Cycloxidim tolerant ZP maize production under different herbicide treatments

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Abstract
The yield and weediness of ZP 684Ultra maize hybrid under application of cycloxydim, alone or in combination with some postemergence herbicides for broad-leaf weed control, were evaluated. Maize tolerance to cycloxydim is achieved by the introduction of CTM allele into a single cross hybrid, for the maximal herbicide dose proposed by producer to be used in practice. The application of herbicides included nine treatments: cycloxydim+mesotrione, cycloxydim+tembotrione, only cycloxydim, all at different rates, and untreated control.
Grain yield was significantly higher in all treatments than in the control, and also in 2010 than in 2011. The most effective against weeds and yield productive were combinations of cycloxydim and tembotrione.

Key words: maize, production, cycloxydim tolerance, weeds

Introduction
The production of maize, as wide row crop, could be successful only with effective weed control. Cycloxydim is a systemic herbicide for post emergence application in dicot crops to selectively control grass weeds. The control of all grass weeds during the period when their number and coverage are optimal is possible by the application of Focus Ultra herbicide in tolerant maize crop, since there are no limits in herbicide application tied to crop (Malidža et al., 2007). With the aim of the complete protection of cycloxydim tolerant maize against weeds, the Focus Ultra preparation can be combined with the preparations for broad-leaf weeds control.
Cycloxydim-Tolerant Maize (CTM) was developed by researchers at the University of Minnesota in 1990. CTM plants were regenerated from tissue culture selected for callus growth in the presence of cycloxydim, and the resulting plants were shown to contain a mutation, expressed as a single, partially dominant gene that conferred tolerance to the herbicide (Parker et al., 1990). CTM hybrids were created by crossing the CTM inbred lines developed in the initial phase of the programme (Szél et al., 2010). The right of its use was obtained by the BASF Company, which is an owner of a herbicide licence. This company's preparation, the Focus Ultra herbicide, contains 100 g l⁻¹ of active ingredient, i.e. cycloxydim. It has to be noted that Focus Ultra cannot be applied in common maize hybrids and breeding of hybrids tolerant to cycloxydim achieved higher flexibility in control of annual and perennial grass weed species in maize crop.
Tolerance to cycloxydim can be achieved by the introduction of one CTM allele into a single cross maize hybrid, for the herbicide rates up to 4 l ha⁻¹, which is maximal dose proposed by producer to be used in practice (Vancetovic et al., 2009). The CTM homozigote was tolerant up to the final observed rate of 12 l ha⁻¹, but this dose is only of theoretical importance because cycloxydim provided excellent control of a broad range of important grass weeds in maize at rates from 100-200 g a.i. ha⁻¹ (Landes et al., 1996).
Critical to the success of this technology has been yield performance of CTM hybrids. At the same time, performance and herbicide tolerance do not exclude each other and can surely co-exist (Knezevic and Cassman, 2003). To be accepted, this coexistence must secure high profitability to maize producers. It has been developed eight ZP Ultra hybrids that were realised by the Commission for the Variety Realising (Vančetović et al., 2011). The objective of this study was to investigate the effects of the application of Focus Ultra herbicide at different rates, alone or in combination with two post-emergence broad-leaf weed control herbicides on the weed abundance and grain yield of ZPSC 684 Ultra hybrid.

Material and methods
Field experiments were conducted during 2010 – 2011 at the Maize Research Institute “Zemun Polje”, Belgrade. The winter wheat was the previous crop. The experimental area was ploughed in autumn, followed by one pass each of a disk harrow and a field cultivator prior to sowing. The maize hybrid ZPSC 684 Ultra was mechanically sown on the May 12th and April 29th in each year. The well known standard hybrid ZPSC 684 was converted into Ultra hybrid by the introduction of the dominant CTM gene into the ZP maize inbred by the inbred-backcrossing method, while segregating progenies were at the same time treated with the herbicide to destroy plants with no CTM allele.

The experiment was split plot design with four replications. Herbicides were applied on the June, 15 and May, 28 in each year, respectively by the tractor sprayer L.S.M. 220, Agroart, Stara Pazova with the capacity of 220 l ha⁻¹ equipped with 11004 nozzles.

Table 1. Herbicide treatments

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Herbicide combinations</th>
</tr>
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<tbody>
<tr>
<td>T1</td>
<td>cycloxydim+mesotrione, 300+250 g a.i. l⁻¹ (Focus ultra+Callisto, 3+0.25 l ha⁻¹)</td>
</tr>
<tr>
<td>T2</td>
<td>cycloxydim+mesotrione, 200+250 g a.i. l⁻¹ (Focus ultra+Callisto, 2+0.25 l ha⁻¹)</td>
</tr>
<tr>
<td>T3</td>
<td>cycloxydim+mesotrione, 150+250 g a.i. l⁻¹ (Focus ultra+Callisto, 1.5+0.25 l ha⁻¹)</td>
</tr>
<tr>
<td>T4</td>
<td>cycloxydim+tembotrione, 300+88 g a.i. l⁻¹ (Focus ultra+Laudis, 3+2 l ha⁻¹)</td>
</tr>
<tr>
<td>T5</td>
<td>cycloxydim+tembotrione, 200+88 g a.i. l⁻¹ (Focus ultra+Laudis, 2+2 l ha⁻¹)</td>
</tr>
<tr>
<td>T6</td>
<td>cycloxydim+tembotrione, 150+88 g a.i. l⁻¹ (Focus ultra+Laudis, 1.5+2 l ha⁻¹)</td>
</tr>
<tr>
<td>T7</td>
<td>cycloxydim, 400 g a.i. l⁻¹ (Focus ultra 4 l ha⁻¹)</td>
</tr>
<tr>
<td>T8</td>
<td>cycloxydim, 600 g a.i. l⁻¹ (Focus ultra 6 l ha⁻¹)</td>
</tr>
<tr>
<td>T9</td>
<td>cycloxydim+tembotrione, 600+88 g a.i. l⁻¹ (Focus ultra+Laudis, 6+2 l ha⁻¹)</td>
</tr>
<tr>
<td>C</td>
<td>Control</td>
</tr>
</tbody>
</table>

The elementary plot was 56.0 m² and whole biomass of weed plants (g m⁻²) was recorded after uprooting weeds manually from randomly selected two places with a 0.25 m² measuring per elementary plot, one month after herbicide application. The maize grain yield was obtained at the end of the growing season and calculated with 14 % of moisture.

The data were processed by statistical procedure using the package STATISTICA 8.0 for Windows (Analytical software, Faculty of Agriculture, Novi Sad, Serbia). The differences between treatments were determined by analysis of variance (ANOVA) and analysed by LSD-test (5 %) and multiple polynomial regression analysis.

Meteorological conditions during growing seasons were pretty different in 2010 and 2011. The mean daily temperatures were higher (20.1 °C) while the sum of precipitation was lower (273.3 mm) in 2011 than in long-term average (19.3 °C and 337.7 mm) what makes this year extremely dry for maize production. On the contrary, the 2010 year (19.3 °C and 447.2 mm) was more favourable for maize growing. A dry spell during the spring and summer in 2011 year was especially important since it coincided with maize sowing and the application of herbicides.

Results and discussion
The most abundant weed species in the investigated maize field were *Amaranthus hybridus* L., *Hibiscus trionum* L., *Polygonum convolvulus* L., and *Portulaca oleracea* L. as annual, and *Convolvulus arvensis* L. as perennial weed species. The grass weed species were almost absent. Despite lower amount of precipitation, the higher weed infestation of maize crop in most treatments was observed in 2011 than in 2010, (Figure 1). This is probably result of interaction between herbicide application and meteorological conditions and slower sprouting and lower vigour of ZPSC 684 Ultra hybrid in conditions of insufficient soil moisture. The presence of weeds was significantly \((p < 0.05)\) lowered in variants with herbicide application. The best effect of herbicides, in regard to weed biomass, was achieved by combination with Focus Ultra and Laudis in variants T5 and T9 in 2010, and T5 and T6 in 2011.

![Figure 1. Weed biomass in different herbicide treatments](image)

Irrespective to lower efficiency of applied herbicides to *Convolvulus arvensis* in all experimental variants in both years, the combinations of Focus Ultra + Laudis showed better effect than Focus ultra + Callisto. But, tembotrione was not efficient enough for *Polygonum convolvulus* control which was highly present in variant T4 and T6, (Santel, 2009). Even though the major advantages of cycloxydim are its wide range of activity, reliable efficiency and its timing flexibility up to the shooting stage of the grass weeds, the activity of cycloxydim for succesfull weed control in maize should be supplemented with suitable broadleaf herbicides (Landes et al., 1996; Malidža and Orbović, 2004). Oposite of this experiment and according to results of Malidža and Orbović (2004), in conditions with domination of grass weeds, like *Sorghum halepense*, application of Focus Ultra herbicide alone in quantities of 1.5 and 2.1 ha\(^{-1}\) was more efficient than application of some combinations with herbicides for broad-leaf weeds control, particularly during dry years. The application of 4 and 6 l ha\(^{-1}\) of Focus Ultra at treatments T7, T8 and T9 caused a transitory bleaching of the newly-formed leaves of ZPSC 684 maize hybrid but only in 2010, without affecting grain yield (Malidža et al., 2007).

Grain yield of ZPSC 684 Ultra maize hybrid was significantly higher in all variants with herbicide application, compared to untreated control (6.6 and 4.9 t ha\(^{-1}\)). The average grain yield was higher in 2010 significantly (10.4 t ha\(^{-1}\)), than in 2011 (8.9 t ha\(^{-1}\)), (Table 2). In both experimental years and on the average, the highest yield was achieved with T6 and T4 treatments, which included application 1.5 and 3 l ha\(^{-1}\) of Focus Ultra and 2 l ha\(^{-1}\) of Laudis.
Compared to these treatments, in T9 with application of Focus Ultra in the higher amount, grain yield was lower more than 1 t ha\(^{-1}\), irrespective to the high herbicide efficiency against weeds.

Table 2. Grain yield of ZP 684 Ultra hybrid (t ha\(^{-1}\))

<table>
<thead>
<tr>
<th></th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>T5</th>
<th>T6</th>
<th>T7</th>
<th>T8</th>
<th>T9</th>
<th>C</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>11.3</td>
<td>9.2</td>
<td>9.5</td>
<td>12.8</td>
<td>10.8</td>
<td>12.6</td>
<td>10.7</td>
<td>9.3</td>
<td>11.1</td>
<td>6.6</td>
<td>10.4</td>
</tr>
<tr>
<td>2011</td>
<td>9.7</td>
<td>9.7</td>
<td>6.2</td>
<td>10.5</td>
<td>9.6</td>
<td>11.0</td>
<td>8.3</td>
<td>9.5</td>
<td>9.2</td>
<td>4.9</td>
<td>8.9</td>
</tr>
</tbody>
</table>

According to regression analysis, the significant correlation between grain yield of ZP 684 Ultra maize hybrid and weed biomass can be noticed at treatments T3, T4 and T5, (Figure 2). The increase of grain yield in T4, T6 and T9 was accomplished owing to significant decrease in weed biomass.

Figure 2. The regression analysis of interdependence between average maize grain yield and weed biomass, 2010-2011

**Conclusion**

The development of cycloxydim tolerant maize varieties offers, combined with the use of the respective herbicides, new possibilities for targeted effective weed control in maize. The most suitable herbicide treatment for efficient weed control and high yield achieving in ZP 684 Ultra maize hybrid, for agro ecological conditions of Zemun Polje, are those that included recommended rates of cycloxydim up to a 4 l ha\(^{-1}\) in combination with herbicides for broad-leaf postemergence weed control.

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Proizvodnja kukuruza tolerantnog prema cikloksidimu uz primjenu herbicida

Sažetak
Istražavana je visina prinosa i stupanj zakorovljenosti ZP 684Ultra hibrida kukuruza nakon primjene cikloksidima, pojedinačno i u kombinaciji s herbicidima za suzbijanje širokolistih korova. Tolerantnost kukuruza prema maksimalno preporučenoj količini cikloksidima za primjenu u praksi, postignuta je unošenjem CTM alela u jednostruki hibrid. Primjena herbicida je uključivala devet tretmana: cikloksidim+mezotrion, cikloksidim+tembotrion i cikloksidim, svi tretmani u više različitih količina i netretiranu kontrolu.

Prinos zrna je bio značajno veći u tretmanima s primjenom herbicida u odnosu na netretiranu kontrolu u 2010.godini. u odnosu na 2011. godinu gdje je prinos smanjen. Najveću učinkovitost na korove i na produktivnost kukuruza polučile su kombinacije cikloksidima i tembotriona.

Ključne riječi: kukuruz, prinos, tolerantnost, cikloksidim, korovi