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EFFECT OF MAGNESIUM AND CADMIUM SUPPLEMENTATION ON YIELDS AND QUALITY OF POPPY (*Papaver somniferum* L.)

ODDZIAŁYWANIE DODATKU MAGNEZU I KADMU NA PLON I JAKOŚĆ MAKU (*Papaver somniferum* L.)

Abstract: In a vegetation pot experiment with poppy, 'Opál' variety, we explored the effect of soil supplementations of magnesium (0.78 g Mg · pot^{-1}) and as foliar dressing (3 % solution) in the form of $Mg(NO_3)_2$ at a natural (0.14 mg Cd · kg^{-1}) and increased level (1 mg Cd · kg^{-1}) of cadmium in the soil on the chemical composition of the plants, seed yields, content of morphine in the straw and cadmium content in the seeds.

The following six variants were used in the experiment: 1) N (control), 2) N + $Mg(NO_3)_2$ into the soil, 3) N + $Mg(NO_3)_2$ foliar dressing, 4) N (control) + Cd, 5) N + $Mg(NO_3)_2$ into the soil + Cd, 6) N + $Mg(NO_3)_2$ foliar dressing + Cd.

The level of magnesium in plants in the DC 41 stage (stem elongation growth) increased in the magnesium-fertilised variants. The level of Cd in plants grown in soil with a natural Cd content increased in all the Mg-fertilised variants to 0.29–0.45 mg Cd · kg^{-1} compared with 0.27 mg Cd · kg^{-1} in the control variant. Of the plants grown in soil with the increased Cd content the highest Cd level was monitored in the control variant (1.29 mg Cd · kg^{-1}), while in the other variants the Cd level decreased after the application of magnesium to 0.51 and 0.69 mg Cd · kg^{-1}, respectively. In the DC 41 stage the dry matter weight of one plant ranged irregularly from 2.16 to 3.82 g and the highest value was achieved in the variant with a supplementation of cadmium and nitrate form of magnesium.

Poppy seed yields were statistically insignificant in all variants and ranged between 2.28 and 2.74 g of seeds per plant.

The content of morphine in straw (empty capsule + 15 cm of stem) ranged only between 0.92 and 1.05 %, and the effect of magnesium or cadmium was insignificant.

At a natural level of Cd in the soil the differences in its content in seeds were not significant and ranged between 0.479 and 0.612 mg Cd · kg^{-1}. In variants where the soil was supplemented with Cd its content in the seeds increased significantly (1.413–2.176 mg Cd · kg^{-1}) compared with variants with a natural Cd content in the soil. When Mg was applied to soil with an increased Cd level we saw that the Cd level in seeds decreased significantly when compared both with the controls and to foliar application of magnesium.

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Applications of Mg increased its content in plants, stabilised yields and did not increase the Cd content in poppy seeds which increased only after goal-directed Cd supplementation in the soil.

Keywords: poppy, cadmium, magnesium, soil application, foliar application

In 2008 poppy was sown in the Czech Republic for purposes of the food (poppy seed) and pharmaceutical (alkaloids) industry in an area of almost 75,000 ha. This enormous increase in the area of sown poppy demonstrates, in the first place, the economic benefits which this crop, traditional in Central Europe, brings. That is why it is necessary to set up a compact technology of cultivation of this crop, the integral part of which is indisputably complete nutrition assuring a sufficient supply of nutrients acceptable for the plant. Apart from the indispensability of biogenic nutrients, to a great extent contributing to the formation of yields of poppy seed and poppy straw, we must also focus on the presence of substances which deteriorate the quality, particularly in terms of its subsequent consumption as food.

One of the many factors limiting the use of poppy as food is the content of heavy metals in the seeds, especially of cadmium. This alien element troubles the farmers as the results of controls of the Czech Agriculture and Food Inspection Authority carried out from 2002 to 2006 confirmed; the average content of Cd ranged between 0.56 and 0.70 mg $\cdot$ kg^{-1} [1]. The use of poppy in the food industry is limited by the legislation of the Czech Republic, ie the Decree of the Ministry of Health [2], according to which the maximal admissible amount of Cd in 1 kg of oil plants intended for direct consumption and use is 0.50 mg $\cdot$ kg^{-1} [3]. The risk of Cd entering the plant is enhanced especially in areas where the soil pH value is low, where the content of organic compounds is low and naturally where the content of Cd in the soil is high [4–7]; an amount as low as 6 mg of releasable Cd in 1 kg of soil is toxic for plants and for soil bacteria [7]. Also atmospheric deposits and mineral P fertilisers made from phosphates with a high content of cadmium play an important role in Cd contamination [8]. A number of literature sources describe the effect of macrobiogenic (P and Ca) and particularly microbiogenic elements (namely Zn) on the intake of Cd by the plant and its distribution and utilisation in tissues [9–16]. However in literature facts explaining the mutual effect of cadmium and magnesium and their impact on the plant organism and metabolism of poppy are rather sporadic [17]. And it is no other than magnesium which is an element having a positive effect not only on yields but particularly on the quality of the poppy seeds; it decreases Cd utilisation in seeds [17].

The present study is focused on the effect of soil and foliar applications of Mg in interaction with the natural content of Cd and with soil supplementation on the content of nutrients and Cd in poppy plants in the stage of elongation growth, on yields of poppy seeds, yields of straw (empty capsules + 15 cm of stem), the content of morphine in the straw and Cd content in seeds.

Material and methods

The vegetation pot experiment with poppy was established on 27 March 2007 in plastic pots which held 9.5 kg of medium-heavy soil characterised as Fluvisol. Table 1 gives the agrochemical characteristics of the soil before the establishment of the study.

Table 1

Agrochemical properties of soil (Melich III)

Soil acidity $pH/CaCl_2$	Content of available nutrients [$mg \cdot kg^{-1}$]			
	P	K	Ca	Mg
7.6	72	94	2074	111

Among the evaluated parameters of soil fertility was the soil reaction (1:5 soil: 0.01 $mol \cdot dm^{-3}$ $CaCl_2$ solution) and the contents of available nutrients (P, K, Ca and Mg) specified after soil extraction with the leaching agent Mehlich III (1:10 soil: leaching agent Mehlich III) [18]. The amount of phosphorus in the extract was determined colorimetrically (UV/VIS spectrophotometer ATI Unicam 8625). Potassium, calcium and magnesium were determined using the method of atomic absorption spectrophotometry (AAS) on the Carl Zeiss Jena AAS-30 apparatus. Apart from the content of available nutrients we determined the total content of Cd in the soil extract with *aqua regia* [19] and detected a low value of 0.14 $mg \cdot kg^{-1}$.

We explored the effect of both soil and foliar (3 % solution) applications of magnesium in the form of $Mg(NO_3)_2$ at a natural and increased level of cadmium (Table 2).

Table 2

Experiment design

Variant of fertilization		Dose of nutrients		Dose of cadmium
		Nitrogen	Magnesium	
		[$g \cdot pot^{-1}$]		[$mg \cdot kg^{-1}$]
1	N (control)	0.9	0.00	0
2	N + $Mg(NO_3)_2$ into the soil	0.9	0.78	0
3	N + $Mg(NO_3)_2$ foliar dressing	0.9	0.78	0
4	N (control) + Cd	0.9	0.00	1
5	N + $Mg(NO_3)_2$ into the soil + Cd	0.9	0.78	1
6	N + $Mg(NO_3)_2$ foliar dressing + Cd	0.9	0.78	1

Variants where magnesium was applied to the soil (variants 2 and 5) were fertilised on 28 March 2007 according to the above pattern, ie 0.78 g Mg per pot. Later on soil of variants 4 – 6 was supplemented with cadmium in a dose of 1 $mg \cdot kg^{-1}$ of soil in the form of cadmium acetate $(CH_3COO)_2Cd \cdot 2H_2O$. Nitrogen was balanced out in all the variants of fertilisation to the same level (0.9 g N per pot) with ammonium nitrate (34.5 % N). All the nutrients and cadmium were dissolved and applied to the soil in the form of watering. Shallow sowing of poppy, 'Opál' variety, was conducted after the soil had settled naturally (2 April 2007).

The plants began to emerge evenly 10 days after sowing. In the stage of 4–6 true leaves (9 May 2007) the plants were singled to 7 plants per pot. On 18 May 2007 foliar application of magnesium followed in variants 3 and 6 in the stage of 8–10 leaves. For the application we used a 3 % solution of $Mg(NO_3)_2$. On a regular basis during vegetation the plants were watered with demineralised water, sampled for chemical analyses, they were maintained weed-free and the preparations Karate 2,5 EC and Discus were used as pest control against beet aphid (*Aphis fabae*) and downy mildew of poppy (*Peronospora arborescens*).

The plants were harvested on 8 August 2007, ie 4 plants per pot. The results were assessed using the programme STATISTICA 7.1 CZ by the method of variance analysis (ANOVA) followed by Tukeye's test at a 95 % level of significance ($p \leq 0.05$).

Results and discussion

Analyses of the plant matter

The range of the nitrogen levels in the stage of elongation growth (DC 41) of all fertilisation variants was narrow, ie between 3.59 and 4.21 %; the type or form of the applied fertilisers was insignificant. Application of Mg fertilisers had a positive effect on the level of magnesium in the plant. Compared with the control (unfertilised) variants its content increased in variants where both soil and foliar fertilisation with this nutrient was applied (by 12.2–13.0 % and by 4.1–15.2 %, respectively). Magnesium fertilisation had no marked impact on the contents of the other macrobiogenic elements which ranged within the optimal values (Table 3).

Table 3

Chemical composition of the poppy plants in the stage of elongation growth (DC 41)

Variant of fertilization		N	P	K	Ca	Mg	S	Cd
		[% dry matter]						[mg · kg^{-1}]
1	N (control)	3.87	0.57	3.57	2.86	0.49	0.40	0.27
2	N + $Mg(NO_3)_2$ into the soil	4.00	0.53	3.95	3.02	0.55	0.40	0.29
3	N + $Mg(NO_3)_2$ foliar dressing	4.21	0.58	4.10	2.89	0.51	0.42	0.45
4	N (control) + Cd	3.59	0.60	3.82	2.51	0.46	0.40	1.29
5	N + $Mg(NO_3)_2$ into the soil + Cd	3.97	0.55	4.00	2.78	0.52	0.35	0.51
6	N + $Mg(NO_3)_2$ foliar dressing + Cd	3.90	0.49	3.29	2.65	0.53	0.36	0.69

After soil application of magnesium the amount of cadmium in plants grown in soil with natural cadmium content (variants 1–3) increased to 0.29 and after foliar application to 0.45 ppm Cd; compared with the control plants it increased 7.4 and 66.7 %, respectively. In plants grown in soil where the Cd level was purposely increased to 1 ppm (variants 4–6) the level of Cd was the highest in the control variant (variant 4) and the correlation between cadmium intake by the poppy plant and the level in the soil was close [20]. Much like magnesium the effect of the increased Cd doses did not markedly influence the content of macrobiogenic elements. The results of experiments of Zhang et al [21] imply that increased doses of Cd in the soil cause excessive accumulation of P and K in plant roots but it probably inhibits subsequent translocation into the aboveground parts of the plants. In our experiment cadmium concentration in the plant decreased relatively after soil application of the Mg fertiliser to 39.5 % of the control variant and after foliar application by almost one half (53.5 % of the value of the unfertilised variant). Literature also states that Mg intake on Cd-contaminated soil is higher [22]. This fact was not proved in our experiment and confirmed the results of Jiang et al [23] who discovered that the effect of the Cd level on the intake and translocation of Mg was low.

The dry matter weight of one plant fluctuated irregularly from 2.16 to 3.82 g and the highest values were achieved in variants after foliar application of the nitrate form of magnesium, ie both without and with cadmium supplementation (variant 3 and 6). The average intake of nutrients by poppy plants is dependent on the dry matter weight of one plant and its content. This is the main reason of the fluctuation in nutrient intake among the variants of fertilisation (Table 4). In terms of their amount, the order of the intake of nutrients was as follows: N > K > Ca > P > Mg > S. Cadmium intake by plants was on a low level and a more marked increase was seen after soil supplementation.

Table 4

Average nutrient and Cd uptake by the poppy plant in the stage of elongation growth (DC 41)

Variant no.	Weight of 1 plant	N	P	K	Ca	Mg	S	Cd
	[g dry matter d.m.]	[mg per plant]						[μg per plant]
1	2.35	90.9	13.3	83.8	67.2	11.5	9.4	0.63
2	2.24	89.6	11.8	88.5	67.6	12.3	8.9	0.64
3	2.50	105.3	14.5	102.5	72.3	12.7	10.5	1.00
4	2.16	77.5	12.9	101.2	66.5	9.9	8.6	2.70
5	2.18	86.5	11.9	87.2	60.6	11.3	7.6	1.10
6	3.82	148.9	18.7	125.6	101.2	20.2	13.7	2.60

Results of yields

Soil application of Cd did not have a marked effect on poppy seed yields. While poppy seed yields of the control (unfertilised) variant and in combination with soil application of $Mg(NO_3)_2$ (variants 4 and 5) slightly decreased compared with variants with a natural supply of Cd (by 2.0 % between variants 1 and 4 and by 6.2 % between variants 2 and 5), interaction between the increased Cd level in soil and foliar application of magnesium (var. 6) relatively increased its level in comparison with variant 3. ie by 6.1 %. This fact is at variance with results of the experiment which showed that soil application of cadmium reduced yields by as much as 25 % [20].

Table 5 shows that no statistically significant differences ($p \le 0.05$) in poppy seed yields were detected between variants with a natural (variants 1–3) Cd level in the soil and the yields ranged between 9.74 and 10.31 g of seeds per pot. On the basis of these results it is apparent that the effect of foliar nutrition with magnesium nitrate was higher than soil application. Foliar application of magnesium (variant 3) increased the production of poppy seed against the soil-supplemented variant (variant 2) by 5.7 %, as compared with the unfertilised variant (variant 1) by 5.9 %.

Table 5

Yields of poppy (seed and straw) and morphine content in straw

Variants of fertilization		Seed yield [g · pot^{-1}]	Seed yield relative [%]	Yields of straw [g · pot^{-1}]	Content of morphine [%]
1	N (control)	9.74 a	*100.0*	21.29 a	0.92
2	N + $Mg(NO_3)_2$ into the soil	9.75 a	*100.1*	24.23 ab	1.00
3	N + $Mg(NO_3)_2$ foliar dressing	10.31 a	*105.9*	27.53 b	0.93
4	N (control) + Cd	9.55 a	*100.0*	18.89 a	0.93
5	N + $Mg(NO_3)_2$ into the soil + Cd	9.15 a	*95.8*	19.22 a	1.05
6	N + $Mg(NO_3)_2$ foliar dressing + Cd	10.94 a	*114.6*	22.23 a	0.97

$p \le 0.05$ – statistical significance at a 95 % level of significance; variants with the same letters (a) showed statistically insignificant differences.

The trends in yields of variants grown in soil with a purposely increased Cd level are similar. The increase in poppy seed yields after foliar application of magnesium was even more marked (Table 5) but not statistically significant ($p \le 0.05$). On the contrary, soil application of magnesium nitrate reduced seed yields by 4.2 % as compared with the control variant.

Total per-pot yields of poppy straw (empty capsule + 15 cm of stem) fluctuated among the variants. In the experiment with a natural Cd level in the soil we detected a statistically significant ($p \le 0.05$) increase in straw production as a result of foliar nutrition with magnesium (variant 3) as compared with the control variant. Where the soil was supplemented with Cd the straw yields of all variants decreased as against the variants with a natural Cd level. The effect of foliar application of magnesium was similar and increased yields by 17.7 % as against the control and by 15.7 % as against soil application, but not significantly ($p \le 0.05$).

In all variants the morphine content in straw exceeded the average value given for the 'Opál' variety. In variants without Cd supplementation it ranged between 0.92 and 1.00 % and in variants where Cd was applied it ranged between 0.93 and 1.05 %. According to literary data there is a positive correlation between the Cd content and production of alkaloids in poppy (narcotine in seeds and morphine in the capsules) [24] coupled with the positive effect of Mg application on the morphine content [17, 25]; however in our experiment the doses of magnesium, form of its application and soil supplementation of cadmium did not have a significant effect on the morphine content.

The content of Cd in poppy seeds increased considerably after its soil application. Table 6 demonstrates that after soil supplementation with Cd its content in poppy seeds increased evenly in the control variant and in the variant with a foliar application of $Mg(NO_3)_2$, 3.5 times on average. In spite of the universally stated capacity of plants to accumulate most of the Cd in roots, followed by vegetative organs and least in generative organs, Chizzola [20, 26] presented similar conclusions as above saying that most of the Cd in the plant is utilised in seeds.

Table 6

Cd content in seeds

Variants of fertilization		Content of cadmium in seed		
		[mg · kg^{-1}]	relative^x [%]	relative^y [%]
1	N (control)	0.607 a	*100.0**	*100.0*
2	N + $Mg(NO_3)_2$ into the soil	0.479 a	*100.0***	*78.9*
3	N + $Mg(NO_3)_2$ foliar dressing	0.612 a	*100.0****	*100.8*
4	N (control) + Cd	2.094 a	*345.0**	*100.0*
5	N + $Mg(NO_3)_2$ into the soil + Cd	1.413 b	*295.0***	*67.5*
6	N + $Mg(NO_3)_2$ foliar dressing + Cd	2.176 a	*355.5****	*103.9*

^{x} – elevated Cd content in soil versus natural Cd content; ^{y} – $Mg(NO_3)_2$ application versus control; $p \le 0.05$ – statistical significance at a 95 % level of significance; variants with the same letters (a) showed statistically insignificant differences.

In variants with a natural level of Cd in the soil (variants 1–3) the content of cadmium in seeds did not differ significantly ($p < 0.05$). In the magnesium-unfertilised control variant (variant 1) its content was 0.607 mg Cd · kg^{-1} of seeds. Hoffmann and Blasenbrei [27] discovered that the average Cd content in poppy seeds was 0.739 mg Cd · kg^{-1} d.m. The Cd content dropped more markedly after supplementary soil fertilisation with $Mg(NO_3)_2$, but it was not statistically significant ($p < 0.05$). In relative terms the content of the heavy metal decreased by 21.1 % under the effect of soil application of Mg. Foliar application of magnesium did not much change the cadmium content in poppy seeds.

A similar trend was discovered in variants where cadmium was supplemented to the soil prior to sowing. The highest content of Cd in poppy seed (2.176 mg · kg^{-1}) was detected in the variant after foliar magnesium fertilisation (variant 6); its content was almost the same as in the control variant (Table 6). Soil application of $Mg(NO_3)_2$ significantly ($p \le 0.05$) reduced the content of cadmium in seeds, ie from 2.094 to 1.413 mg · kg^{-1}, ie by 32.5 %.

Conclusion

While the amount of Cd in plants grown in soil with a natural level of Cd increased after soil and foliar application of magnesium by 7.4 and 66.7 %, respectively, Mg fertilisation considerably reduced its content in the plant matter if the heavy metal was supplemented prior to sowing. Foliar nutrition with magnesium nitrate increased poppy seed yields much more than its soil application regardless of the soil level of Cd. Foliar application increased yields as compared with the magnesium-unfertilised variant both at a natural content of Cd and with intentional soil supplementation, ie by 5.9 % and 14.6 %, respectively. It was the very interaction between the increased content of soil

Cd and foliar Mg application that resulted in the highest poppy seed yields (10.94 g · pot^{-1}). Foliar Mg applications also had a positive effect on straw yields (empty capsule + 15 cm of stem). Soil application of Cd reduced straw yields regardless of Mg fertilisation. The magnesium dose, form of its application and cadmium supplementation of the soil had no significant effect on the morphine content.

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ODDZIAŁYWANIE DODATKU MAGNEZU I KADMU NA PLON I JAKOŚĆ MAKU (*Papaver somniferum* L.)

Abstrakt: W wazonowym doświadczeniu wegetacyjnym z makiem odmiany 'Opal' badano oddziaływanie magnezu stosowanego doglebowo (0,78 g Mg · wazon^{-1}) lub dolistnie (roztwór 3 %) w formie $Mg(NO_3)_2$ w warunkach naturalnej (0,14 mg Cd · kg^{-1}) oraz zwiększonej (1 mg Cd · kg^{-1}) zawartości kadmu w glebie na skład chemiczny roślin, plon nasion, zawartość morfiny w słomie oraz zawartość kadmu w nasionach.

Doświadczenie obejmowało sześć następujących wariantów: 1) N (kontrola), 2) N + $Mg(NO_3)_2$ doglebowo, 3) N + $Mg(NO_3)_2$ dolistnie, 4) N (kontrola) + Cd, 5) N + $Mg(NO_3)_2$ doglebowo + Cd, 6) N + + $Mg(NO_3)_2$ dolistnie + Cd.

Zawartość magnezu w roślinach w stadium DC 41 (wzrost wydłużeniowy łodygi) zwiększała się w wariantach nawożonych magnezem. Poziom Cd w roślinach rosnących na glebie z naturalną zawartością Cd wzrósł we wszystkich wariantach nawożonych magnezem do 0,29–0,45 mg Cd · kg^{-1} w porównaniu z 0,27 mg Cd · kg^{-1} w wariancie kontrolnym. Największą zawartość Cd w roślinach na glebie ze zwiększoną zawartością Cd stwierdzono w wariancie kontrolnym (1,29 mg Cd · kg^{-1}), podczas gdy w pozostałych wariantach poziom Cd zmniejszał się po zastosowaniu magnezu odpowiednio do 0,51 i 0,69 mg Cd · kg^{-1}. W stadium DC 41 plon suchej masy jednej rośliny wahał się nieregularnie od 2,16 do 3,82 g, a największą wartość osiągnął w wariancie z dodatkiem kadmu i azotanu(V) magnezu.

Plony nasion maku we wszystkich wariantach wahały się od 2,28 do 2,74 g nasion z rośliny i nie różniły się znacząco statystycznie.

Zawartość morfiny w słomie (puste główki + 15 cm łodygi) wahała się od 0,92 do 1,05 %, a wpływ magnezu lub kadmu był statystycznie nieistotny.

Przy naturalnej zawartości Cd w glebie, zawartości Cd w nasionach wahały się od 0,479 do 0,612 mg Cd · kg^{-1}, a różnice były statystycznie nieistotne. W wariantach, w których do gleby dodano Cd, jego zawartość w nasionach zwiększała się znacznie (1,413–2,176 mg Cd · kg^{-1}) w porównaniu z wariantami z naturalną zawartością Cd w glebie. Gdy Mg dodano do gleby ze zwiększoną zawartością Cd, stwierdzono, że poziom Cd w nasionach znacznie obniżył się w porównaniu zarówno z obiektami kontrolnymi, jak i z dolistnym stosowaniem magnezu.

Stosowanie Mg zwiększało jego zawartość w roślinach, ustabilizowało plony, a nie zwiększało zawartości Cd w nasionach maku, która wzrastała tylko po ściśle ukierunkowanym dodatku Cd do gleby.

Słowa kluczowe: mak, kadm, magnez, nawożenie doglebowe, dokarmianie dolistne