mg) and Cd content were determined. The concentration of nitrogen was determined using the method according to Kjeldahl. The contents of potassium, calcium and magnesium were determined by means of atomic absorption spectrophotometry (AAS) on the Carl Zeiss Jena AAS-30 apparatus. The content of phosphorus in the extract was determined colorimetrically on the UV/VIS spectrophotometer, ATI Unicam 8625. Cadmium in the plants was determined after microwave decomposition by atomic absorption spectrophotometry.

Yields were evaluated using the method of variance analysis (programme STATISTICA 7.1) followed by Tukey's tests at a 95% level of significance ($p < 0.05$).

Results and discussion

The application of magnesium (variants 2 and 4) explicitly increased its content in the plant matter (Tab. 3). In a similar way the content of Cd increased markedly in variants where it was supplemented in the soil (variants 3 and 4). When we compared the variant not fertilised with magnesium with a natural content of Cd (variant 1) with variants where Cd was applied to the soil (variant 3) we saw that the concentration of Cd in the plant matter increased almost tenfold manifesting the close correlation between the uptake of cadmium by the poppy plant and its content in the soil [17]. Ciecko et al. [18] reported that the uptake of magnesium increased on Cd-contaminated soil; this finding was not confirmed in our experiment. Jiang et al. [19] arrived at similar conclusions; they discovered that the effect of the Cd content on the uptake and transfer of Mg was small. The results of chemical analyses of the plants (Tab. 3) further showed that the applied doses of Mg and Cd were not reflected in the P and K contents. More marked was the interaction of both of these elements (variant 4) on nitrogen concentration, which increased in contrast to the other variants.

Table 3

Chemical analyses of plants in the stage of elongation growth (DC 41) 22 June 2006

	Variants of fertilization	[%] dry matter					[ppm]
		N	P	K	Ca	Mg	Cd
1	no fertilizer without Cd	3.31	0.55	4.90	2.34	0.26	0.11
2	Mg without Cd	3.32	0.47	4.54	2.72	0.39	0.16
3	no fertilizer with Cd	3.28	0.45	3.62	2.07	0.22	1.02
4	Mg with Cd	3.74	0.39	4.73	2.57	0.34	0.83

Poppy seed yields were affected by Mg fertilisation, but this result was not statistically significant (Tab. 4) although the difference in yields between the 1st and 2nd variant was almost 20%. Soil application of Cd stimulated yield-formation even more. Due to the effect of the heavy metal the yields of variant 3 increased significantly, *ie* by 32.1%, compared with variant 1. Seed production was the highest when Mg fertilisation was combined with

a supplementation of cadmium (9.85 g · pot^{-1}). We observed that Cd had a synergic effect and boosted higher utilisation of nutrients what was reflected in the final seed yields. On the other hand Chizzola [17] reported that yields dropped as much as 25% after soil application of cadmium.

The differences in straw yields (empty capsules + 15 cm of stem) among the variants were not statistically significant (Tab. 4); the weight ranged between 27.11 and 31.17 g per pot.

Table 4

Experimental results of yields

	Variants of fertilization	Seed yield		Yields of straw [g · pot^{-1}]	Content of morphine [%]
		[g · pot^{-1}]	[rel.%]		
1	no fertilizer without Cd	7.20 a	100.0	27.11 a	0.74
2	Mg without Cd	8.63 ab	119.9	31.17 a	0.78
3	no fertilizer with Cd	9.51 b	132.1	29.02 a	0.70
4	Mg with Cd	9.85 b	136.8	27.22 a	0.76

$p \leq 0.05$ - statistical significance at a 95% level of significance. Variants with identical letters express statistically insignificant differences.

Owing to Mg fertilisation the content of morphine in the straw increased as compared with the variants not fertilised with Mg, both without and with Cd supplementation (by ca 5.4% and ca 8.6%, respectively, and it corresponds with the findings of Ramanathan [20] who discovered that the morphine content increased when magnesium was applied separately or in combination with microelements.

Table 5

Cd content in seeds

	Variants of fertilization	Content of cadmium in seed	
		[ppm]	[rel.%]
1	no fertilizer without Cd	0.287 a	100.0
2	Mg without Cd	0.251 a	87.5
3	no fertilizer with Cd	2.702 b	941.5
4	Mg with Cd	1.390 c	484.3

$p \leq 0.05$ - statistical significance at a 95% level of significance. Variants with identical letters express statistically insignificant differences

Table 5 shows the Cd content in poppy seed. After soil application of Cd its content in seeds increased as was expected, compared with the variant with a natural soil supply. Generally speaking most of the Cd is accumulated in roots, then in the vegetative organs and the least in generative organs. In contrast Chizzola [17, 21] reported that most of the Cd in the poppy plant is utilised in the seeds. In his experiments the Cd concentration in seeds was 1.700 mg · kg^{-1} d.m. when a dose of 4 mg Cd · kg^{-1} was applied in the soil. According to Hoffmann and Blasenbrei [22] the average Cd content in poppy seed was 0.739 mg Cd · kg^{-1} d.m., in semi-finished products 0.317 mg Cd · kg^{-1} d.m. and in baked goods 0.107 mg Cd · kg^{-1} d.m. Comparisons of control variant with a natural (variant 1) and increased (variant 3) content of soil Cd showed that the concentration of the heavy metal in seeds increased similarly as in the plant matter in stage DC 41, *ie* almost tenfold. However, after Mg application the content of the heavy metal declined, particularly in

variants where it was supplemented (variants 3 and 4) and where the application of magnesium nitrate statistically significantly reduced the Cd content by almost 50%. Richter and Lošák [23] drew the same conclusions; in their experiment the increased doses of Mg decreased the Cd content from 0.123 mg Cd · kg $^{-1}$ d.m. to 0.097÷0.098 mg Cd · kg^{-1} d.m. what is on average by 20%. It can be assumed that there is an antagonism between Cd and Mg in terms of uptake by the root system, as it is between Cd and Zn where both ions mutually compete for the same active centres of membrane carriers.

Conclusion

In the stage of elongation growth the application of Mg and Cd increased their content in the plant matter. Interaction between the two elements was reflected more markedly also in the uptake of N; the P and K contents did not change under the effect of Mg and Cd supplementation. Mg fertilisation increased the yields of poppy seed by almost 20% and soil application of Cd stimulated yield formation even more. A combination of Mg fertilisation and Cd supplementation of 9.85 g · pot^{-1} resulted in the highest seed production. The differences in straw (empty capsules + 15 cm of stem) yields among the variants were not statistically significant. Due to Mg fertilisation the morphine content in straw increased regardless of Cd supplementation. After application of Cd to the soil its content in poppy seed increased as expected. However, after Mg application the content of the heavy metal decreased, namely in variants where it was supplemented (by almost 50%). Here the increased content of Mg in the plants obviously worked despite the competitive inhibition restricting the uptake and transport of Cd in the plant.

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WPŁYW NAWOŻENIA MAGNEZEM I DODATKU KADMU DO GLEBY NA PLONOWANIE I PARAMETRY JAKOŚCIOWE MAKU (*Papaver somniferum*)

Streszczenie: Celem badań prowadzonych w doświadczeniu wazonowym było poznanie wpływu nawożenia magnezem, zastosowanym w formie azotanu magnezu, oraz dodatku kadmu do gleby na parametry ilościowe i jakościowe maku, odmiana 'Opál'. W czasie wegetacji (stadium DC 41) nawożenie miało pozytywny wpływ na zawartość Mg i Ca w roślinie. Stosowanie Mg miało też wpływ synergiczny na pobieranie N i zwiększało jego zawartość w roślinie. W wariantach, w których dodawano kadmu, jego zawartość w roślinie wzrastała. W wyniku nawożenia plony nasion maku zwiększały się w porównaniu z wariantami nienawożonymi; zarówno w wariancie z naturalną zawartością Cd, jak i w wariancie z dodatkiem Cd, odpowiednio o 3,6 i 19,9%. Porównując plony z poszczególnych wariantów nienawożonych magnezem, stwierdzono, że w wariancie z większym dodatkiem Cd wzrastały one statystycznie istotnie (o 32,1%), podobnie jak w wariantach, w których zastosowano Mg. Zauważono, że kadm ma wpływ synergiczny, powodując lepsze wykorzystanie składników pokarmowych, co objawiało się większymi plonami nasion. Nie było statystycznie istotnych różnic w plonach słomy maku pomiędzy wariantami. Na skutek stosowania Mg wzrastała zawartość morfiny w słomie maku zarówno w wariantach z naturalną zawartością Cd, jak i z jego dodatkiem (odpowiednio o około 5,4 i 8,6%). Jak oczekiwano, zawartość Cd w nasionach maku wzrastała w wariantach, w których dodano go do gleby. Porównanie pomiędzy wariantami nienawożonymi z dodatkiem magnezu i wariantami z naturalną i zwiększoną zawartością Cd wykazało, że zawartość metali ciężkich w nasionach wzrastała w podobnym stopniu jak w materiale roślinnym, tj. prawie dziesięciokrotnie. Nawożenie magnezem zmniejszało zawartość kadmu, zwłaszcza w wariantach, w których metal ten był dodawany (o blisko 50%).

Słowa kluczowe: mak, magnez, kadm, nawożenie, nasiona, słoma, plon, morfina