Original Paper

Effect of poppy (*Papaver somniferum* L.) fertilization with potassium and magnesium on the seed yield and its quality

Tomáš Lošák[1]*, Jakub Elbl[1], Antonín Kintl[2], Ladislav Varga[3], Ladislav Ducsay[3], Július Árvay[3], Reinhard W. Neugschwandtner[4], Johann Vollmann[4], Krzysztof Gondek[5], Monika Mierzwa-Hersztek[5], Lenka Demková[6], Pavel Čermák[7]

[1]*Mendel University in Brno, Czech Republic*
[2]*Agricultural Research, Ltd., Troubsko, Czech Republic*
[3]*Slovak University of Agriculture in Nitra, Slovak Republic*
[4]*University of Natural Resources and Life Sciences Vienna (BOKU), Tulln, Austria*
[5]*University of Agriculture in Krakow, Poland*
[6]*University of Prešov, Slovak Republic*
[7]*Crop Research Institute in Prague, Czech Republic*

Article Details: Received: 2022-05-10 | Accepted: 2022-05-30 | Available online: 2022-09-30

https://doi.org/10.15414/afz.2022.25.03.242-246

In a vegetation pot experiment we explored the effect of fertilizers with potassium (KCl; 0.9 g K_2O/6 kg of soil) and magnesium (ESTA Kieserite; 0.3 g MgO/6 kg of soil) applied together or separately to poppy on soil with good K and Mg supply on the seed yield, oil content and cadmium in the seed. Seed yields increased significantly after the application of KCl and ESTA Kieserite, respectively by 23.89% and 21.68%, as compared to the unfertilized control. Combined application of both fertilizers stimulated the yields significantly, i.e. by 15.26%. The seed oil content showed no significant changes among the treatments and ranged only between 42.1 and 43.6%. The pot production of oil in the fertilized treatments increased to 2.21–2.44 g/pot compared to 1.92 g/pot in the unfertilized control. The Cd content in seeds was very low, there were no differences among the treatments and it ranged only between 0.204 and 0.214 mg/kg fresh matter – FM (threshold level of 1.20 mg/kg wet weight). Therefore, the application of both KCl and ESTA Kieserite fertilizers can be recommended on soils well supplied with both nutrients.

Keywords: nutrition, KCl, ESTA Kieserite, oil, cadmium

1 Introduction

In recent years the importance of poppy (*Papaver somniferum* L.) production has increased because of the use of poppy seeds in food products (bakery). The Czech Republic has a very long tradition in the production of poppy seed and the country ranks among the most important producers and exporters of poppy seed in Europe (Lošák & Richter, 2004, 2004a). Characteristic of poppy is a short vegetation period and weak root system. In poppy, a balanced supply of all the macro- and microelements in the soil is necessary as it is positively reflected in yields and quality of production (Costes et al., 1976; Ramanathan, 1979). In the system of nutrition and fertilisation, potassium and magnesium, besides nitrogen, is worth of attention. According to Edelbauer & Stangl (1993) the nutrient removals of the shoot mass considering a plant density of 270000/ha amount to 92.7 kg K/ha (which is the highest uptake of all macroelements) and 15.3 kg Mg/ha. The share of seed is 8.0 kg potassium and 4.0 kg magnesium. Poppy straw is a big soil supplier of potassium. In the Czech Republic the consumption of K from mineral fertilizers has been low and insufficient on a long-term basis, currently it amounts to 7.2 kg K_2O/ha of agricultural land (Budňáková, 2021); magnesium has not been recorded. Hence we see an increasing proportion of land where the supply of potassium and magnesium is decreasing. Potassium (K) is an essential element in plant nutrition,

***Corresponding Author:** Tomáš Lošák. Mendel University in Brno, Zemědělská 1, 613 00, Brno, Czech Republic. e-mail: losak@mendelu.cz ORCID: https://orcid.org/0000-0002-6043-6960

and its ability to influence meristem growth, water status, photosynthesis and long distance transport of assimilates is well established. Magnesium (Mg) is an important macronutrient with a number of physiological functions in the plant. The importance of magnesium in the plant is in many ways connected with photosynthesis. It is the central atom of chlorophyll, and it activates enzymatic processes. Magnesium also favourably influences assimilation (Mengel & Kirkby, 2001).

Poppy is a crop susceptible to cadmium (Cd) accumulation in the seed. To guarantee food safety, the European Commission has set maximum levels of Cd and other contaminants in different food products; for poppy seed, a threshold level of 1.20 mg/kg wet weight (European Commission, 2021). Cadmium is considered as one of the most toxic heavy metals causing adverse health effects to the human body upon chronic intake (Vollmann et al., 2015; Vollmann & Lošák, 2016; Järup & Åkesson, 2009). The risk of Cd entering the plant is enhanced especially in areas where the soil pH value is low, where the content of organic matter is low and naturally where the content of Cd in the soil is high (Öborn et al., 1995). The uptake of Cd and other heavy metals may be affected by a broad spectrum of microbial communities (Saeed et al., 2021). Recently, there are studies which support the effect of mineralization combined with presence of microorganism *Agrobacterum fabrum* on the immobilization of Cd in the soil (Zafar-ul-Hye et al., 2020).

The aim of this study was to evaluate the effect of fertilizers with potassium and magnesium applied together or separately to poppy on soil with good K and Mg supply on the seed yield, content of oil and cadmium in the seed.

2 Material and methods

The vegetation pot experiment with spring poppy variety Maraton was established on 4 April 2018 in the outdoor vegetation hall of the Botanical Garden and Arboretum of Mendel University in Brno, Czech Republic. Mitscherlich vegetation pots were filled with 6 kg of medium heavy soil indicated as cambisol (the agrochemical properties are given in Table 1). The total content of Cd in the soil extract (*aqua regia*) was 0.18 mg/kg which is a low content.

Table 1 Agrochemical characteristics of the soil

$pH/CaCl_2$	mg/kg (Mehlich III)			
	P	K	Ca	Mg
6.81	95	179	2522	196
neutral	good	good	good	good

On the same day (4 April 2018) poppy was sown ca 0.5 cm deep into the soil. At the stage of the first pair of leaves (22 April 2018) the plants were thinned to 11 plants/6 kg of soil. At the same time more soil was carefully added to the height of the root collar. On 27 April 2018 the plants were additionally fertilized with nitrogen at a rate of 0.3 g N/pot in the form of calcium nitrate (15.5% N). On 7 May 2018 the plants were again thinned to the final number of 6 plants/pot and additionally fertilized with potassium and magnesium at the stage of 5 poppy leaves (application of dissolved fertilisers). Doses of nutrients: 0.9 g K_2O/pot in KCl (potassium chloride, muriate of potash, 50% K_2O) and 0.3 g MgO/pot in ESTA Kieserite (25% MgO, 50% SO_3). All the nutrients are water soluble. There were 4 treatments (Table 2) and each treatment was grown in 4 replications. The fungicide Ridomil Gold (5 g/2 l water) was also applied. On 14 May 2018 all the treatments were fertilized with nitrogen in calcium nitrate to a total rate of 0.9 g N/pot. The stage of flowering began on 13 June 2018 and maturing began on 16 July 2018. During vegetation the plants were kept free of weeds and were watered on a regular basis. Poppy plants were harvested at the stage of full maturity on 27 July 2018.

Table 2 Treatments of the pot experiment

Treatment no.	Type of fertilizer	Dose of K_2O/MgO (g/pot)
1	unfertilized control	0/0
2	KCl	0.9/0
3	ESTA Kieserite	0/0.3
4	KCl + ESTA Kieserite	0.9/0.3

The seed yields were assessed after harvest. Using standard laboratory methods in an accredited laboratory (ČSN EN ISO 11885) the content of fat was determined gravimetrically using water-cooled Soxhlet's extractor by direct sample extraction with petrolether (Garcia-Ayuso & Luque de Castro, 1999). A multivariate study of the performance of a microwave-assisted Soxhlet extractor for olive seeds was used (López-Mesas et al., 2007). Cadmium in the seeds was determined after microwave decomposition by ICP-OES.

The yields were processed statistically by SW Statistica 12 (Dell Software, Round Rock, Texas, USA), using the method of analysis of variance (ANOVA) followed by post-hoc Tukey test at p <0.05. In the tables the differences are marked with letters (a, b, c), and different letters indicate significant differences among the variants.

3 Results and discussion

3.1 Seed yield

The soil nutrient content is assessed according to the following categories: low – satisfactory – good – high – very high. On this basis we adjust the rates of the respective nutrients, or fertilizers, what is very important especially at the present time when the prices of mineral fertilizers are soaring. If the nutrient content is high and very high the nutrient is not applied as a fertilizer. In the other cases fertilization is necessary; even if the supply is good we must apply what is called maintenance fertilization, i.e. apply the same amount of nutrients as is taken per 1 ha due to harvesting the crop.

In 2018, due to the weather conditions in the Czech Republic, on the majority of land the poppy producers faced serious problems caused by water deficit – drought. Either the poppy plants did not germinate at all or after germination they dried up. Therefore many farmers sowed poppy over again or they ploughed in the plants and went for an alternative crop.

Our pot experiment was conducted according to the methodology with no complications. Even though the pots were watered regularly, the weather – high temperatures during most of the vegetation season were not favourable for the poppy plants and generally resulted in lower yields. In terms of yields the poppy plants responded positively to the applied nutrients and/or fertilizers; see Table 3. The seed yields increased statistically significantly (Table 3) with all the fertilizers by 15.26–23.89% compared to unfertilized control (treat. 1). The application of KCl (treat. 2) increased yields by 23.89% as against the unfertilized control. This marked stimulation in seed yields can be attributed both to the positive reaction of poppy to potassium application when its supply in the soil was good only and the synergic effect of K on the uptake and utilisation of NO_3^- from the nitrogenous fertiliser $Ca(NO_3)_2$.

Also Lošák et al. (2005) discovered that applications of KCl stimulated poppy seed yields by 4.0–11.9%. Likewise Gupta et al. (1978) reported that an application of N-P-K in a 2 : 1 : 1 ratio was positively reflected, among others, in higher poppy seed yields and morphine concentration. As opposed to our results Kahar & Nigam (1990) did not discover a statistically significant effect of potassium fertilisation on yields in two-year field trials. The application of ESTA Kieserite (treat. 3) increased the yields by 21.68% as against the unfertilized control. It is assumed that the fertilizer provided both water-soluble magnesium and sulphur which increases the utilization of nitrogen (Lošák & Richter, 2003). However if both fertilizers were applied at the same time (treat. 4), yields did increase significantly by 15.26%, but only in comparison with the unfertilized control. The reason may be both a higher soil salinity from the two fertilizers and mutual antagonism between K and Mg. Garcia et al. (1999) confirmed that magnesium uptake by the plant is also affected by the antagonistic effect of K.

3.2 Oil content in seeds (%)

Although the oil content of poppy seed is not the crucial parameter for sales, plant nutrition and fertilization may stabilize or increase its content as was confirmed e.g. in oilseed rape (Lošák & Richter, 2003) or false flax (Lošák et al., 2010). In our experiment we did not see statistical changes in the oil content among the treatments, the content ranged only between 42.1 and 43.6% (Table 4). In pot production the oil content (g/pot) increased in the

Table 3 Seed yield results (g/pot)

Treatment no.	Type of fertilizer	Seed yield (g/pot)	Seed yield (rel. %)
1	unfertilized control	4.52 a	100.00
2	KCl	5.60 c	123.89
3	ESTA Kieserite	5.50 c	121.68
4	KCl + ESTA Kieserite	5.21 b	115.26

Treatments indicated with the different letters (a, b, c) in individual columns differ statistically significantly at the level of significance $p < 0.05$

Table 4 Content of oil in poppy seeds (%)

Treatment no.	Type of fertilizer	Oil content in seeds (%)	Oil production (g/pot)
1	unfertilized control	42.5 a	1.92
2	KCl	43.6 a	2.44
3	ESTA Kieserite	42.1 a	2.31
4	KCl + ESTA Kieserite	42.4 a	2.21

Treatments indicated with the different letters (a, b) in individual columns differ statistically significantly at the level of significance $p < 0.05$

Table 5 Content of cadmium in poppy seeds (mg/kg fresh matter)

Treatment no.	Type of fertilizer	Cadmium content in seeds (mg/kg fresh matter)
1	unfertilized control	0.214 a
2	KCl	0.204 a
3	ESTA Kieserite	0.212 a
4	KCl + ESTA Kieserite	0.214 a

Treatments indicated with the different letters (a, b) in individual columns differ statistically significantly at the level of significance $p < 0.05$

fertilized treatments to 2.21–2.44 g/pot as compared to 1.92 g/pot in the unfertilized control (Table 4).

3.3 Cadmium content in seed

Poppy with low cadmium contamination of the harvest product is important for ensuring poppy-food safety; consequently, soil quality and agronomic practices appear as key factors for achieving that goal. Some years ago false information spread among Czech farmers that magnesium fertilization could increase the Cd content in poppy seeds. This false argument was disproved by a number of pot and field experiments with NPKMg fertilizers (Lošák, Richter, not published). In our experiment the Cd content was very low, it ranged only between 0.204 and 0.214 mg/kg FM (Table 5) and was not affected by fertilization. This Cd-level was far below the maximum allowed in the present EU regulation (European Commission, 2021). Richter and Lošák (2006) reported that the application of two rates of Mg decreased the Cd content in poppy seed from 0.123 mg/kg (unfertilized control) to 0.097–0.099 mg/kg (i.e. by ca 20%). The uptake of Cd is enhanced by the acid soil reaction (pH), and was not anticipated in our experiment as the soil reaction was neutral (pH 6.81).

4 Conclusions

The effect of fertilization of poppy with KCl and ESTA Kieserite on soil with a good supply of both nutrients was positive; it increased seed yields by 21.68–23.89% as against the unfertilized control even when the two fertilizers were applied separately. In the case of ESTA Kieserit it is assumed that also sulphur, which is an important macroelement for oil plants, had a positive effect on yields. Combined application increased yields by only 15.26%. Fertilization did not affect the oil content nor the Cd content in seed. The content of Cd in seed was much below the threshold level of 1.20 mg/kg wet weight. Applications of fertilizers containing potassium and magnesium can be recommended also on soils well supplied with these nutrients and the rate of the nutrients (fertilizers) can be calculated on the basis of the consumption normative and poppy seed yields.

Acknowledgments

Supported by K+S Minerals and Agriculture GmbH and by the Ministry of Agriculture of the Czech Republic, institutional support MZE-RO1722.

We would like to thank the staff of the Botanical Garden and Arboretum of Mendel University in Brno for their help with the experiment.

References

Budňáková, M. (2021). *Personal Information.* The Ministry of Agriculture of the Czech Republic.

Costes, B. et al. (1976). Mineral Nutrition in Papaver *Somniferum* L. *Physiologia plantarum*, 36(2), 201–207. https://doi.org/10.1111/j.1399-3054.1976.tb03936.x

ČSN EN ISO 11885. Zdroj: https://standards.iteh.ai/catalog/standards/cen/80575ed7-7a08-480c-b5f6-6750c2664fe3/en-iso-11885-2009

Edelbauer, A., & Stangl, J. (1993): Nutrient Uptake by Waldviertler Graumohn (*Papaver somniferum*, L.) during the vegetative period. *Bodenkultur*, 44(1), 15–27.

European Commission. (2021). Commission Regulation (EU) No 2021/1323 of 10 August 2021 setting maximum levels of cadmium for certain foodstuffs. *Official Journal of the European Union*, L288/13 of 11.08.2020.

Garcia, M. et al. (1999). Effect of various potassium-calcium ratios on cation nutrition of grape grown hydroponically. *Journal of Plant Nutrition*, 22(3), 417–425. https://doi.org/10.1080/01904169909365639

Garcia-Ayuso, LE., & Luque de Castro M (1999). A multivariate study of the performance of a microwave-assisted Soxhlet extractor for olive seeds. *Analytica Chimica Acta*, 382, 309–316. https://doi.org/10.1016/S0003-2670(98)00795-8

Gupta, R. et al. (1978). *Status Report on Opium Poppy*. ICAR, New Delphi (Memo).

Järup, L., & Åkesson, A. (2009). Current status of cadmium as an environmental health problem. *Toxicology and Applied Pharmacology*, 238(3), 201–208. https://doi.org/10.1016/j.taap.2009.04.020

Kahar, L., & Nigam, K. (1990). Response of opium poppy (*Papaver somniferum*, L.) to phosphorus and potassium. *Indian Journal of Agricultural Science*, 60(6), 417–418.

Lopéz-Mesas, M. et al. (2007). Alternative methods for the wool wax extraction from wool scouring wastes. *Grasas y Aceites*, 58(4), 402–407. https://doi.org/10.3989/gya.2007.v58.i4.453

Lošák, T., & Richter, R. (2003): The influence of nitrogen and sulphur on the yield and oil content of winter rape. *Fertilizers and Fertilization*, 4(17), 160–168.

Lošák, T., & Richter, R. (2004). Split nitrogen doses and their efficiency in poppy (*Papaver somniferum* L.) nutrition. *Plant, Soil and Environment*, 50(11), 484–488. https://doi.org/10.17221/4062-PSE

Lošák, T., & Richter, R. (2004a). Split Application of Nitrogen in the Poppy (*Papaver somniferum*, L.) Nutrition. *Oilseed Crops*, 25(1), 145–150.

Lošák, T. et al. (2005). Potassium and its forms in the nutrition of poppy (*Papaver somniferum*, L.). *Fertilizers and Fertilization*, 3(24), 379–383.

Lošák, T. et al. (2010). Influence of combined nitrogen and sulphur fertilization on false flax (*Camelina sativa* [L.] Crtz.) yield and quality. *Acta Alimentaria*, 39(4), 431–444. https://doi.org/10.1556/aalim.39.2010.4.5

Mengel, K., & Kirkby, E.A. (2001). *Principles of Plant Nutrition*. 5th ed., London, Kluwer Academic Publishers.

Öborn, I. et al. (1995). A field study on the influence of soil pH on trace element levels in spring wheat (*Triticum aestivum*), potatoes (*Solanum tuberosum*) and carrots (*Daucus carota*). *Water Air and Soil Pollution*, 85, 835–840. https://doi.org/10.1007/BF00476933

Ramanathan, V. S. (1979). Effect of Micronutrients on the Yield of Opium and Its Morphine Contents in Opium Poppy. *Indian Journal of Agricultural Research*, 13, 85.

Richter, R., & Lošák, T. (2006). Can magnesium nutrition influence the yielding and chemical composition of straw and seeds of poppy (*Papaver somniferum* L.)? *Ecological Chemistry and Engineering*, 13(9), 965–972.

Saeed, Q. et al. (2021). Rhizosphere Bacteria in Plant Growth Promotion, Biocontrol, and Bioremediation of Contaminated Sites A Comprehensive Review of Effects and Mechanisms. *International Journal of Molecular Sciences*, 22(19), 10529. https://doi.org/10.3390/ijms221910529

Vollmann, J. et al. (2015). Soybean cadmium concentration: validation of a QTL affecting seed cadmium accumulation for improved food safety. *Euphytica*, 203(1), 177–184. DOI:10.1007/s10681-014-1297-8

Vollmann, J., & Lošák, T. (2016). Reduction of Cadmium Uptake in Crop Plants: a Case Study from Soybean. In *Proceedings from International Conference SOIL – the non-renewable environmental resource.* Brno: Mendel University in Brno (pp. 340–346).

Zafar-ul-Hye, M. et al. (2020). Effect of Cadmium-Tolerant Rhizobacteria on Growth Attributes and Chlorophyll Contents of Bitter Gourd under Cadmium Toxicity. *Plants*, 9(10), 1386, https://doi.org/10.3390/plants9101386