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THE IMPACT OF MORPHOREGULATOR ON THE PRODUCTIVITY OF COMMON OATS (*Avena sativa* L.)

WPŁYW REGULATORA WZROSTU NA PRODUKTYWNOŚĆ OWSA ZWYCZAJNEGO (*Avena sativa* L.)

Abstract: The aim of the studies was to consider the use of one registered morphoregulator in the Slovak oats with practical recommendations for the selected (most commonly grown) varieties. Since plant producers are not very experienced in the application of the morphoregulator to some varieties, the most widely grown oat varieties were used in the experiment. The field trial was established in 2009, 2010 and 2011 at the CVRV – VURV (Research Institute for Plant Production) Piešťany, the VŠS (Research Breeding Station) Vígľaš--Pstruša. The impact of the morphoregulator on reducing the stem and enhancing the number of productive tillers was confirmed in all the monitored varieties. Basing on the results of the trial, we do not recommend the application of CCC for 'Auron', 'Atego' and especially 'Valentin' varieties. For 'Vendelin' and 'Zvolen' varieties we recommend to consider the economic acceptability of morphoregulator applications. As economically acceptable we can recommend application of the morphoregulator only for the 'Flamingstern' variety.

Keywords: morphoregulator, lodging rate, oat (*Avena sativa* L.), stem, tillers

Introduction

Synthetic regulators of plant growth are classified as phytohormone analogues and growth retardants depending on their chemical structure and physiological effects on plants [1].

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Tolbert [2, 3] was the first who described the effect of the morphoregulator chlormequat chloride [CCC, chlormequat (2-chloroethyl)-trimethylammonium chloride] on growth and shoot elongation in wheat. Applications of chlormequat to field plots of cereals at the 3- to 5-leaf growth stages reduced the height of wheat (*Triticum aestivum* L.) the most, followed by barley (*Hordeum vulgare* L.), and oats (*Avena sativa* L.). Height reductions were cultivar-specific in the three crops. Lodging was temporarily delayed by the use of chlormequat, while disease incidence, seed yields, protein, lignin, and cellulose content of the straw were unchanged. Of 53 barley cultivars treated with chlormequat, 35 showed variable degrees of height reduction with 5 reduced significantly to a maximum of 13.2 %; 6 showed no response, while 12 grew taller following treatment. In general, the reaction of barley cultivars to chlormequat followed the genetic relationships similar to those determined by isozyme patterns [4].

The influence of growth regulators chlormequat chloride, ethephon, trinexapac-ethyl, and a combination of chlormequat chloride and ethephon on decreasing sunflower height was examined in the years 2006–2009. Height was reduced by as much as 63 cm by double application of chlormequat chloride (915 g · ha^{-1}) + ethephon (465 g · ha^{-1}) at early and later growth stages (BBCH 32 and 50) [5].

The major factor associated with lodging sensitivity is the length of the stem. Lodging is often associated with quantity and quality losses in grain yields and evidently increases harvesting and drying expenses. Abundant nitrogen fertilization, in combination with high precipitation, favours stem elongation and hence results in increased risk of lodging. At high latitudes the long days and a low angle of incident radiation further promote stem elongation. Inhibiting stem elongation by PGR application generally reduces the risk of lodging. To shorten the stem, PGRs are applied at early stem elongation phases (CCC) [6].

CCC and ethephon applied to oat prior to onset of stem elongation resulted in similar short-term reduction in stem elongation of the main shoot and T1 and T2 tillers [7]. This indicates that even when tillers are not directly exposed to PGR application, the elongation retarding effect may be transferred to the tillers [7]. Application of plant growth regulators (PGR) to control lodging in cereal crops often increases the number of tillers and/or spikes. Spring barley plants treated with an early application of CCC (ZGS 13 or ZGS 30) or ethephon (ZGS 30) produced greater numbers of shoots, appearing later in time, than control plants. Early PGR treatment increased the number of spike-bearing shoots, primarily by enhancement of tiller numbers (tiller-derived spikes) rather than the spike production rate (tiller survival) [8].

The highest decrease in plant height of winter wheat was obtained in treatments where for the first time CCC was applied at a rate of 1 $dm^3 \cdot ha^{-1}$ and for the second – Modus 0.4 $dm^3 \cdot ha^{-1}$, Terpal C 0.7 $dm^3 \cdot ha^{-1}$, or Cerone 0.5 $dm^3 \cdot ha^{-1}$ at BBCH 39–45 were used [9].

When PGR treatments prevent lodging or reduce its magnitude, the advantageous effects on yield quality and quantity and easier harvesting are likely to make the treatments profitable. When there is no lodging PGR treatments should increase the yield to cover at least the management expenses to be cost-effective. To reach this

threshold level, 150 to 300 kg · ha^{-1} yield improvement is likely to be the minimum requirement, depending on the crop and PGR [6].

In Slovakia there are only two preparations registered in non-food oats that contain the active substance chlormequat chloride. These are: Retacel Extra R 68 and Chlormelam 720 SL. The permitted rate is 3.5 dm^3 · ha^{-1} from the appearance of the first node to the second node (BBCH 31–32) [10].

The effects of single and repeated early applications of chlormequat (at up to and including Zadoks growth stage (GS) 32) on the growth and development of the winter oat cultivar 'Bulwark' were investigated in two seasons of field experiments at Tenby, UK. At maturity, reductions in stem length and lodging were best achieved by chlormequat applied at GS 32; this treatment shortened the stems by an average of 24 % in 1985/86 and 31 % in 1986/87. Earlier applications were significantly less effective [11].

Field plot experiments were established for studying the influence of growth regulators MLU 208, MLU 2081 [various mixtures of 2,3-dichloroisobutyric acid (DCiB) with chlormequat chloride (CCC)] and CCC on the length of shoot axis, susceptibility to lodging and grain yield of oats (*Avena sativa* L.) and oil seed rape (*Brassica napus* L.). With the lodging-resistant oat varieties 'Alfred' and 'Solidor', MLU 208 and MLU 208L caused stem reductions of 10 % and yield increases up to 6.5 % despite the fact that the untreated controls showed hardly any lodging. CCC, applied as comparative treatments, had no yield-increasing effect although a stem reduction of approx. 8 % was recorded [12].

Lodging of oats during growth is more frequent than when growing wheat or barley. It coheres with the higher number of sclerenchym cells in the stem in the above mentioned crops and is more traumatic for oat producers.

The aim of the experiments was to consider the use of one registered morphoregulator in the Slovak oats with practical recommendations for the selected (most commonly grown) varieties.

Material and methods

The field experiment was conducted in 2009–2011 at CVRV-VÚRV Piešťany, in the VSS Vígľaš-Pstruša characterised as a potato-wheat production area (altitude 375 m), with an average annual temperature of 7.76 ^{o}C and annual precipitation of 611 mm. The oats were sown in a crop rotation always after red clover in four replications on a plot of the size of 10 m^2. Nitrogen fertilizer rates were applied with respect to inorganic nitrogen in the soil.

Phosphorus fertilization (in the form of Amofos 21 % P) 12 kg · ha^{-1} and potassium (as potassium salt 60 % K_2O) 96 kg · ha^{-1} were applied once, in autumn. Nitrogen in the form of ammonium nitrate with dolomite (27 % N) was applied before sowing, for the planned harvest of 4 Mg · ha^{-1}.

The most frequently grown varieties of common oat of Slovakia were the object of investigation in the experiment. From the total of six tested oat varieties, three ('Zvolen', 'Vendelin' and 'Valentin' varieties) were bred at the VŠS Vígľaš-Pstruša, two varieties were of Czech origin ('Auron' and 'Atego') and one of German origin

('Flamingstern' variety). Each variety was planted with the same quantity of germinating grains – 5.0 million per 1 ha.

For each variety there was a variant treated by morphoregulator Retacel Extra R 68 (CCC), at a rate of 3.5 $dm^3 \cdot ha^{-1}$ applied in the phase between the first and second node (BBCH 31–32), and the untreated variant. The block method of sowing was used in the trial with random arrangement of plots. Sowing was performed using the Řyord sowing-machine at the plot "Kostolisko I" on 5th April 2009 for the first time, at the plot "Tri duby" on 1st April 2010 for second time and in the third trial at the plot "Kocaň I" on 28th March 2011. Harvesting was carried out with the Wintersteiger harvester on 3rd August 2009, 9th August 2010 and 10th August 2011. Meteorological characteristics are shown in Table 1.

Table 1

Meteorological characteristics of the experimental plot in 2009–2011

Month	March	April	May	June	July	August
Temperature [°C]						
Average (last 50 years)	2.8	8.4	13.1	16.3	17.8	17.3
2009	3.4	11.5	14.4	16.1	19.8	19.5
2010	2.5	9.1	13.6	17.5	20.6	17.6
2011	4.3	10.8	13.5	17.5	20.5	17.6
Precipitation [mm]						
Average (last 50 years)	29.8	46.7	63.9	85.2	75.6	62.0
2009	49.4	11.0	62.8	96.4	34.2	35.6
2010	52.2	55.0	132.8	207.1	100.2	121.9
2011	8.1	55.0	61.2	85.7	123.2	34.7

The effect of the morphoregulator on the crop structure of each variety was investigated, *ei*: average height, lodging before harvest (according to point breeding scale 1–9), the number of productive tillers on m^2 and yield. On the basis of these results the height reduction, stage of lodging reduction and increase of productive tillers number was calculated.

The results were processed statistically using analysis of variance (ANOVA) followed by testing according to LSD.

Results and discussion

The application of the morphoregulator strongly influenced the structure of the crop (average height, lodging and number of productive tillers) but was also strongly influenced by variety and year (Tables 2 and 3). This fact is confirmed by the Peltonen-Sainio and Rajala [13], who confirmed the CCC treatment had resulted in more panicles per square meter. The results are in agreement with the previous finding of Rajala [6] who observed a reduction in stem elongation, shoot growth and that

Table 2

Modeling of some characteristics of 'Auron', 'Atego' and 'Zvolen' varieties of oats after application of morphoregulator

Specification	Morpho-regulator	'Auron'			Average	'Atego'			Average	'Zvolen'			Average
Year		2009	2010	2011		2009	2010	2011		2009	2010	2011	
Average height [cm]	—	105.0	117.0	103.0	108.3 bB	98.0	110.0	97.0	101.7 bB	100.0	114.0	102.0	105.3 bB
	CCC	102.0	101.0	97.0	100.0 aA	88.0	92.0	92.0	90.7 aA	98.0	99.0	95.0	97.7 aA
$LSD_{0.05}$ test (small letters) $LSD_{0.01}$ test (big letters)					2.93 4.02				3.04 4.18				3.20 4.40
Height reduction [%]		2.3	5.7	5.9	4.6	10.3	16.4	5.2	10.6	2.0	13.2	6.9	7.0
Lodging before harvest (point breeding scale 1–9)	—	7.0	7.0	7.0	7.0 aA	9.0	7.0	8.0	8.0 aA	8.0	7.0	8.0	7.7 aA
	CCC	8.0	7.0	8.0	7.6 aA	9.0	8.0	9.0	8.6 aA	9.0	8.0	9.0	8.66 bB
$LSD_{0.05}$ test (small letters) $LSD_{0.01}$ test (big letters)					0.87 1.22				0.92 1.26				0.53 0.73
Stage of lodging reduction (point breeding scale 1–9)		1.0	0.0	1.0	0.66	0.0	1.0	1.0	0.66	1.0	1.0	1.0	1.0
Number of productive stems on m^2	—	572.0	508.0	488.0	522.7 aA	576.0	548.0	536.0	570.7 aA	548.0	504.0	504.0	518.7 aA
	CCC	640.0	532.0	600.0	590.7 bB	636.0	660.0	588.0	610.7 bB	584.0	516.0	572.0	557.3 bB
$LSD_{0.05}$ test (small letters) $LSD_{0.01}$ test (big letters)					18.40 22.27				13.62 18.71				11.76 16.15
Increase of productive tillers [%]		11.9	10.5	22.9	15.1	10.4	20.4	9.7	10.3	6.5	2.3	13.4	7.4

Table 3

Modeling of some characteristics of 'Vendelin', 'Valentin' and 'Flamingstern' varieties of oats after application of morphoregulator

Specification	Morpho-regulator	'Vendelin'			Average	'Valentin'			Average	'Flamingstern'			Average
Year		2009	2010	2011		2009	2010	2011		2009	2010	2011	
Average height [cm]	—	107.0	112.0	102.0	107.0 bB	91.0	105.0	94.0	96.7 bB	97.0	114.0	97.0	102.7 bB
	CCC	100.0	87.0	98.0	95.0 aA	80.0	95.0	87.0	87.3 aA	89.0	102.0	96.0	95.7 aA
$LSD_{0.05}$ test (small letters) $LSD_{0.01}$ test (big letters)					4.93 6.77				1.44 1.98				2.53 3.48
Height reduction [%]		6.5	23.3	4.0	11.3	12.1	9.5	7.5	9.7	8.8	10.5	1.1	6.8
Lodging before harvest (point breeding scale 1–9)	—	7.0	7.0	7.0	7.0 aA	9.0	8.0	9.0	8.66 aA	6.0	6.0	6.0	6.0 aA
	CCC	8.0	9.0	8.0	8.33 bB	9.0	9.0	9.0	9.0 aA	7.0	7.0	7.0	7.0 bB
$LSD_{0.05}$ test (small letters) $LSD_{0.01}$ test (big letters)					0.82 1.13				0.47 0.64				1.01 1.38
Stage of lodging reduction (point breeding scale 1–9)		1.0	2.0	1.0	1.33	0.0	1.0	0.0	0.33	1.0	1.0	1.0	1.0
Number of productive stems on m^2	—	496.0	536.0	560.0	530.7 aA	568.0	544.0	590.0	567.3 aA	536.0	510.0	495.0	513.7 aA
	CCC	540.0	584.0	660.0	594.7 bB	688.0	592.0	696.0	658.7 bB	624.0	582.0	536.0	580.7 bB
$LSD_{0.05}$ test (small letters) $LSD_{0.01}$ test (big letters)					13.07 17.95				15.97 21.93				10.0 13.73
Increase of productive tillers [%]		8.8	8.9	17.8	11.8	21.1	8.8	17.9	15.9	16.4	14.1	8.3	12.9

Table 4

Average yields after application of morphoregulator (varieties: 'Auron', 'Atego', 'Zvolen', 'Vendelin', 'Valentin', 'Flamingstern')

Variety	Morphoregulator	'Auron'			'Atego'			'Zvolen'		
Year		2009	2010	2011	2009	2010	2011	2009	2010	2011
Yield [Mg · ha^{-1}]	—	6.54	4.76	5.95	6.22	4.47	5.22	6.66	4.82	5.26
	CCC	6.33	4.51	5.75	6.29	4.28	5.14	7.21	4.54	5.18
Average	—	5.76			5.30			5.58		
	CCC	5.53			5.24			5.64		
Variety	Morphoregulator	'Vendelin'			'Valentin'			'Flamingstern'		
Year		2009	2010	2011	2009	2010	2011	2009	2010	2011
Yield [Mg · ha^{-1}]	—	6.61	4.90	5.86	7.55	4.94	5.73	5.91	3.95	4.47
	CCC	6.79	4.71	5.94	7.13	4.61	5.57	6.18	4.58	4.53
Average	—	5.79			6.07			4.78		
	CCC	5.81			5.77			5.10		
LSD total – years	$\alpha \le 0.05$	0.242								
	$\alpha \le 0.01$	0.327								
LSD total – treatment	$\alpha \le 0.05$	0.198								
	$\alpha \le 0.01$	0.267								
LSD total – varieties	$\alpha \le 0.05$	0.342								
	$\alpha \le 0.01$	0.462								

elongation may change assimilate demands and distribution within the plant and thus provide excess resources that in turn may stimulate, for example, root growth, tiller and spikelet initiation and grain set and growth. Tripathi et al [14] detected the most consistent effect of chlormequat and ethephon on reduction in plant height and when environmental conditions are conducive to lodging, these reductions in plant height are often accompanied by reductions in lodging.

All varieties identically responded in all the years by reducing their height – at least by 1.1 % ('Flamingstern' variety in 2011) to 23.3 % ('Vendelin' variety in 2010). The impact of the morphoregulator on lodging before harvest, expressed on a scale from 1 to 9, was not very marked and especially varieties with a high resistance to lodging ('Valentin', 'Atego' or 'Auron' varieties) were not influenced by CCC in some years. The morphoregulator quite significantly increased the number of productive tillers in all tested varieties and in all the years (the 'Zvolen' variety achieved the lowest growth and the 'Auron' variety reached the highest, *ie* 2.3 % in 2010 and 22.9 % in 2011, respectively) (Tables 2 and 3).

The results presented in Table 4 refer to the significant influence of the variety on the yields of oat grain and also significant differences between the experimental years, which is in accord with the above mentioned quotations.

The lowest oat yields were obtained in 2010 when the highest total sum of precipitation (especially from May to August) and the lowest temperature in two spring months (March, April) was noted (see Table 1). The negative effect on the yield of all oat varieties was statistically confirmed. No significant differences were detected in the yields of grain treated by the morforegulator and the untreated variant. Browne et al [15] also confirmed not significant effect of chlormequat chloride on the yields of oat.

The yields of 'Valentin' and 'Vendelin' varieties were statistically significantly higher than of 'Flamingstern' and 'Atego' varieties. 'Valentin', 'Vendelin' and 'Auron' varieties achieved significantly higher yields than 'Zvolen', 'Atego' and 'Flamingstern' varieties. The yields of 'Zvolen' variety were significantly higher than of 'Flamingstern' variety. On the whole we can evaluate the impact of morphoregulators as positive, however only a non-significant effect on the increase of yields of the 'Zvolen', 'Vendelin' and especially 'Flamingstern' varieties. This is related mainly to a medium ('Vendelin' and 'Zvolen' varieties) and lower ('Flamingstern' variety) resistance to lodging. On the contrary we can assess the impact of the morphoregulator as negative (yield reduction) but also with non-significant effects on the 'Auron' and 'Atego' and especially 'Valentin' varieties. This is related with a medium ('Auron' variety) and high resistance to lodging ('Atego' and 'Valentin' varieties).

The average price of the product Retacel R 68, according to the prices of the company Alchem, is 4.19 EUR per litre VAT excluded (5.028 EUR per litre VAT included). At a rate of 3.5 litres per ha the cost is 17.598 EUR VAT included.

Conclusions

1. Overall the average yield of oat in three-year field experiments reached 5.53 $Mg \cdot ha^{-1}$.

2. 'Vendelin' and 'Valentin' oat varieties reached the highest whereas 'Flamingstern' variety the lowest average harvests in the trial.

3. The negative effect on oat yielding was statistically confirmed in 2010, when the highest total sum of precipitation during the vegetation season and the lowest temperature in the spring was registered.

4. It was confirmed a significant effect of the variety and insignificant impact of CCC on the dynamics of oat grain yields.

5. In case of all varieties and years the impact of CCC on reducing the tiller height and increasing its productive numbers was confirmed. The effect of CCC on lodging before harvest, expressed on a scale from 1 to 9, was not considerable, especially for 'Valentin', 'Atego' or 'Auron' varieties with a high resistance to lodging.

6. The application of CCC for 'Auron', 'Atego' and especially 'Valentin' varieties is not recommended, for 'Vendelin' and 'Zvolen' varieties it can be recommended after considering the economic viability, but we can recommend CCC application only for the 'Flamingstern' variety.

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WPŁYW REGULATORA WZROSTU NA PRODUKTYWNOŚĆ OWSA ZWYCZAJNEGO (*Avena sativa* L.)

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Abstrakt: Celem badań było rozważenie stosowania jednego z zarejestrowanych regulatora wzrostu w uprawie owsa z praktycznymi zaleceniami dla wybranych, najczęściej uprawianych odmian w Słowacji. Ponieważ producenci nie mają dużego doświadczenia w stosowaniu regulatora wzrostu w uprawie niektórych odmian, w doświadczeniu uwzględniono najpowszechniej uprawiane odmiany owsa.

Doświadczenia polowe zakładano w latach 2009, 2010 i 2011 w CVRV-VURV (Instytut Badawczy Uprawy Roślin) Piešťany, VSS (Stacja Badawcza Hodowli) Vígľaš-Pstruša. Dla wszystkich monitorowanych odmianach został potwierdzony wpływ regulatora wzrostu na skrócenie źdźbeł i zwiększenie liczby pędów produkcyjnych. Na podstawie wyników badań nie zaleca się stosowania CCC w przypadku odmian 'Auron', 'Atego', a zwłaszcza 'Valentin'. W przypadku odmian 'Vendelín' i 'Zwolen' zaleca się rozważenie efektywności ekonomicznej stosowania tego regulatora wzrostu. Tylko w przypadku odmiany 'Flamingstern' można zalecić stosowanie CCC jako ekonomicznie akceptowalne.

Słowa kluczowe: regulator wzrostu, wskaźnik wylegania, owies (*Avena sativa* L.), źdźbło, pędy