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RESPONSE OF FODDER MAIZE CULTIVARS TO THE MIXTURE OF FLORASULAM AND 2.4-D (MUSTANG 306 SE HERBICIDE)

Grażyna Szymańska[1], Hanna Sulewska[1], Agnieszka Faligowska[1], Karolina Ratajczak[1], Bartosz Tomczak[2]

[1]*Department of Agronomy, Poznan University of Life Sciences, Dojazd 11, 60-632 Poznań*
[2]*Dow AgroSciences Polska*

Abstract. The aim of this study was to evaluate the effect of Mustang 306 SE herbicide selectivity (mixture of florasulam 6.25 $g \cdot l^{-1}$ and 2.4-D 300 $g \cdot l^{-1}$) applied to 13 fodder maize hybrids. Two doses of the herbicide were applied (0.6 and 1.2 $dm^3 \cdot ha^{-1}$) at the 5-6 leaf stage of maize (BBCH scale 15–16). The first visual evaluation of selectivity was carried out 7 days after the treatment and was continued at 7-day intervals, until no symptoms of plant injuries were found. The mixture of florasulam and 2.4-D had no influence on grain yield of the tested maize hybrids; however, thousand grain weight decreased after its application. Susceptibility of individual maize hybrids to Mustang 306 SE herbicide varied and was most dependent on the weather patterns. The most severe injury symptoms in all the tested hybrids were observed in the second year of the study at low soil moisture.

Key words: phytotoxicity, maize hybrids, florasulam, 2.4-D, grain yield

INTRODUCTION

The application of herbicides constitutes an integral part of maize cultivation technology and is currently one of the most basic pesticide treatments with favorable effects on yield [Idziak and Woźnica 2013]. Cultivation of maize in wide row spacing, at low seeding rate and slow growth of seedlings at the beginning of the vegetation season may lead to a situation where weeds become dangerous competitors for nutrients, water and light [Adamczewski et al. 1997, Evans et al. 2003, Gąsiorowska and Makarewicz 2008, Idziak and Woźnica 2008]. That is why proper application of herbicides has a significant effect on yield levels and may affect economical results of cultivation of any species [Sulewska and Koziara 2006, Sulewska et al. 2012]. According to the literature, one of the most negative effects of herbicides is that they are not always selective to the cultivated plants. They can disrupt a number of plant life processes, which can adversely affect plant morphology (causing necrosis, growth inhibition, deformation) and lead to abnormal photosynthesis, inhibition of amino acid synthesis, and even complete destruction of plants [Rola and Gołębiowska 2003, Waligóra and Szpurka 2009]. Long-term studies on the response of maize cultivars to herbicides indicate that lower selectivity of individual hybrids can result from an interaction of genotypic characteristics, weather and environmental conditions, as well as the mode of action of the herbicides [Gołębiowska and Sekutowski 2007, Rola and Gołębiowska 2003, Weber and Gołębiowska 2009b]. Gołębiowska and Kowalczyk [2007] also claimed that maize from warmer climate zones with small daily temperature amplitudes, in conditions of cold spring and low soil moisture at the beginning of vegetation can become less

[1] *Corresponding address* – Adres do korespondencji: ptasz@up.poznan.pl

tolerant to herbicides due to the slower decomposition of active ingredients and their lower rate of translocation in plants.

Due to the increased cultivation area of maize in Poland and wide range of assortment offer on Polish seed market, cultivars that have stable yields and are adapted to the changeable climate, soil conditions and various methods of chemical protection, are currently in high demand [Weber and Gołębiowska 2009a]. Therefore, it is necessary to conduct studies on new maize hybrids emerging on the market in terms of their susceptibility to herbicides, especially with the widely used herbicide Mustang 306 SE. In the future, this may provide a chance of avoiding any losses and choosing a variety that is least susceptible to any chemical treatment.

The aim of this study was to evaluate selectivity of the herbicide Mustang 306 SE (a mixture of florasulam and 2.4-D) applied in thirteen newest hybrids of fodder maize.

MATERIAL AND METHODS

Field selectivity trials were carried out in 2009 and 2010 on the fields of the Experimental Station in Złotniki, belonging to the Poznań University of Life Sciences (N 52°29′ N, 16°49′ E). The experiments were established after winter triticale on luvisols soil, sand grade, shallowly deposited on light clay [FAO 2006] with pH of 5.8–5.9. The herbicide Mustang 306 SE (a mixture of florasulam and 2.4-D) was applied at two rates: 0.6 $dm^3 \cdot ha^{-1}$ (registered rate) and 1.2 $dm^3 \cdot ha^{-1}$, and its effect was evaluated against the control plot, where weeds were controlled manually. The following cultivars were tested: Sudoku (FAO 210–220), Bredero (FAO 230), Sunaro (FAO 230–240), Suzy (FAO 240–250), PR 39D23 (FAO 260), PR 38A79 (FAO 270), Mas 24.A (FAO 260), Es Titania (FAO 240), Pravor (FAO 230–240), Es Palazzo (FAO 230), Es Beatle (FAO 250), Mas 23.B (FAO 250) and LG 32.16 (FAO 250). The tested herbicide was applied at the 5–6 leaf stage of maize (BBCH scale 15–16) using a bicycle sprayer equipped with a Tee Jet 110 03 VP nozzle, calibrated to 200 $dm^3 \cdot ha^{-1}$ spray volume at 0.15 MPa. The area of individual plots was 21 m^2 (15 m x 1.4 m). The tested maize varieties were sown with a pneumatic seeder at a density of 89 thousand seeds·ha^{-1} and a depth of 5 cm. The mineral fertilizer rates (148 kg N·ha^{-1}; 60 kg P·ha^{-1}; 90 kg K·ha^{-1} respectively) were matched to the level of individual nutrients in soils. The first visual assessment of selectivity was conducted 7 days after treatment, according to EPPO standards PP/135 (3) [EPPO 1982], and was continued at 7-day intervals until no symptoms of plant injuries could be found. The scope of phytotoxic plant injury was estimated according to the EWRC scale (1 – no injury; 9 – complete kill). Plant injuries were then compared with the reference plots not treated. Additionally, the experiment assessed the effect of chemical weed control to such characteristics as grain yield (at 15% moisture), 1000 grain weight, ear number per square meter, grain moisture content, plant height and grain test weight.

Data were evaluated statistically using the analysis of variance for two-factorial experiments. The diversity of results was measured using t-Student's test on the basis of least significant differences (LSD) with statistical significance $\alpha = 0.05$.

RESULTS AND DISCUSSION

Years of the trial characterized by significant differences in weather conditions. Detailed weather conditions during the growing seasons of 2009–2010 are shown in Table 1. In both years the conditions during the day of the application were similar. The temperature during the spraying in 2009 was 19.0°C and 20.0°C in 2010, with air humidity of 50% and 80%, respectively. However, the years differed in terms of soil moisture. The first year (2009) was signifi-

Table 1. Mean air temperature and sum of precipitations in 2009–2010 in the Experimental Station Złotniki

Month	Air temperature (°C)					Precipitations (mm)				
	Decade			Mean	1951 –2010	Decade			Total	1951 –2010
	I	II	III			I	II	III		
2009										
IV	13.8	12.8	16.1	14.2	8.5	0.0	4.0	12.0	16.0	31.3
V	14.5	14.9	15.8	15.1	14.2	9.0	13.5	69.8	92.3	48.0
VI	14.7	15.8	19.5	16.7	17.4	33.5	45.0	50.6	129.1	57.8
VII	22.8	21.4	21.0	21.7	19.1	46.6	32.8	25.2	104.6	74.5
VIII	22.4	20.9	21.0	21.4	18.4	6.7	19.4	0.0	26.1	54.2
IX	18.7	17.2	15.0	17.0	13.8	41.7	0.0	12.2	53.9	45.8
X	11.7	4.9	7.2	7.9	9.1	12.8	30.9	15.7	59.4	34.8
2010										
IV	8.9	10.3	12.4	10.5	8.5	16.5	11.0	11.0	38.5	31.3
V	11.1	11.3	13.6	12.0	14.2	18.3	48.2	68.1	134.6	48.0
VI	20.3	17.5	19.9	19.2	17.4	17.0	8.6	1.0	26.6	57.8
VII	23.3	25.3	20.6	23.0	19.1	18.7	10.1	72.1	100.9	74.5
VIII	20.2	20.8	17.9	19.6	18.4	47.3	33.8	51.3	132.4	54.2
IX	13.1	13.5	13.5	13.4	13.8	21.4	18.1	29.0	68.5	45.8
X	9.3	5.6	5.9	6.9	9.1	0.0	1.8	5.4	7.2	34.8

cantly more moist; total precipitation during 3 weeks after the application was 116.0 mm, while it was only 9.6 mm in 2010.

The two-year study showed that maize hybrids used in the experiments responded differently to the mixture of florasulam and 2.4-D (Mustang 306 SE) applied in the tested doses. Injuries of maize plants were found after applying both doses of the herbicide. The typical phytotoxic symptoms caused by Mustang 306 SE included growth inhibition, disturbed leaf inclination, spotting and deformation of leaf blades and leaf curling in later stages of development. Such symptoms were also confirmed by studies of other authors [Gołębiowska and Sekutowski 2007, Kierzek 2008]. Gołębiowska et al. [2009] stated that the mode of action of Mustang 306 SE, containing florasulam that inhibits the biosynthesis of amino acids (ALS) enzyme, and 2.4-D, a growth regulator ingredient, in some cultivars can cause leaf curving, which may limit tassel emergence, delay pollination and inhibit plant growth. In the first year of the study, among all the 13 tested hybrids transient symptoms of phytotoxicity were observed only in three cultivars (Bredero, Mas 24.A and Mas 23.B). Plant injuries were observed on those tested cultivars only after application of the higher dose of herbicide (1.2 $dm^3 \cdot ha^{-1}$). The degree of injury in the EWRC scale for these cultivars ranged from 2º to 3º and the symptoms were evident the longest in the hybrid cv. Bredero (approx. 6 weeks). However, during drought conditions in 2010 all maize hybrids were less tolerant to the mixture of florasulam and 2.4-D (Table 2). It should be emphasize here that in 2010 the application of the herbicide at the recommended dose (0.6

Table 2. Selectivity assessment of maize plants after the application of different doses of a mixture of florasulam + 2.4 D in 2010

Hybrid	Treatment	Crop damage (1–9°)					
		Time after application (weeks)					
		1	2	3	4	5	6
Sudoku	Mustang 306 SE 0.6 $dm^3 \cdot ha^{-1}$	1*	3	2	1	1	1
	Mustang 306 SE 1.2 $dm^3 \cdot ha^{-1}$	2	4	3	1	1	1
Bredero	Mustang 306 SE 0.6 $dm^3 \cdot ha^{-1}$	1	1	1	1	1	1
	Mustang 306 SE 1.2 $dm^3 \cdot ha^{-1}$	3	4	4	4	2	1
Sunaro	Mustang 306 SE 0.6 $dm^3 \cdot ha^{-1}$	1	1	1	1	1	1
	Mustang 306 SE 1.2 $dm^3 \cdot ha^{-1}$	3	2	2	1	1	1
Suzy	Mustang 306 SE 0.6 $dm^3 \cdot ha^{-1}$	1	3	2	1	1	1
	Mustang 306 SE 1.2 $dm^3 \cdot ha^{-1}$	2	3	2	1	1	1
PR 39D23	Mustang 306 SE 0.6 $dm^3 \cdot ha^{-1}$	1	2	1	1	1	1
	Mustang 306 SE 1.2 $dm^3 \cdot ha^{-1}$	3	2	2	1	1	1
PR 38A79	Mustang 306 SE 0.6 $dm^3 \cdot ha^{-1}$	1	1	1	1	1	1
	Mustang 306 SE 1.2 $dm^3 \cdot ha^{-1}$	2	2	2	1	1	1
Mas 24.A	Mustang 306 SE 0.6 $dm^3 \cdot ha^{-1}$	2	1	1	1	1	1
	Mustang 306 SE 1.2 $dm^3 \cdot ha^{-1}$	3	4	3	2	1	1
Es Titania	Mustang 306 SE 0.6 $dm^3 \cdot ha^{-1}$	1	1	1	1	1	1
	Mustang 306 SE 1.2 $dm^3 \cdot ha^{-1}$	1	2	2	1	1	1
Pravor	Mustang 306 SE 0.6 $dm^3 \cdot ha^{-1}$	1	1	1	1	1	1
	Mustang 306 SE 1.2 $dm^3 \cdot ha^{-1}$	3	3	2	1	1	1
Es Palazzo	Mustang 306 SE 0.6 $dm^3 \cdot ha^{-1}$	1	1	1	1	1	1
	Mustang 306 SE 1.2 $dm^3 \cdot ha^{-1}$	1	2	2	1	1	1
Es Beatle	Mustang 306 SE 0.6 $dm^3 \cdot ha^{-1}$	1	1	1	1	1	1
	Mustang 306 SE 1.2 $dm^3 \cdot ha^{-1}$	3	3	2	1	1	1
Mas 23.B	Mustang 306 SE 0.6 $dm^3 \cdot ha^{-1}$	1	1	1	1	1	1
	Mustang 306 SE 1.2 $dm^3 \cdot ha^{-1}$	2	4	3	1	1	1
LG 32.16	Mustang 306 SE 0.6 $dm^3 \cdot ha^{-1}$	2	1	1	1	1	1
	Mustang 306 SE 1.2 $dm^3 \cdot ha^{-1}$	4	3	2	1	1	1

*1 – no injury, 9 – plant death

$dm^3 \cdot ha^{-1}$) resulted in visible phytotoxic symptoms only in cv. Sudoku and Suzy, while temporary injury symptoms were observed in cv. PR 39D23 and Mas 24.A. Such a different response of maize hybrids to the herbicide mixture in the individual years could be explained by different environmental conditions concerning soil moisture after the experiments. The first year was significantly moist resulting in a better health condition of plants. Moreover, the herbicide did not interfere with the physiological processes in maize plants. There are numerous reports in litera-

ture that confirm the effect of weather patterns on lower plant tolerance to herbicides. According to some researchers, varietal characteristics and tolerance of cultivated plants is lowered during adverse weather conditions, especially during the spring season with low humidity and high temperatures [Gołębiowska and Rola 2008, Gołębiowska and Sekutowski 2007, Gołębiowska et al. 2009, Kierzek 2008]. In the second year of the experiment, lower tolerance was also observed among the tested maize hybrids when the dose of applied herbicide was higher. Similar results were obtained by Kierzek [2008], though it needs to be stressed that author, while assessing susceptibility of plants to the mixture of florasulam and 2.4-D, applied in different doses and at delayed dates of treatment, observed that phytotoxicity was more dependent on the date of the test, rather than the herbicide dosage. In both years of the experiment, the most severe and persistent phytotoxic effect of the florasulam and 2.4-D mixture was observed in the hybrid cv. Bredero. In the second year, a higher dose of the herbicide was applied in the test variants and the experiments showed that hybrid cv. Sudoku, Mas 24.A, Mas 23.B and LG 32.16 were less tolerant to the substance than the other tested cultivars. According to Gołębiowska et al. [2009], such a diversified response is determined genetically and can be modified by a number of ways through climate, soil conditions and human influence. What is more, the mode of action of ALS inhibitor herbicides that inhibits biochemical processes in the tissue can interfere with proper plant growth in sensitive cultivars, which can lead to changes in their morphology. Kierzek [2008] reported that phenoxy acid herbicides, especially 2.4-D, due to their variable effects on weed control and potential induction of phytotoxic reactions, are rarely used for weed control in maize.

Following the application of Mustang 306 SE no significant changes were observed in plant height, yielding, number of ears per unit area, grain moisture or grain test weight (Table 3). However, different results were presented by Weber and Gołębiowska [2009b], who after application of Mustang 306 SE at 1.2 $dm^3 \cdot ha^{-1}$ obtained lower grain yields in comparison to the treatment where the herbicide dose was reduced by 50%. They also showed that this herbicide had relative discrimination index in differentiation of yields. Due to the partial selectivity of Mustang 306 SE in relation to the tested maize hybrids, thousand grain weight was significantly lower in comparison to the untreated control. Gołębiowska et al. [2009] obtained similar results and stated that the phytotoxic effect of Mustang 306 SE (0.6 $dm^3 \cdot ha^{-1}$) was manifested in the decrease of thousand grain weight in cv. PR39H32. Similar effects of this herbicide were also reported by those authors in their earlier studies [Gołębiowska and Sekutowski 2007]. There is also some information in the literature indicating that the application of a mixture of Mustang 306 SE + Antywylegacz liquid 675 SL (chlormequat 675 $g \cdot dm^3$) + Cerone 480 SL (ethephon 480 $g \cdot dm^3$) resulted in a significant increase in thousand grain weight and in yielding of winter wheat [Marczewska-Kolasa and Kieloch 2009]. Idziak et al. [2012] also pointed out that pinoxaden and florasulam used independently and in mixtures have no effect on winter wheat and at the same time they promote a higher grain yield and an increase in thousand grain weight.

The analysis of variance showed high variability in grain yield of tested maize hybrids (Table 3). The medium early hybrid Es Titania was the cultivar with the highest yield (12.3 $t \cdot ha^{-1}$) and the highest tolerance to florasulam and 2.4-D mixture. It is also worth mentioning that hybrids Suzy and PR 38A79 that were temporarily injured by the herbicide produced high grain yields (12.4 and 12.6 $t \cdot ha^{-1}$, respectively). Hybrids Pravor and Es Palazzo had the lowest yields (under 11.0 $t \cdot ha^{-1}$). It can be assumed that this could have been caused by worse genotypic adaptation to environmental conditions in the Wielkopolska region, which was indicated in study by Weber and Gołębiowska [2009a]. Gołębiowska and Kowalczyk [2007] also showed that maize hybrids of foreign origin are less tolerant to lower temperatures in the early stages of growth and development. As a result, after the application of herbicides more extensive injuries can be

Table 3. Grain yield, yield components and morphological characteristics of maize plants (mean of 2010–2011)

Experimental factor	Plant height (cm)	Grain yield ($t \cdot ha^{-1}$)	Number of cobs ($szt \cdot m^2$)	Thousand grain weight (g)	Grain moisture (%)	Grain test weight ($kg \cdot hl^{-1}$)
Maize hybrids						
Sudoku	234	12.1	7.8	266	35.3	74.7
Bredero	231	11.4	8.4	326	35.5	69.6
Sunaro	240	11.4	8.6	310	34.4	73.9
Suzy	235	12.4	8.8	308	36.3	72.1
PR 39D23	220	11.1	8.9	294	35.8	74.5
PR 38A79	256	12.6	8.1	300	39.9	66.5
Mas 24.A	244	11.6	7.7	328	36.2	71.6
Es Titania	251	12.3	8.7	354	33.5	77.3
Pravor	242	10.2	8.2	302	34.7	77.2
Es Palazzo	248	10.8	7.2	318	33.3	71.7
Es Beatle	250	11.4	7.8	343	34.8	72.1
Mas 23.B	256	11.7	8.2	323	35.9	69.0
LG 32.16	231	11.3	8.2	357	34.4	72.7
$LSD_{0.05}$	n.s.	1.3	n.s.	33	1.6	n.s.
Herbicide						
Untreated	242	11.6	7.8	324	35.9	73.4
Mustang 306 SE 0.6 $l \cdot ha^{-1}$	242	11.5	8.4	316	34.7	72.9
Mustang 306 SE 1.2 $l \cdot ha^{-1}$	239	11.6	8.4	312	35.6	71.3
$LSD_{0.05}$	n.s.	n.s.	n.s.	6	n.s.	n.s.

n.s.– non-significant differences

observed, which may lead to yield reductions, especially following low temperatures and low soil moisture, in comparison to the hybrids that were selected for the Polish climate.

Our studies also showed that the hybrids differed in thousand grain weight and grain moisture (Table 3). Hybrids LG 32.16, Es Titania and Es Beatle has the highest thousand grain weight (357, 354 and 343 g, respectively), while cv. Sudoku and PR 39D23, considered as moderately susceptible to the mixture of florasulam and 2.4-D, had significantly lower thousand grain weight, which was 266 g and 294 g, respectively. The medium late PR 38A79 hybrid had the significantly highest grain moisture (39.9%). Grain moisture content in other hybrids was definitely lower, between 33.3 and 36.3%. According to Szmigiel and Oleksy [2004], grain moisture content in individual maize hybrids depends first of all on their earliness, followed by weather patterns and canopy density. They also indicated that the late cultivars had higher grain moisture contents at the time of harvest.

CONCLUSIONS

1. The mixture of florasulam and 2.4-D in the applied doses (0.6 and 1.2 $dm^3 \cdot ha^{-1}$) did not affect grain yields of the tested maize hybrids. However, its application, regardless of the dose, led to lower thousand grain weight.
2. Susceptibility of individual maize cultivars to the mixture of florasulam and 2.4-D was diversified and was most dependent on weather conditions. The most intensive phytotoxic response in all the tested hybrids was observed in the second year of the study, at low soil moisture.
3. The mixture of florasulam and 2.4-D applied in a higher dose (1.2 $dm^3 \cdot ha^{-1}$) appeared to be the most selective in relation to cv. Es Titania and Es Palazzo. The most acute phytotoxic symptoms of the longest duration were observed on cv. Bredero.
4. The diversified response of the tested cultivars to the herbicide Mustang 306 SE indicates that it is necessary to evaluate susceptibility of new cultivars to herbicides that are commonly used in the agricultural practice.

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G. Szymańska, H. Sulewska, A. Faligowska, K. Ratajczak, B. Tomczak

REAKCJA ODMIAN KUKURYDZY PASTEWNEJ NA STOSOWANIE MIESZANINY SUBSTANCJI AKTYWNYCH FLORASULAM + 2,4-D (MUSTANG 306 SE)

Synopsis. Celem przeprowadzonych badań była ocena selektywności herbicydu Mustang 306 SE (mieszanina florasulamu + 2,4-D) stosowanego w uprawie 13 mieszańców kukurydzy pastewnej. Herbicyd stosowano w dwóch dawkach (0,6 oraz 1,2 $dm^3 \cdot ha^{-1}$) w fazie 5–6 liści kukurydzy (BBCH 15–16). Pierwszą wizualną ocenę selektywności przeprowadzono 7 dni po zabiegu i kontynuowano ją w odstępach 7-dniowych aż do momentu stwierdzenia braku objawów uszkodzeń roślin. Mieszanina 2,4-D + florasulam nie miała wpływu na plon ziarna badanych mieszańców kukurydzy. Zastosowanie tej mieszaniny prowadziło natomiast do obniżenia masy tysiąca ziaren. Wrażliwość poszczególnych mieszańców kukurydzy na stosowanie herbicydu Mustang 306 SE była zróżnicowana i zależała przede wszystkim od układu warunków pogodowych. Silniejszą reakcję fitotoksyczną roślin wszystkich badanych mieszańców, stwierdzono w drugim roku badań w warunkach słabego uwilgotnienia gleby.

Słowa kluczowe: fitotoksyczność, mieszańce kukurydzy, florasulam, 2,4-D, plon ziarna

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