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Management of Maize Stand Height using Growth Regulators

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Abstract

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Effect in reducing maize plant height using growth regulators ethephon, chlormequat chloride (CCC), CCC + ethephon, and mepiquat chloride + prohexadione-Ca was studied in field experiments during 2010 and 2011. It was found that maize plant height could be reduced by as much as 125 cm (49% of control) using a double application of ethephon (576 g a.i./ha) at growth stages BBCH 18–19 and BBCH 34–36. The other growth regulators displayed weak or no influence. An optimum level of shortening was achieved using ethephon (576 g a.i./ha) at BBCH 34–36 (reducing plant height by 40–90 cm), but it is necessary to count upon yield loss of 0.5–0.6 t/ha.

Keywords: chlormequat chloride (CCC); ethephon; mepiquat chloride; prohexadione-Ca; grain yield

Plant growth regulators are synthetic compounds used to reduce the 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, growth regulators are antagonistic to gibberellins and auxins, the plant hormones primarily responsible for shoot elongation (Rademacher 2000). Many types of plant growth regulators having norbornanodiazetine, triazole, pyrimidine, 4-pyridine, and imidazole structures are used in agriculture and horticulture. These inhibitors of special cytochrome P450-dependent monooxygenases are involved in regulating terpenoid metabolism in relation to phytohormones and sterols, and thus they influence cell division, cell elongation, and senescence (Grossmann 1990).

From a physiological point of view, the regulation of root growth and germination depends upon gibberellin and its antagonist chlormequat chloride (CCC) (Bianco *et al*. 1996). Whereas the onset of germination is not inhibited by CCC, inhibiting effects do occur from the elongation stage and in relation to root growth. Similar experiments in the USA came to similar findings (Jones & Phillips 1967). In cereal crops, for example, CCC and ethephon have been applied to support tillering and prevent lodging of wheat, barley, and oats (Green *et al*. 1988; Rajala & Peltonen-Sainio 2001; Rajala *et al*. 2002; Rajala 2004).

Lovett and Camphell (1973) studied the effects of the 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.

An array of other compounds with growth-regulating effects is used also in cereals and oil crops. The most widely used preparations in oilseed rape are metconazole and tebuconazole (Balodis &

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Gaile 2009), which are applied in autumn to improve overwintering and in spring to reduce stand height. Koutroubas *et al.* (2014) studied the effect of foliar application of paclobutrazol at 12.5 g a.i./ha, mepiquat chloride at 25.0 g a.i./ha, and CCC at 1500 g a.i./ha 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, thus providing a basis for reducing the risk of plant lodging. 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 lodging. Increases in the seed yield under different application rates of mepiquat chloride ranged between 13.7 and 20.1% over the untreated control. Furthermore, the interaction of application rate and stage was significant; spraying of pea plants with 25 g a.i./ha of mepiquat chloride at early blooming stage had the most beneficial effects on the evaluated characteristics.

Only rather limited information is available about application of growth regulators in maize. Peña-Uribe *et al.* (2012) reported the effect of oligogalacturonides on maize growth and development as well as on activation of maize ribosomal protein S6 kinase (S6K). They found that oligogalacturonides inhibit coleoptile growth and modify root architecture of maize seedlings. Their Western blot analyses indicated a modulation of maize S6K activity from seedlings and embryonic axes in response to oligogalacturonides treatment. These results show that oligosaccharides regulate growth and development through modulation of the target of rapamycin (or TOR) signalling pathway in maize.

The importance of ethephon as a growth-regulating compound consists in the fact that upon metabolism by the plant it is converted into ethylene, which in turn regulates plant growth and maturity. It is often used on wheat, coffee, tobacco, cotton, and rice to accelerate ripening (Rajala *et al.* 2002).

Alarcon *et al.* (2009, 2012) reported that maize roots growing in aerated solutions varied strikingly in the amounts of ethylene they produced at various stages of development. They observed that as endogenous ethylene increased, root elongation diminished. Supplying exogenous 1-aminocyclopropane-1-carboxylic acid to these roots inhibited their elongation while increasing the fresh weight of the apex and ethylene production. Application of the ethylene biosynthesis inhibitor 2-aminoethoxyvinyl glycine and of silver thiosulfate, which inhibits ethylene activity, was also observed to reduce growth even as it increased swelling. Inasmuch as growth was seen to diminish when ethylene concentrations were reduced or ethylene action was impaired, their findings support the view that ethylene is necessary for root growth. Because treatment with 1-aminocyclopropane-1-carboxylic acid also inhibited root elongation, they remarked that ethylene is inhibitory at both low and high concentrations and that root growth apparently accommodates progressively to higher ethylene concentrations.

Kötting *et al.* (1988) found that applying the plant growth regulator CCC at fixed stages in the development of maize plants caused significant increase in the number of kernels per ear and of the grain yield per pot. Plant height was not affected.

In recent years, the cropping area planted to maize has been growing in the Czech Republic. Problems with diseases and pests have increased accordingly and are expected to worsen in future. In view of the standard plant height of 200–250 cm in maize after anthesis until harvest, protection treatments against harmful organisms can be applied only until early anthesis of the female flowers. Later, no application machinery can pass through the stand without damaging it.

Reduction in maize plant height below 200 cm would allow self-propelled sprayers to go through a maize stand without seriously damaging it. Due to a new threat to maize for grain, namely corn rootworm (*Diabrotica virgifera virgifera*), the State Phytosanitary Administration of the Czech Republic issued the Regulation No. SRS 065898/2011 on emergency phytosanitary measures to protect against the spread of corn rootworm. Following the European Commission Decision 2003/766/EC, it prescribes measures against the spread of this pest and defines the regions concerned. One of the measures is a treatment against adult corn rootworms, which shall be made immediately after the announcement of a warning. Adult beetles first appear in the stand in late June to early July, however, by that time the maize is already too tall for application machines. Shortening maize height would also enable protecting stands against adult corn rootworm beetles.

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The objective of our work was to determine whether the plant height of maize can be reduced using the selected growth regulators and whether their effects have a negative influence on plants and grain yield.

MATERIAL AND METHODS

The location where the field experiments were conducted (49°17'13.708''N, 17°22'13.296''E) ranks among the most fertile lands in the Czech Republic and lies within the Central European climatic zone. It is a warm and slightly humid area with mean annual temperature of 8.7°C and total annual precipitation of 599 mm. Meteorological data for the experimental years are summarised in Tables 1 and 2. By FAO classification, the soil is of Luvi-Haplic Chernozem type with deep, structural, clay loam topsoil.

The experiments were conducted in 2010 and 2011. A HEGE 95 seeder was used to plant maize with final spacing of 14 cm in the row. The plot area was 20 m^2 and plots were arranged in a randomised complete block. There were four rows 75 cm apart in the plot and each treatment was in four replications. The variety Aurelia (FAO 290) was planted in both experimental years. Conventional soil preparation was used for the experiments in both experimental years (primary soil tillage in autumn, then secondary tillage and planting in spring). Planting was on April 29, 2010 and May 6, 2011. Fertilisation was in autumn only, using in both trial years 200 kg/ha Amofos-brand granulated fertilizer (12% N and 52% P_2O_5). The growth regulators used and application rates per hectare are given in Table 3. In both 2010 and 2011, treatments were carried out at two growth stages: the first (early) treatment at BBCH 18–19 (8–9 leaves) and the second (later) at BBCH 34–36 (4–6 nodes detectable). Also in both years, applications of the same doses and preparations were performed at each of the two growth stage points (i.e. double applications).

Treatments were applied using a small-plot backpack sprayer (R&D Sprayers; Bellspray, Inc., Opelousas, USA) based on compressed air with a six-nozzle boom on 3 m spray spacing. Water was applied at the rate of 350 l/ha, and air pressure was 0.3 MPa. In both years, the following preparations exhibiting growth regulation effects were applied: Retacel Extra R68 (CCC 720 g/l), Terpal C (CCC 305 g/l + ethephon 155 g/l), Medax Top (mepiquat chloride 228.86 g/l + prohexadione-Ca 42.39 g/l), and Cerone 480 SL (ethephon 480 g/l). Plant height before harvest, grain yield in t/ha corrected to 14% moisture, 1000-grain weight (TGW) at 14% moisture, ear length in cm on 10 ears from each plot, and height of main ear setting were measured. Slight lodging occurred in 2010 and so the number of lodged plants also was recorded in that year. Plant height was measured at five points in each plot. Grain was harvested using a Wintersteiger Advance combine harvester (Wintersteiger AG, Ried/I, Austria) with an adapter for maize. To avoid the effects of neighbouring plots,

Table 1. Temperature at the research institute Agrotest fyto, Ltd., Kroměříž, Czech Republic

	2010			2011		
	average temperature (°C)	deviation from the long-term average (°C)	characteristics of the month	average temperature (°C)	deviation from the long-term average (°C)	characteristics of the month
January	–4.2	–2.9	cold	–0.2	1.1	normal
February	–0.5	-0.7	normal	–0.9	–1.1	cold
March	4.8	0.5	normal	5.3	1.0	normal
April	9.6	0.5	normal	11.8	2.7	very warm
May	13.1	–1.2	normal	14.6	0.3	normal
June	18.2	1.2	warm	18.4	1.4	warm
July	21.4	2.6	extraordinary warm	18.0	–0.8	cold
August	19.1	0.5	normal	20.1	1.5	warm
September	13.4	–0.9	normal	16.7	2.4	very warm
October	7.4	–1.8	cold	9.5	0.3	normal
November	7.2	3.6	extraordinary warm	2.9	–0.7	normal
December	–3.6	–3.8	cold	2.8	2.6	very warm
Year average	8.9	–0.2	normal	10.0	0.9	warm

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Figure 2. Precipitation at the research institute Agrotest fyto, Ltd., Kroměříž, Czech Republic

	2010			2011		
	amount of rainfall (mm)	average long-term total (%)	characteristics of the month	amount of rainfall (mm)	average long-term total (%)	characteristics of the month
January	65.0	283	extraordinary wet	22.5	98	normal
February	32.5	125	normal	3.9	15	very dry
March	12.3	42	dry	35.9	123	normal
April	62.6	156	wet	45.5	113	normal
May	202.9	313	extraordinary wet	84.2	130	normal
June	84.6	102	normal	72.0	87	normal
July	95.5	131	wet	119.7	164	wet
August	85.6	131	wet	49.4	76	normal
September	70.2	132	normal	11.0	21	very dry
October	16.1	43	normal	23.9	63	normal
November	49.9	122	normal	0.5	1	extraordinary dry
December	34.0	105	normal	12.8	39	very dry
Year	811.2	143	extraordinary wet	481.3	85	dry

just the two central rows in each plot were harvested for research purposes. The entire experimental area was treated at preemergence against weeds using a tank mix of the herbicides acetochlor (1152 g a.i./ha) and flurochloridone (375 g a.i./ha).

The data were analyzed statistically using STATISTICA 7.0 software for analysis of variance (ANOVA). Subsequently, the differences among mean values were tested using Tukey's test.

RESULTS

The results for 2010 are summarised in Table 3. The height of corn plants was generally significantly reduced (in the range of 25–125 cm) by the application of CCC (305 g/l) + ethephon (155 g/l) and ethephon (480 g/l) depending on the preparation used and time of application. Ethephon 576 g a.i./ha in BBCH 18–19 reached a height reduction of about 46 cm, CCC 458 + ethephon 233 g a.i./ha in BBCH 18–19 height reduction of about 25 cm, ethephon 2 × 576 g a.i./ha in BBCH 18–19 and 34–36 height reduction of about 125 cm, CCC 2 × 458 + ethephon 2 × 233 g a.i./ha in BBCH 18–19 and 34–36 height reduction of about 89 cm, ethephon 576 g a.i./ha in BBCH 34–36 height reduction of about 96 cm, CCC 458 + ethephon 233 g a.i./ha in BBCH 34–36 height reduction of about 67 cm compared to control.

The reduction in plant height was due to shortening of the internodes length after application. Grain yield was reduced in all treatments. The earlier applications reduced yields in the range of 0.34 t/ha to 2.1 t/ha relative to the control. Yield reduction in the case of two applications ranged from 0.92 t/ha to 2.54 t/ha, and that from later applications was in the range from 0.07 t/ha to 1.1 t/ha. Yield reductions were statistically significant by CCC 2 × 160 g a.i./ha in BBCH 18–19 yield reduction of 1.21 t/ha, ethephon 576 g a.i./ha in BBCH 18–19 yield reduction of 2.10 t/ha, mepiquat chloride + prohexadione 344 + 63 g a.i./ha in BBCH 18–19 yield reduction of –1.24 t/ha, CCC 2 × 2160 g a.i./ha in BBCH 18–19 and 34–36 yield reduction of –1.04 t/ha, ethephon 2 × 576 g a.i./ha in BBCH 18–19 and 34–36 yield reduction of –2.54 t/ha, mepiquat chloride + prohexadione 2 × 344 + 63 g a.i./ha in BBCH 18–19 and 34–36 yield reduction of –1.55 t/ha, and mepiquat chloride + prohexadione 344 + 63 g a.i./ha in BBCH 34–36 yield reduction of –1.10 t/ha.

Thus, the earlier applications and double applications brought the greatest reductions. Yield reduction due to later application was statistically significant only for the application of mepiquat chloride + prohexadione-Ca. Significant reduction in TGW occurred in the cases of two applications of CCC (720 g/l), for all applications of CCC + ethephon and mepiquat chloride + prohexadione-Ca, as well as for early and double applications of ethephon. Ear length was not affected significantly, and the height of ear setting was affected significantly only in the cases of CCC + ethephon and ethephon.

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Table 3. Effects of growth regulators in maize (variety Aurelia) on yield, 1000-grain weight, ear length, plant height, height of main ear, and lodging (2010 and 2011)

Growth regulators	Dose (g a.i./ha)	Growth stage at application	Yield at 14% humidity		TGW at 14% humidity		Ear length		Plant height		Height of main ear		Number of lodged plants (per plot)
			(t/ha)	dif.	(g)	dif.	(cm)	dif.	(cm)	dif.	(cm)	dif.	
2010													
Control			10.51		322		14		254		101		31
CCC	2160	BBCH 18–19	9.31	–1.21*	318	–4	14	0	245	–9	92	–8	21
Ethephon	576		8.41	–2.10**	296	–26**	12	–2	209	–46**	63	–38**	0
CCC + ethephon	458 + 233		9.75	–0.77	301	–21**	14	0	229	–25*	75	–25**	0
Mepiquat chloride + prohexadione-Ca	344 + 63		9.27	–1.24*	310	–12	14	0	253	–1	102	1	52
CCC	2× 2160	BBCH 18–19 and 34–36	9.48	–1.04*	302	–20**	14	0	238	–16	89	–11	24
Ethephon	2 × 576		7.98	–2.54**	284	–38**	12	–2	129	–125**	58	–42**	0
CCC + ethephon	2 × 458 + 233		9.59	–0.92	293	–29**	13	–1	165	–89**	62	–39**	0
Mepiquat chloride + prohexadione-Ca	2 × 344 + 63		8.96	–1.55*	305	–17*	14	0	241	–14	94	–7	39
CCC	2160	BBCH 34–36	10.08	–0.44	310	–12	14	0	248	–6	94	–7	17
Ethephon	576		9.96	–0.55	303	–19*	13	–1	158	–96**	71	–30**	0
CCC + ethephon	458 + 233		10.45	–0.07	318	–3	13	–1	188	–67**	83	–18*	0
Mepiquat chloride + prohexadione-Ca	344 + 63		9.41	–1.10*	287	–34**	15	1	242	–12	91	–10	24
2011													
Control			12.53		338		16		262		117		–
CCC	2160	BBCH 18–19	11.83	–0.69	340	2	16	0	266	4	120	3	–
Ethephon	576		10.24	–2.29**	327	–11	14	–2	223	–39**	88	–29**	–
CCC + ethephon	458 + 233		11.23	–1.29*	344	6	17	1	241	–20*	95	–22**	–
Mepiquat chloride + prohexadione-Ca	344 + 63		12.19	–0.34	351	13	17	1	266	4	117	0	–
CCC (720 g/l)	2 × 2160	BBCH 18–19 and 34–36	11.94	–0.59	334	–4	16	0	267	5	128	11	–
Ethephon (480 g/l)			9.43	–3.09**	329	–9	14	–2	156	–106**	59	–58**	–
CCC (305 g/l) + ethephon (155 g/l)	2 × 458 + 233		11.64	–0.88	326	–12	15	–1	205	–57**	84	–33**	–
Mepiquat chloride (228.86 g/l) + prohexadione-Ca (42.39 g/l)	2 × 344 + 63		12.74	0.21	360	22*	15	–1	265	3	113	–4	–
CCC (720 g/l)	2160	BBCH 34–36	11.74	–0.79	349	11	16	0	261	–1	111	–6	–
Ethephon (480 g/l)	576		11.87	–0.65	335	–3	16	0	221	–41**	95	–22**	–
CCC (305 g/l) + ethephon (155 g/l)	458 + 233		11.43	–1.10*	352	14	16	0	234	–28*	93	–24**	–
Mepiquat chloride (228.86 g/l) + prohexadione-Ca (42.39 g/l)	344 + 63		12.08	–0.44	339	1	17	1	258	–4	101	–16*	–

*significant at 0.05 level of probability, ** significant at 0.01 level of probability; BBCH 18–19 = 8–9 leaves unfolded; BBCH 34–36 = 4–6 nodes detectable; dif. – difference compared to control; TGW – 1000-grain weight; CCC – chlormequat chloride

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In 2010, heavy rains and strong winds caused slight lodging of maize plants. The level of lodging did not exceed a 45° angle to the vertical axis. No lodging occurred only where CCC + ethephon and ethephon had been applied.

Results for 2011 are summarised in Table 3. Plant height was significantly reduced only after the application of CCC (305 g/l) + ethephon (155 g/l) and ethephon (480 g/l) in the range of 20–57 cm and/or 39–106 cm depending on the preparation used and time of application. Ethephon 576 g a.i./ha in BBCH 18–19 reached a height reduction of about 29 cm, CCC 458 + ethephon 233 g a.i./ha in BBCH 18–19 height reduction of about 22 cm, ethephon 2 × 576 g a.i./ha in BBCH 18–19 and 34–36 height reduction of about 58 cm, CCC 2 × 458 + ethephon 2 × 233 g a.i./ha in BBCH 18–19 and 34–36 height reduction of about 33 cm, ethephon 576 g a.i./ha in BBCH 34–36 height reduction of about 22 cm, CCC 458 + ethephon 233 g a.i./ha in BBCH 34–36 height reduction of about 24 cm and mepiquat chloride + prohexadione 344 + 63 g a.i./ha in BBCH 34–36 height reduction of about 16 cm compared to control.The reduction in plant height was caused by shortening of the internodes length after application. Yield reductions were statistically significant by ethephon 576 g a.i./ha in BBCH 18–19 yield reduction of –2.29 t/ha, CCC + ethephon 458 + 233 g a.i./ha in BBCH 18–19 yield reduction of –1.29 t/ha, ethephon 2 × 576 g a.i./ha in BBCH 18–19 and 34–36 yield reduction of –3.09 t/ha, and CCC + ethephon 458 + 233 g a.i./ha in BBCH 34–36 yield reduction of –1.10 t/ha.

TGW was not significantly affected in a negative manner in 2011. Ear length was not affected significantly, and the height of ear setting was reduced significantly only in the cases of CCC + ethephon and ethephon applications. No lodging was observed in that year.

There were no visible signs of phytotoxicity on maize plants after growth regulator applications during the experiments.

DISCUSSION

Ethephon was the main compound with growth regulating effects significantly reducing plant height in the experiments. It is possible to shorten maize plants by as much as 100 cm and more with two applications of ethephon (576 + 576 g a.i./ha) during the growing season. Similar results with the active ingredient ethephon were reported also by Koutroubas *et al.* (2004) in sunflower. Baylis and Dickst (1983) reported that a mixture of mepiquat chloride and ethephon shortened the stalk of sunflowers very well and in contrast to the action of daminozide, which had exhibited uneven effects. The timing of growth regulator application is considered to be very important, because it can affect yield. Langan and Oplinger (1987) noted that ethephon had highly significant effects on grain yield, plant height, ear height, and brace root development in maize. Yield was generally decreasing with increasing ethephon rate. Increasing the ethephon rate also decreased plant and ear height.

According to Gallie *et al.* (2009), roots from Zmacs6 (*Zea mays* L.) mutants exhibited significantly reduced ethylene production, thereby leading to increased cell numbers but smaller cell size; accelerated elongation of metaxylem, cortical, and epidermal cells; and increased vacuolation of cells.

In our experiments, the most appropriate stage for possible application of growth regulators to maize proved to be BBCH 34–36. At this growth stage, the preparations containing ethephon considerably reduced plant height while diminishing yield the least. This application time for ethephon was also reported by Spitzer *et al.* (2011) as optimal in experiments with sunflower. Most experimental applications resulted in grain yield reduction. This effect was most apparent in ethephon-based preparations. Application of ethephon at the earliest time (BBCH 18–19) or in two applications (BBCH 18–19 and 34–36) led to considerably greater and statistically significant yield reduction which was in contrast with the effect upon application at BBCH 34–36. The dose of ethephon also plays an important role. Even at ethephon doses of 576 g/ha (the dose used in our experiments) applied at BBCH 34–36, it is necessary to count upon yield loss of 0.5–0.6 t/ha. Lovett and Campbell (1973) reported that mepiquat chloride and paclobutrazol reduced achene yield in sunflower by 26 and 29%, respectively. CCC decreased achene yield at a dose of 3 kg/ha, but at the doses of 1.5 kg/ha and 1.5 + 1.5 kg/ha (two applications).

Norberg *et al.* (1988) recorded reductions in lodging by two varieties of maize ranging from 9% to 30% when they applied ethephon at the rate of 0.56 kg/ha at the ear elongation stage. This rate resulted in the production of 52 fewer kernels per ear and of by 7–17 mg lower kernel weight while increasing the number of harvestable ears by 0.2–0.6 ears/m^2. Increasing the rate of ethephon resulted in a linear

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decrease in harvestable grain yield, except when applied at the ear elongation stage. Ethephon application had small but significant influence on the protein content, kernel density, and kernel breakage susceptibility of the grain produced. Although they observed ethephon application to be effective in reducing lodging of corn plant, ethephon never increased – and usually reduced – harvestable grain yields.

The results of our two-year study showed, that from the selected growth regulators only ethephon shortened maize height sufficiently to enable passing through the maize with mechanical equipment after closing of the rows without causing mechanical damage. Unfortunately, the use of ethephon leads to a decrease in yield. This situation is similar to that when using ethephon in spring barley. While it is known that ethephon works well against lodging, it does so with sacrifice of some yield when no lodging occurs. Ma and Smith (1992) recorded that ethephon, applied in spring barley at ZGS 39, reduced plant height and lodging but decreased yield by as much as 27% because of reductions in the number of grains per spike, number of main culm spikes, and/or weight per grain. Practical use of this study in maize therefore depends on whether the benefit from the protection against such harmful agents as diseases (e.g. *Fusarium*) and pests (*Diabrotica*) in the period after the closure of rows exceeds the negatives associated with the use of ethephon.

Our results show, that the height of ear setting was significantly lowered by applications of CCC + ethephon and of ethephon. This was due to the fact that all applications were made prior to the formation of female inflorescence and the shortening of plants occurred mainly through reducing the length of internodes below the ears. Lower height of ear setting along with generally shorter plants facilitate and accelerate the harvest and thus can also reduce loss of ears caused by their bouncing out of the maize head of the combine harvester.

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