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Management of Poppy (*Papaver somniferum* L.) Stand Height using Growth Regulators

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Abstract

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The possibility of reduce the length of poppy plants and their risk of lodging by applying selected plant growth regulators and effects on the plant and yield were studied in field experiments during 2010–2012. Statistically significant reduction was achieved only with ethephon (576 g a.i./ha) in all experimental years. In 2010 reduction for metconazole (60 g a.i./ha) was recorded. In 2012, ethephon at rates of 576 and 288 g a.i./ha prevented significantly poppy lodging. The 576 g a.i./ha rate was phytotoxic and decreased yield. The commonly used 576 g a.i./ha rate diminished heights by 16–20 cm in all experimental years and significantly reduced lodging in 2012, but decreased yields in two of the 3 years.

Keywords: chlormequat chloride; ethephon; metconazole; difenoconazole; paclobutrazol; phytotoxicity; lodging

Plant growth regulators (PGRs) are synthetic compounds used to reduce shoot length of plants. This is achieved primarily by diminishing cell elongation but also by decreasing cell division. In their effect on the morphological structure of plants, PGRs are antagonistic to gibberellins and auxins, the plant hormones primarily responsible for shoot elongation (Rademacher 2000).

The first synthetically derived PGR applied to wheat, chlormequat chloride (CCC), had been found to decrease height and increase stem diameter (Tolbert 1960). With cereal crop varieties in the 1960s being predominantly tall in stature, subsequent studies focused on the ability of CCC to reduce lodging (Lowe & Carter 1970). Another PGR, ethephon, achieved similar results and was widely tested in cereals during the 1980s (Nafziger *et al.* 1986).

With breeding of cereals reducing the tendency to lodge, subsequent studies largely focused on earlier application of PGRs to influence yield components in wheat and barley. More recently, with a trend towards earlier sowing dates and general adoption of complete crop management packages, in particular higher nitrogen and fungicide inputs, crop lodging has again become more problematic and the use of PGRs commonly beneficial (Rademacher 2000). New PGRs, termed by Grossmann (1992) as the second (in particular triazoles) and third (acylcyclohexanedione) generation, are now applied to a number of agricultural and horticultural crops to reduce vegetative growth and potentially modify yield, its components, and quality.

An array of other compounds with growth-regulating effects is used in cereals and oil crops. The most widely used preparations in oilseed rape are metconazole and tebuconazole (Balodis & Gaile 2009), which are applied in autumn to improve overwintering and in spring to reduce stand height.

Lovett and Campbell (1973) studied the effects of three growth regulators – paclobutrazol, mepiquat chloride, and CCC – on sunflower plant height, yield, and number of achenes in flower heads. Mepiquat chloride and paclobutrazol reduced plant height after application until maturity. The height reduction was very pronounced, ranging from 9.5% to 11.7% of the control and was due to shortening of internodes length.

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Koutroubas *et al.* (2004, 2014) studied the effects of foliar application of paclobutrazol, mepiquat chloride, and CCC in single or double applications on sunflower plant morphology, growth, achene yield, and oil content. They determined that paclobutrazol and mepiquat chloride under a single application scheme can reduce plant height in sunflowers without adverse effects on achene and oil yields, thereby providing a basis for reducing the risk of plant lodging. Spitzer *et al.* (2011) found similar results also in sunflower. Elkoca and Kantar (2006) investigated the effects of different doses of mepiquat chloride on growth, lodging control, seed yield, and yield parameters in pea (*Pisum sativum* L.) under field conditions in Turkey. Application rates of 25, 50, 75, and 100 g a.i./ha significantly reduced stem height, increased stem width, and thereby reduced the tendency of the crop to lodge.

There is very little research on the possibilities of using PGRs in poppy. The only substance currently approved for use with poppy in the Czech Republic is metconazole, primarily used as a fungicide, however affecting plant growth, too.

Lodging in poppies results in losses in capsule and seed yield (Kumar *et al.* 2010), and in Tasmania annual losses have been estimated at 10% of the total crop. The height of capsules from lodged plants is lower than are the fronts of harvesters and so these capsules remain unharvested.

The objectives of our work were to determine whether it is possible by applying selected PGRs to reduce the length of poppy plants and thus their risk of lodging and whether this would have negative effects on the plant and yield.

MATERIAL AND METHODS

The location where the field experiments were conducted (49°17'13.708''N, 17°22'13.296''E) lies among the most fertile lands in the Czech Republic. It is in a warm and slightly humid area with mean annual temperature of 8.7°C and total annual precipitation of 599 mm. Conventional soil preparation was used for the experiments in all experimental years (soil tillage in autumn and smoothing and sowing in spring).

The experiments were conducted during 2010–2012. Fields were sown with the Maraton variety using an Amazone combination seed drill and sowing rate of 1.2 kg/ha (2010 – 66 plants/m^2, 2011 – 58 plants/m^2, and 2012 – 63 plants/m^2). Plot size was 10 m^2 and the plots were randomly arranged and repeated 4 times. The substances used, their combinations, and BBCH stages are presented in Table 1. Treatments were applied using a small-plot backpack sprayer based on compressed air, water rate of 300 l/ha, air pressure 0.3 MPa and nozzle type Lechler LU 120-02. Average temperatures by the application were 16.2°C in 2010, 18.2°C in 2011, and 19.4°C in 2012. Plant height before harvest (of 10 randomly selected plants on the plot), seed yield in t/ha corrected to 8% moisture (harvested whole plot), and phytotoxicity (visual

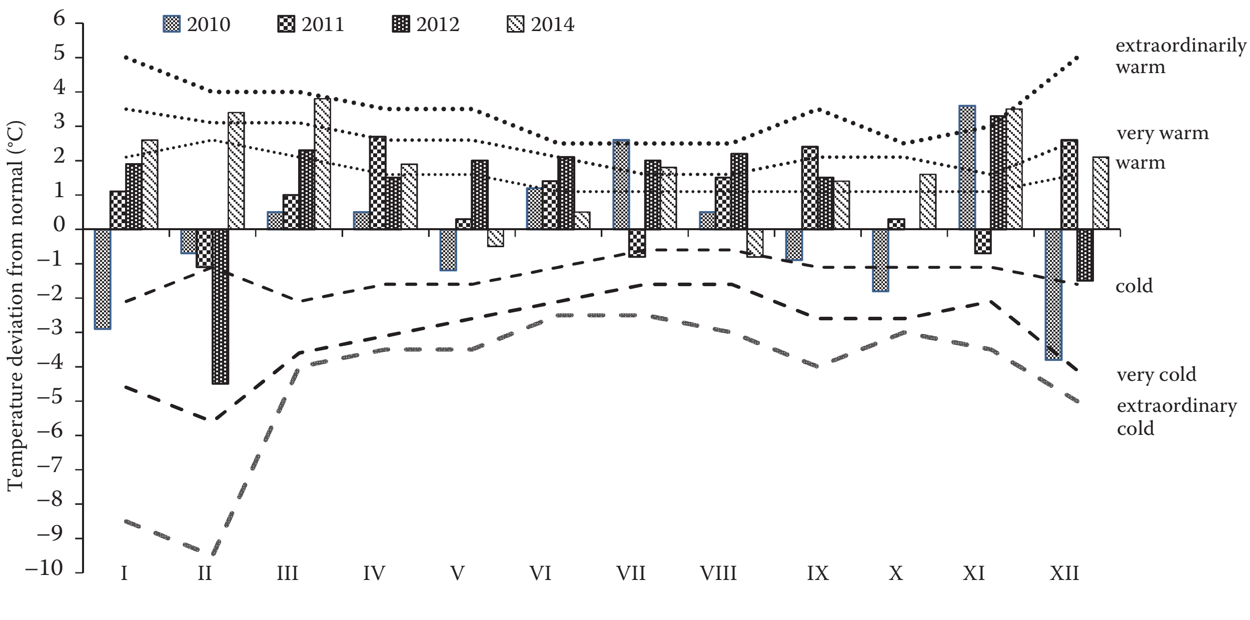

Figure 1. Temperature 2010–2014

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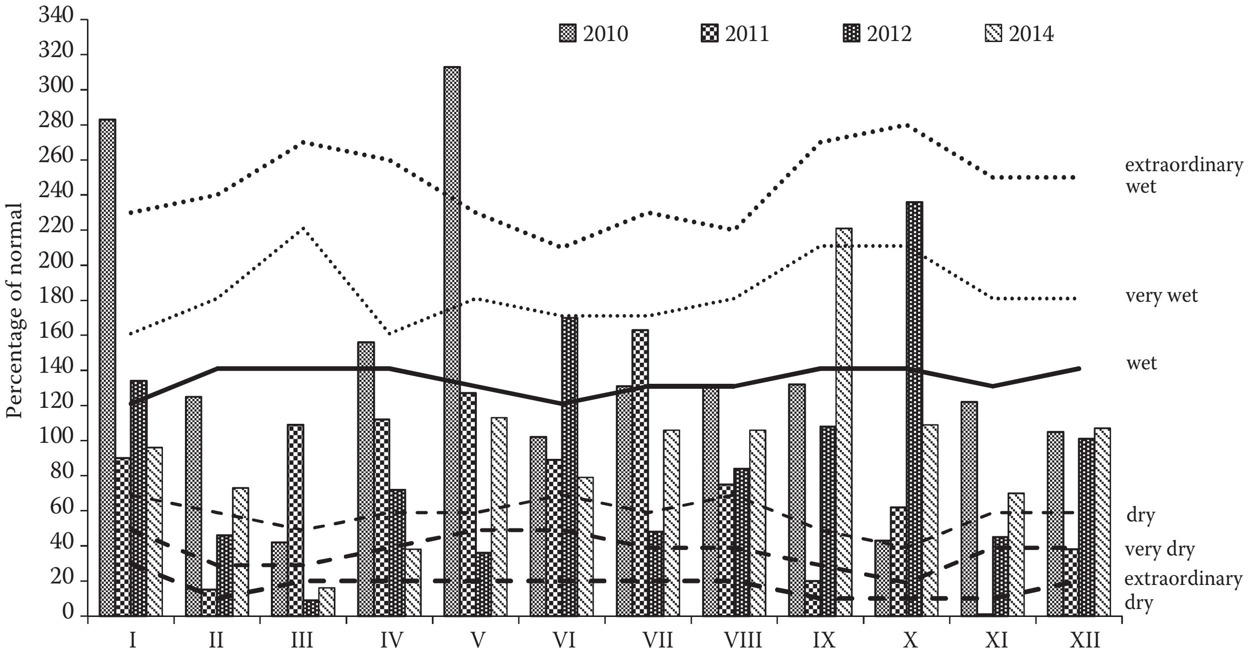

Figure 2. Precipitation 2010–2014

assessment of the whole plot) to poppy were measured. Phytotoxicity was determined as the percent of damaged plants vs the control. Lodging occurred only in 2012 and could be assessed as the proportion of plot area with lodging, denoting lodged plants as those bent more than 45° towards the ground. Grain was harvested using a combine harvester. The entire experimental area in all years was treated at pre-emergence using the herbicide mesotrione (120 g a.i./ha). Nitrogen fertilisation was 60 kg/ha N at BBCH stage 12–14. Meteorological data are summarised in Figures 1 and 2. The data on plant height, yield, phytotoxicity (% dry buds), and lodged area were analysed statistically using Statistica 7.0 (2013) software for analysis of variance (ANOVA). Subsequently, the differences among mean values were evaluated using Tukey's test.

RESULTS

The results are summarised in Table 1.

In 2010, difenoconazole (250 g a.i./ha) + paclobutrazol (125 g a.i./ha) and metconazole (60 g a.i./ha) reduced poppy height only at higher application rates. For ethephon (288 and 576 g a.i./ha), height was reduced at both rates but there was strong phytotoxicity. Poppy heads were deformed. Some heads did not develop at all and remained at the budding stage. At the higher rate of ethephon (576 g a.i./ha), this phytotoxicity led to reduced yield compared to the control. Difenoconazole (250 g a.i./ha) + paclobutrazol (125 g a.i./ha) and metconazole (60 g a.i./ha) did not display phytotoxicity, and their application resulted in higher yields at both rates of difenoconazole (250 g a.i./ha) + paclobutrazol (125 g a.i./ha) and at the lower rate of metconazole (60 g a.i./ha).

In 2011, the plants had diminished reactions to PGR application. The highest application rate for ethephon (576 g a.i./ha) resulted in the greatest height reduction – by 16 cm compared to the control. This reduction was accompanied by strong phytotoxicity which manifested itself identically as in the previous year and also affected yield, although not as strongly as in 2010. For metconazole (60 g a.i./ha), no growth reduction was recorded at either application rate. No phytotoxicity was recorded and yield was positively affected compared to the control.

Application of difenoconazole (250 g a.i./ha) + paclobutrazol (125 g a.i./ha) at both rates resulted in slight height reduction of 3–7 cm compared to the control without any negative effect on yield or determined phytotoxicity.

In 2012, the plants reacted similarly as in 2011. The highest application rate for ethephon (576 g a.i./ha) resulted in the greatest height reduction. This reduction was again accompanied by strong phytotoxicity which manifested itself identically as in 2011. The

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Table 1. Effect of growth regulators on plant height, yield, phytotoxicity, and lodging for 2010–2012

	Application rate (g a.i./ha)	Plant height		Yield		Dry buds (%) BBCH 61–63	Lodged area (%) of plots before harvest
		cm	diff. (cm)	(t/ha)	diff. (%)		
2010							
Control		85		0.59		0	
Ethephon	576	65	–20**	0.32*	55	35**	
Ethephon	288	75	–10*	0.64	109	15**	
Metconazole	60	65	–20**	0.51	88	0	
Metconazole	30	85	0	0.83*	141	0	
Paclobutrazol+difenoconazole	125+250	65	–20**	0.68	117	0	
Paclobutrazol+difenoconazole	62.5+125	85	0	0.69	118	0	
2011							
Control		130		2.12		0	
Ethephon	576	114	–16*	2.00	94	15**	
Ethephon	288	126	–4	2.03	96	5	
Metconazole	60	130	0	2.29	105	0	
Metconazole	30	132	2	2.25	102	0	
Paclobutrazol+difenoconazole	125+250	128	–2	2.48*	113	0	
Paclobutrazol+difenoconazole	62.5+125	125	–5	2.44	111	0	
2012							
Control		123		1.02		0	52
Ethephon	576	107	–16*	0.87*	85	15*	14**
Ethephon	288	117	–6	1.09	107	1	17**
Metconazole	60	122	–1	1.09	107	0	63
Metconazole	30	119	–4	1.26*	124	0	60
Paclobutrazol+difenoconazole	125+250	121	–2	0.97	95	0	66
Paclobutrazol+difenoconazole	62.5+125	122	–1	1.22*	120	0	63

Statistical evaluation was made separately for every year: *significant at 0.05, **significant at 0.01 level of probability; application in 2010 on June 22 at BBCH 61 (beginning of flowering); in 2011 and 2012 on June 7 at BBCH 51 (inflorescence or flower buds visible)

lower rate resulted in diminished reduction of only 6 cm compared to the control, although with almost no phytotoxicity. At the higher rate, phytotoxicity negatively affected yield, albeit not so strongly as in 2010. At the lower rate, yield was increased.

For metconazole (60 g a.i./ha), no growth reduction was recorded at either application rate. No phytotoxicity was recorded, and yield was positively affected compared to the control. Application of difenoconazole (250 g a.i./ha) + paclobutrazol (125 g a.i./ha) at both rates resulted in slight height reduction compared to the control without any effect on yield or phytotoxicity. In this year, lodging occurred as a result of a powerful storm. In the control, lodging occurred on approximately 52% of the plot. Plots treated with metconazole (60 g a.i./ha) and difenoconazole (250 g a.i./ha) + paclobutrazol (125 g a.i./ha) showed the same lodging as the control. For ethephon, lodging was significantly lower at 14% of the plot area for the higher rate (576 g a.i./ha) and 17% at the lower rate (288 g a.i./ha).

DISCUSSION

The results from 2010–2012 clearly indicate a great variance among the experimental years. This is most apparent in the yields recorded for the control. A low yield in 2010 contrasts with an exceptionally high yield in 2011. The main reason for the unfavourable poppy development in 2010 was extreme precipitation, which began at the end of April and continued throughout May and almost to mid-June. In May alone, 203 mm fell (vs the long-term norm for May of 64.8 mm) and only 3 days without rain were recorded. This resulted in nitrogen being washed out of the

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soil as well as poor plant development. Fertilisation subsequent to the rain did not fully compensate for the loss of plant biomass, as is clear from the fact that plant height at the end of May was ca. 70 cm in 2010 but ca. 130 cm in 2011–2012. A strong rate of plant height reduction was recorded following PGR application, not only for ethephon (576 g a.i./ha), but also for metconazole (60 g a.i./ha) and for difenoconazole (250 g a.i./ha) + paclobutrazol (125 g a.i./ha) at the full rates. None of the subsequent experimental seasons showed such a great height reduction for metconazole (60 g a.i./ha) or difenoconazole (250 g a.i./ha) + paclobutrazol (125 g a.i./ha).

It is highly likely that, in addition to the overall unfavourable course of weather over the season, the reason for this was an absence of wax layer on the surface of poppy leaves. The long-enduring rain in May washed the wax layer off the leaves. In 2010, treatments were applied 7 days after the end of precipitation. At this time, the wax layer had not fully recovered. This could have resulted in high plant intake of the active ingredient and subsequently in plant height reduction by 20 cm in comparison to the control.

According to Shepherd and Griffiths (2006), a wide range of abiotic stresses affect plants, which use their epicuticular wax layer as a protective barrier. This layer consists predominantly of such long-chain hydrocarbon compounds as alkanes, primary alcohols, aldehydes, secondary alcohols, ketones, and esters. Pinke *et al.* (2014) stated that the epicuticular wax layer of opium poppy provides a natural defence against herbicides.

It is apparent that weakening of the protective wax layer on poppy leaves can result in increased penetration of PGRs into the plant and thus to increased activity as well as potential expression of phytotoxicity.

In all experimental years, substantial poppy plant height reduction was found only with ethephon (576 g a.i./ha). In experimental years 2010 and 2011 some reduction was recorded also with difenoconazole (250 g a.i./ha) + paclobutrazol (125 g a.i./ha), but this reduction was small except in 2010. With metconazole (60 g a.i./ha) application, plant height reduction occurred only in 2010 and in other years was negligible or non-existent. The effects of applying PGRs on plant height may depend on a number of circumstances. In addition to weather conditions, important roles are played by the crop, application date, and the amount of active ingredient.

In poppies, Nagy *et al.* (1989) found that paclobutrazol and a CCC–ethephon mix applied at the beginning of bud development increased stem diameter. Ethephon applied alone as well as in combination with CCC reduced plant vigour and stem height. At high rates, paclobutrazol was shown to reduce stem height in poppy. Our experiments indicated that only ethephon (576 g a.i./ha) had an effect of diminishing lodging via plant height reduction while not hurting yield, and then only at the lowest application rate of 288 g a.i./ha. This was confirmed in 2012 when a strong storm caused lodging in the poppy experiments. Only the treatments with ethephon at rates of 288 g a.i./ha and 576 g a.i./ha had almost no lodging, and just the lower rate was associated with increased yield. Although the higher rate of 576 g a.i./ha was the best experimental variant in terms of lodging, its 15% rate of phytotoxicity (damage to buds on the main stem) caused diminished yield in comparison to the control. For the other variants, high rates of lodging were accompanied by increased yield. The fungicidal activity of metconazole (60 g a.i./ha) and difenoconazole (250 g a.i./ha) + paclobutrazol (125 g a.i./ha) resulted in plants remaining free of disease. The active ingredient of ethephon has no fungicidal activity.

Phytotoxicity, which manifested itself within the experiments as drying and gradual bud death on the main stem of poppy plants, was determined only after ethephon treatment. At the application rate of 576 g a.i./ha (twice the rate commonly used with cereals), phytotoxicity was 15–35% and led to substantially diminished yields in all experimental years. The commonly used rate of 288 g a.i./ha led to decreased heights in all experimental years, albeit within the lower range of 16–20 cm, as well as to decreased yields in two of the three years. Negative effects on yield from ethephon have been described in cereals by a number of authors. The timing of ethephon treatment is of particular importance inasmuch as applications at or near BBCH 39 may lead to diminished grains per ear due to its inducing pollen sterility (Foster & Taylor 1993). Dry conditions following ethephon treatment of barley may even result in diminished yield losses (Knapp *et al.* 1987).

CONCLUSION

Data from all three experimental seasons with the use of selected PGRs show that it is possible to shorten poppy plants. But it is important to take into consideration, too, the high probability of negative yield effects. If these effects will not be offset by substantial positive

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influences, such as to protect poppy from lodging, the use of PGRs cannot be recommended. The data also showed, however, that it is not possible simply to transfer experience with the same substances from rapeseed, cereals, and sunflower to use with poppy.

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