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II Potassium Sulphate and Potassium Chloride in the Nutrition of Poppy (*Papaver somniferum* L.) in Relation to Nitrogen Supply

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Abstract

A pot trial was carried out to study the effect of varied K and N nutrition on seed yields and concentration of the alkaloid morphine in the straw of poppy (*Papaver somniferum* L. var. Buddha) grown in soil low in available potassium. Both K and N were supplied to the pots which contained 9.5 kg soil, at two levels, (K_1, K_2 and N_1, N_2), K in the form of K_2SO_4 (SOP) or KCl (MOP) and N in the form of ammonium nitrate (NH_4NO_3). Potassium was applied at rates of 0.845 (K_1) and 1.69 g K_2O per pot (K_2), equivalent to 56 and 112 kg K_2O/ha, and nitrogen at 0.9 (N_1) and 1.5 g N per pot (N_2), equivalent to 60 and 100 kg N/ha respectively. The relative effectiveness of both potassium fertilizer sources in increasing seed yields was greater in treatments with the lower level of nitrogen supply (N_1), but in terms of production, higher seed yields were obtained at the higher N supply (N_2). At the lower level of N supply (N_1), seed yields increased significantly after the application of SOP and MOP by 7.3-13.6 per cent and 15.8-21.5 per cent, respectively, as compared with the control without K fertilizer supply. At the higher level of nitrogen supply (N_2) only the lower rates of applied K (K_1) significantly increased yields; i.e. SOP by 9.9 per cent and MOP by 8.8 per cent, compared to the control. At each level of N supply, with the exception of one treatment (N_2 K_2 (SOP)), neither the level nor form of K supply resulted in any significant difference between morphine concentrations in the poppy straw (empty ripe capsule +15 cm of stem). At the lower level of nitrogen, the morphine content ranged between 2.11 and 2.21 per cent and at the higher level between 2.04 and 2.40 per cent.

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Commercial field of poppy plants in the Czech Republic. Photo by Tomáš Lošák.

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Introduction

The Czech Republic has a long tradition of poppy seed production for pharmaceutical purposes, and ranks amongst the most important producers and exporters of poppy seed in Europe (Vašák *et al.*, 2003), with 88 per cent of production exported to Austria, Russia, Germany, Poland and Holland. The average consumption of poppy seed in the Czech Republic as a foodstuff is approximately 0.3 kg/capita/year. The acreage sown has been gradually increasing to ca. 70,000 ha. Unfortunately, however, seed yields fluctuate considerably, ranging from 0.46 and 0.92 mt/ha (Mottl, 2005). Although seed production is of primary importance when growing poppy, farmers can also benefit financially from harvested poppy straw (empty ripe capsule +15 cm of stem) for pharmaceutical purposes (Company Zentiva). Poppy seeds contain alkaloids of which the most important is morphine. The morphine content in the capsule is affected by a number of factors:

- selected variety = genetic potential (varieties Buddha, Lazur: 1-2 per cent of morphine)
- harvesting technology (the capsule itself contains most of the morphine and increasing amounts of stems dilute the morphine content)
- weather during harvest (morphine is washed out by rain)
- level of mineral nutrition

Characteristic of the poppy crop is its short vegetation period and weak root system. If it is to grow successfully, a balanced supply of all the plant macro- and micro-nutrients in the soil is necessary, as reflected in yields and

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quality of production (Costes *et al.*, 1976, Ramanathan, 1979). Sodium (Na) favours poppy development (flowers and capsules), increasing both the content and output of morphine and should therefore be introduced whenever possible in the fertilizing of poppy crops (Costes *et al.*, 1976). Of the major plant nutrients potassium, together with nitrogen, are worthy of attention. According to Edelbauer *et al.* (1993), a stand of 270,000 poppy plants/ha absorbs 92.7 kg K/ha, which is the highest uptake of all the macro plant nutrients. As the seeds absorb only 8 kg K/ha, this means that by far the greatest proportion of potassium absorbed by the plant is concentrated in the vegetative organs.

The purpose of the work was to explore the effect of a combined supply of two rates of N and K application (with two K forms - K_2SO_4 and KCl) on seed yield and morphine concentration in poppy straw.

Table. 1. Soil pH and nutrient availability (mg/kg dry soil).

pH ($CaCl_2$)	P	K	Ca	Mg	S-SO_4^{2-}
			-mg/kg-		
7.6	72	94	2,074	111	5
Alkali	satisfactory	low	good	satisfactory	low

Table 2. Plan of the experiment.

No.	K treatment	K source	N levels (NH_4NO_3)		K levels	Supply of S or Cl
			N_1 (g N/pot)	*N_2 (g N/pot)*	*g K_2O/pot*	*g/pot*
1	K_0	control	0.9	1.5	0	0
2	K_1	SOP	0.9	1.5	0.845	0.3
3	K_2	SOP	0.9	1.5	1.69	0.6
4	K_1	MOP	0.9	1.5	0.845	0.6
5	K_2	MOP	0.9	1.5	1.69	1.2

Note: N and K_2O levels in pots are equivalent to application rates per hectare as follows: 0.9 and 1.5 g N/pot are equivalent to 60 and 100 kg N/ha; 0.845 and 1.69 g K_2O/pot are equivalent to 56 and 112 kg K_2O/ha.

Materials and methods

The pot trial was set up in spring 2007 at the experimental site of Mendel University, Brno. Plastic pots were filled with 9.5 kg of medium-heavy soil, characterised as fluvial soil. Soil pH and available nutrient contents are given in Table 1. With the exception of sulphate sulphur, available nutrients were measured using Mehlich III extractant.

Various fertilizers at the amounts given in Table 2 were applied to the soil by watering one week prior to sowing. Potassium was supplied in the form of K_2SO_4 (SOP) or KCl (MOP) at rates of 0.845g K_2O/pot (K_1) and 1.69 g K_2O/pot (K_2), and nitrogen as ammonium nitrate (NH_4NO_3) at 0.9 g N/pot (N_1) and 1.5 g N/pot (N_2).

The new variety "Buddha" which has a high content of morphine in the poppy straw (i.e. 1-2 per cent), was sown on the 2nd April 2007. Four plants were grown per pot, each treatment being replicated five times (five pots). During the vegetative stage the plants were kept free of weeds, watered with demineralised water and protected with the insecticide Karate 2.5 EC against beet aphid (*Aphis fabae*). The plants were harvested at full maturity on the 23rd July 2007 and seed yield measured in each treatment. The alkaloid morphine in the straw was determined polarographically by means of morphine hydrochloride using the polarograph OH-102 according to the method used at the Opava research institute. Yield data was processed statistically using the method of variance analysis and Tukey's test at a 99 per cent level of significance. In Table 3, differences are marked with letters (a, b, c), which indicate highly significant differences among the treatments.

Results and discussion

At the lower N supply (N_1), the seed yields significantly increased for both rates of potassium in comparison to the control (Table 3). For both sources of potassium, the lower application (K_1) was superior to K_2, possibly due to salinity problems that may have developed in the pots.

Similar results were obtained with N_2 treatments, but at a higher level of seed yields, the higher N application significantly improved seed yields at both levels and sources of K, as well as in the 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 is low, and the synergistic effect of K on the uptake and utilization of nitrate (NO_3^-) directly from the

Table 3. Seed yields and morphine content in straw of poppy plants (var. Buddha) in relation to two levels (and two forms) of K at two levels of N supply.

Treatment No.	K level	Seed yield			Alkaloid morphine in poppy straw		
		N_1	N_2		N_1	N_2	
		-g/pot-			-%-		
1	K_0	7.80 a	10.13 a	**	2.18 a	2.35 b	**
2	$K_{1\ SOP}$	8.86 c	11.13 b	**	2.20 a	2.33 b	**
3	$K_{2\ SOP}$	8.37 b	10.49 a	**	2.11 a	2.04 a	NS
4	$K_{1\ MOP}$	9.48 d	11.02 bc	**	2.20 a	2.40 b	**
5	$K_{2\ MOP}$	9.03 dc	10.69 ab	**	2.21 a	2.24 b	NS

Statistical significance is indicated at a 99 per cent level, i.e. P≤0.01. Treatments with identical letters in the columns (e.g. a) show statistically insignificant differences. Treatments marked with (**) show significance between N levels.

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nitrogenous fertilizer (NH_4NO_3). Nitrate is also likely to have resulted from the ammonium (NH_4) component formed as a consequence of nitrification due to the high pH of the soil. These findings of a response of poppy to K fertilizer agree with results of Lošák *et al*. (2005), who observed that applications of K_2SO_4 and KCl in K-deficient soil stimulated poppy seed yields by 18-25.1 per cent and 4-11.9 per cent, respectively. Likewise, Gupta *et al*. (1978), reported that an application of N-P-K in a 2:1:1 ratio resulted, among other things, in higher poppy seed yields and morphine concentrations in the straw. In contrast to our results, Kadar *et al*. (1990) did not find a statistically significant effect of potassium fertilization on yields in two-year field trials.

In our experiment using the variety Buddha, MOP was superior to SOP in dry matter yield production of poppy seed in three of the four treatments, the exception being (K_1 N_2), the lower level of K at the higher level of N. Differences in response between K forms in poppy seed yield increase appears to be variety dependent, the variety Opal - in contrast to Buddha - showing a preferential response to SOP (Lošák *et al*. 2005). From the farmer's viewpoint, the use of MOP is more attractive because of its lower cost. This can be used to the farmer's benefit because many soils in the Czech Republic are K responsive and the findings presented here suggest that application of MOP to the morphine-rich poppy variety Buddha, increases seed yield and, at the same time, provides a financially lucrative by-product in the poppy straw. The use of SOP may of course play a role on S-deficient soils and with other varieties of poppy.

A major trait of the Buddha variety is the high concentration of the alkaloid morphine in the poppy straw (empty ripe capsule +15 cm of stem). In all treatments in the experiment reported here, this morphine concentration

Poppy plants growing outdoors in pots at the experimental site at Mendel University. Photo by Tomáš Lošák.

exceeded the average value of the Buddha variety. Morphine concentrations for all treatments were within a relatively narrow range between 2.04 and 2.40 per cent. With the exception of only one treatment (K_2 N_2 SOP), which was significantly lower, there were no significant effects of K level or K form on morphine concentration. For N, of the five treatments, three were significantly higher at the higher N level. It should also be taken into account that since the straw yields were also likely to be increased at the higher N supply, total morphine production would also be correspondingly increased. Conflicting results as to the effects of fertilizer application on morphine contents of poppy have been reported elsewhere. Kahar *et al*. (1990) did not find any increase in morphine content in two-year field trials with a combined application of four levels of phosphorus and three levels of potassium. In contrast, Schrodter (1965), reported that phosphorus and potassium were factors limiting the increase in the morphine content in capsules at a medium level of nitrogen fertilization (50–60 kg N/ha). The effect of increasing nitrogen nutrition in raising the morphine content frequently reported in the literature (Lošák, Richter, 2004) was not demonstrated with any certainty in the present experiment.

Conclusion

In the Czech Republic at the present time it is necessary to fertilize about 40 per cent of the acreage of agricultural land (1,200,000 ha) with potassium because K soil supply is insufficient. Poppy plants are an important market crop for the farmers and in terms of plant macro-nutrients, the crop has the highest fertilizer demand for potassium. It is also, of course, necessary to consider this in relation to the harmonious nutrition of the crop with other plant nutrients.

In the pot experiment reported here, raising the N level to an equivalent of

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100 kg N/ha increased seed yields and morphine content of the straw. The application of potassium fertilizers significantly increased seed yield but did not affect morphine content in the straw. In a soil of low K availability, the addition of potassium at equivalent levels of 56 kg K_2O/ha significantly improved seed yield at both low N (60 kg/ha) and high N (100 kg/ha) supply. No significant contribution to morphine concentration of poppy straw was found following the application of potassium. These findings suggest the use of N and K_2O at a rate of application of at least 100 and 56 kg of nutrient/ha respectively for optimum yield and morphine content.

Comparing the two sources of K, MOP was, in general, superior to SOP in cultivation of the variety Buddha in terms of seed yield. This finding in relation to its lower cost makes it the more attractive choice in the cultivation of this morphine-rich variety of poppy for seed production, as well as for the financially lucrative by-product of the poppy straw.

It is recommended that this experiment should be repeated again in the field, primarily to overcome possible problems of salinity associated with the pot experiment.

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