

CHEMICAL METHODS OF WEED CONTROL IN MAIZE (*Zea mays* L.) IN VARIABLE WEATHER CONDITIONS

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Abstract. In years 2009-2011, four strict field experiments were carried out whose aim was to evaluate herbicides registered for maize applied at lowered doses, against variable weather conditions. Herbicides were applied in the following system: preemergence treatment with s-metolachlor + terbuthylazine + mesotrione and foliage treatment at the 4-6-leaf stage of maize with nicosulfuron + rimsulfuron, nicosulfuron, rimsulfuron, and foramsulfuron + iodosulfuron. Adjuvant Atpolan Bio 80 SL was added to herbicides used in the foliage treatment. Regardless of the weather conditions in the particular growth seasons, the best maize weeding effects were obtained after the preemergence application of the mixture s-metolachlor + terbuthylazine + mesotrione, and subsequently the foliage application of nicosulfuron with adjuvant Atpolan Bio 80 SL. In the conditions of delayed and uneven weed emergence (especially the thermophilic weed species), the system of two treatments with lowered herbicide doses protected most effectively the maize plantation against secondary weed infestation.

Key words: adjuvant, foliage treatment, lowered herbicide doses, preemergence treatment, secondary weed infestation, weed control systems

INTRODUCTION

Weed control in maize is the most important treatment. It results from literature that the presence of weeds in the field causes significant yield losses, up to 13% with the application of precautionary methods and nearly 30% in the case of renunciation of any kind of protection [Oerke and Steiner 1996, Dogan *et al.* 2004]. Strong competition on the part of burdensome species and their compensation in the field in extreme cases may lead to nearly 70% loss of maize grain yield [Teasdale 1995]. Increasing maize cultivation area causes plantation infestation to increase. This tendency results mostly from the appearance of species resistant to the application of the same herbicides, which took place in the case of triazine herbicides [Rubin 1996, Paradowski 2008, Green and Owen 2011].

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Unfavourable weather conditions and prolonged draught periods in some regions of Poland are a cause of variable effectiveness of chemical weed control in maize. In the above conditions, of particularly low effectiveness are preemergence herbicides, applied before cultivated plant emergence. After the period of more intense precipitation, mass emergence of new weeds is observed on many plantations, especially of thermophilic species, and therefore it may turn out that earlier preemergence treatment may not guarantee proper plantation protection against weed infestation at the critical stage of maize growth and development. Warm and early spring is conducive to faster weed development [Gołębiowska 2006]. On the other hand, long periods of low temperatures and lack of precipitation after maize sowing lower herbicide effectiveness in relation to species that emerge in masses at a later time [Gołębiowska and Snopczyński 2008].

Another significant factor that causes problems with effective maize plantation protection against weed infestation is cultivation simplifications and departing from traditional crop rotation in favour of several-years-long maize monocultures. It was found that in maize grown in monoculture, *Echinochloa crus-galli* L. and *Chenopodium album* L. significantly increased their participation, and renunciation of traditional crop rotation contributed to the appearance of new weed species, such as *Solanum nigrum* L. or *Galeopsis tetrahit* L., which grew on the plantation up to the harvest [Gołębiowska and Kaus 2009b].

Negative effects of climate change, as well as simplifications in agrotechnics, lead to situations in which the application of a single herbicide treatment in maize may not guarantee full plantation protection against weed infestation during the entire growth season [Gołębiowska *et al.* 2004]. In this situation, there is a necessity for searching for new possibilities of effective systems of weed control in maize in a longer growth period, and also for better cultivation protection against secondary weed infestation [Gołębiowska 2006, Kierzek *et al.* 2011].

The aim of the study was the evaluation of weed control effectiveness in maize with the use of lowered herbicide doses on two application dates: preemergence treatment and subsequently foliage treatment, in relation to variable weather conditions.

MATERIAL AND METHODS

Field experiment was carried out in years 2009-2011 on four individual farms that grew maize for grain in the villages of Nieczajna, Dąbrówka, Gąsawy, and Głuchowo. Data concerning the geographical locations can be found in Table 1. All the experiments were set as split-block design in four repetitions. On every plot of the size of 2.25 x 6 m, the plants were placed in three rows at the spacing of 75 cm.

Weed control treatments were carried out on two dates:

- T0 – directly after sowing – preemergence treatment,
- T2 – at the 4-6-leaf stage of maize – foliage treatment.

Herbicides applied in the system of two independent treatments were used at lowered doses. Active ingredients and doses are given in Table 2. Adjuvant Atpolan Bio 80 SL (methyl ester of rapeseed oil + pH stabilizers) was added to the herbicides applied in the foliage treatment. For comparative reasons, as the standard, preemergence treatment was carried out with the use of herbicide Lumax 537 SE at the recommended dose of 3.5 dm³·ha⁻¹. Weather course before and after treatment dates and between them in the particular years and locations are given in Table 3.

Table 1. List of locations, treatment dates, and chosen weather conditions for the field experiments in years 2009-2011
Tabela 1. Wykaz lokalizacji, terminów wykonywania zabiegów oraz wybrane warunki pogodowe dla doświadczeń polowych w latach 2009-2011

Location Miejscowość	Coordinates Współrzędne	Year Rok	Weather conditions – Warunki pogodowe							
			14 days before To 14 dni przed To				14 days after T2 14 dni po T2			
			precipitation suma opadów	mean temperature średnia temperatura	To*	precipitation suma opadów	mean temperature średnia temperatura	T2	precipitation suma opadów	mean temperature średnia temperatura
Nieczajna	52°34' N; 16°46' E	2009	17.9	12.2	29.04	25.4	13.0	26.05	92.2	12.5
Dąbrowka	52°22' N; 16°44' E	2009	10.4	13.8	04.05	21.2	13.5	26.05	80.4	12.2
Gąsawy	52°36' N; 16°36' E	2010	11.4	8.3	29.04	73.4	11.4	01.06	6.2	18.8
Głuchowo	52°20' N; 16°46' E	2011	0.6	14.1	28.04	9.4	13.9	25.05	9.6	18.8

* treatment date – termin zabiegu; To – preemergence, before emergence of maize (BBCH 00) – doglebowo, przed wschodami kukurydzy BBCH 00; T2 – after emergence – foliage, maize at the 4-6 leaf stage (BBCH 14-16) – powschodowo – nalistnie, w fazie 4-6 liści kukurydzy (BBCH 14-16)

Table 2. List of herbicides and their doses used in the experiments
Tabela 2. Wykaz herbicydów dawek w doświadczeniach

Herbicide Herbicyd	Active ingredient (a.i.) Substancja aktywna (s.a.)	Dose, g a.i. · ha ⁻¹ – Dawka, g s.a. · ha ⁻¹		Percentage of the maximum recommended dose applied in the experiments Procent zalecanej dawki maksymalnej stosowanej w badaniach	
		recommended maximum dose maksymalna według zaleceń	tested lowered doses testowane dawki obniżone	tested lowered doses testowane dawki obniżone	Procent zalecanej dawki maksymalnej stosowanej w badaniach
Lumax 537,5 SE	S-metolachlor- <i>t</i> -terbutylazine + mesotrione	1094+ 656 + 131	470 + 280 + 56		43
Hector 53,6 WG*	nicosulfuron + rimsulfuron	38.6 + 9.6; 30 + 7.5	15 + 3.7		39-50
Milagro 040 SC**	nicosulfuron	40-60	20		33-50
Titus 25 WG	rimsulfuron	15	7.5		50
MaisTer 310 WG***	foramsulfuron + iodosulfuron – methyl-sodium	30 + 1; 45 + 1.5	15 + 0.5		33-50

* herbicide Hector 53.6 WG applied at the recommended dose in the range of 70-90 g·ha⁻¹ – dawka herbicydu Hector 53,6 WG zalecana w zakresie 70-90 g·ha⁻¹
** herbicide Milagro 040 SC applied at the recommended dose in the range of 1.0-1.5 dm³·ha⁻¹ – dawka herbicydu Milagro 040 SC zalecana w zakresie 1,0-1,5 dm³·ha⁻¹
*** herbicide MaisTer 310 WG applied at the recommended dose in the range of 0.1-0.15 kg·ha⁻¹ – dawka herbicydu MaisTer 310 WG zalecana w zakresie 0,1-0,15 kg·ha⁻¹

Table 3. Sum of monthly precipitation in 2009-2011

Tabela 3. Suma miesięcznych opadów atmosferycznych w latach 2009-2011

		Precipitation – Opady, mm					
year rok	location miejscowość	April kwiecień	May maj	June czerwiec	July lipiec	August sierpień	sum April-August suma kwiecień – sierpień
2009	Dąbrówka	16.4	82.0	96.8	92.6	13.8	301.6
2009	Nieczajna	18.3	77.8	92.4	55.6	16.6	260.7
2010	Gąsawy	19.4	73.0	7.6	102.0	92.2	294.2
2011	Głuchowo	7.2	9.4	55.0	88.2	30.0	189.8
Many years' mean Średnia z wielolecia 1951-2010		33.6	52.3	57.0	72.2	55.9	271.0

Observations of the control effects of the most frequently occurring mono-cotyledonous and dicotyledonous weeds were carried out twice, namely four weeks after the final treatment (4 WAT) and several weeks before cob harvest (SW) in order to evaluate secondary weed infestation. For the evaluation of herbicide effect, the visual method was used, that is plant state and condition were compared in the plots treated with herbicides and on the untreated plots (without weed control). The results were presented at the percentage scale, where 0% means lack of herbicide effect, and 100% means complete weed destruction. During the evaluation, also phytotoxic effect of herbicides was estimated in relation to maize plants. From every plot, from 3 linear meters of the medium row, 20 main cobs were collected from 20 plants (distance between plants in rows 15.2 cm), which after drying and threshing were used for evaluating grain yield in $\text{Mg} \cdot \text{ha}^{-1}$ (for the standard grain moisture of 14%). Maize grain yield underwent statistical evaluation with the analysis of variance and t-Student's test. Significance of result diversification was evaluated at the level of $P = 0.05$.

Weather conditions in the three growth seasons are presented in Tables 3 and 4. On the basis of the weather course (precipitation sums and average temperatures in given months), during the period of April to August, Sielianinow's hydrothermal index was calculated (Table 5).

Table 4. Mean monthly air temperature for the experiments in 2009-2011

Tabela 4. Średnia miesięczna temperatura powietrza dla doświadczeń w latach 2009-2011

		Temperature – Temperatura, °C					
year rok	location miejscowość	April kwiecień	May maj	June czerwiec	July lipiec	August sierpień	mean April – August średnia kwiecień – sierpień
2009	Dąbrówka	12.3	13.4	15.5	19.2	19.4	15.9
2009	Nieczajna	11.2	12.8	14.9	18.7	18.7	15.3
2010	Gąsawy	8.3	11.1	16.9	21.5	18.5	15.3
2011	Głuchowo	12.0	14.6	18.7	17.9	18.8	16.4
Many years' mean Średnia z wielolecia 1951-2010		8.1	13.4	16.7	18.5	17.9	14.9

In the outcome Tables (6-9), results that include herbicide effect in regard to the particular species and the effect on maize yield are presented.

Table 5. Sielianinow's hydrothermal index
Tabela 5. Współczynnik hydrotermiczny Sielianinowa

Year Rok	Location Miejscowość	April Kwiecień	May Maj	June Czerwiec	July Lipiec	August Sierpień	September Wrzesień
2009	Dąbrówka	0.44	1.97	2.08	1.56	0.23	–
2009	Nieczajna	0.54	1.96	2.07	0.96	0.29	0.97
2010	Gąsawy	0.78	2.12	0.15	1.53	1.61	–
2011	Głuchowo	0.20	0.21	0.98	1.59	0.53	0.37

values – wartości: 0.00-0.5 drought – 0,00-0,5 – susza; 0.5-1.00 – semi-drought – 0,51-1,00 – półsusza; 1.01-2.00 – good moisture – 1,01-2,00 – dobra wilgotność; 2.01 and above – high moisture – 2,01 i powyżej – duże uwilgotnienie

RESULTS

Weather conditions for the experiments carried out in 2009-2011

Weather conditions before the treatment and several weeks after the treatment have a significant effect on the growth of cultivated plants, but also on the biological activity of herbicides, particularly those applied preemergence. In Table 2, for the particular years and locations, chosen weather parameters have been presented (precipitation sums and average temperatures), depending on the treatment dates (14 days before the preemergence treatment T_0 , between treatments T_0 and T_2 , and 14 days after foliage treatment T_2). For the experiments carried out in year 2009, average temperatures, as well as precipitation before the preemergence treatment and between treatments T_0 and T_2 , were moderate, which guaranteed proper soil moisture and convenient conditions for equal weed and maize plant emergence. After the final foliage treatment T_2 , for two weeks, significant precipitation increase was noted (80.4-92.2 mm), which also undoubtedly affected favourably maize plant growth and shape. In 2010, it is worth noting that precipitation was relatively high in the period from the preemergence treatment (T_0) to the second treatment T_2 (73.4 mm). Very good soil moisture was a favourable factor that affected the activity of the herbicide applied preemergence. In the last research year, 2011, unfavourable humidity conditions were noted both before the preemergence treatment (0.6 mm), between the treatments (9.4 mm), and after the foliage treatment (9.6 mm), which, as an effect, was the major reason for uneven weed emergence (stretching in time in regard to quantity and species), as well as poorer effectiveness of herbicides applied preemergence.

During the analysis of precipitation between April and August 2009, its most favourable quantitative distribution was found (Table 3). In the most crucial months for maize growth and proper development (May-July), precipitation was quite evenly distributed and amounted to, depending on the location, in May 82.0 mm and 77.8 mm, in June 96.8 mm and 92.4 mm, and in July 92.6 mm and 55.6 mm. A little bit less favourable conditions for maize development were noted in 2010, particularly in June (7.6 mm), whereas in July very intensive precipitation was observed (102 mm). The last research year, 2011, was characterized by the worst humidity conditions. In April and May, there was drought (precipitation equal to 7.2 mm and 9.4 mm, respectively), which undoubtedly had an effect on maize growth dynamics and effectiveness of preemergence treatments. Moreover, on the turn of May, sudden temperature decrease and several-day-long ground frost were noted. In 2011, also a significant average temperature increase was noted in comparison with the many-years' average, particularly in the first months of maize

growth. In April, the increase reached nearly 4°C, in May 1.1°C, and in June 2.4°C. The least favourable conditions for proper maize growth in 2011 were confirmed by Sielianinow's hydrothermal index. In the period of April – June, it oscillated between 0.2 and 0.98, which confirms the occurrence of drought or semi-drought. According to the above index, similarly hard conditions for plant growth were also noted in 2009 in April and August, and in June of 2010 (hydrothermal index 0.15).

Concluding, in years 2009 and 2010, favourable weather conditions were noted for maize growth and proper for conducting effective weed control treatments at optimum application times. In the last research year (2011), unfavourable weather conditions in the first month of maize growth were a factor that limited its growth and could significantly affect weeding treatment effectiveness, especially of the treatments based only on preemergence herbicide application.

Impact of the weed control system on the herbicide effect in 2009

Maize plantation located in the village of Nieczajna (Table 6) was highly infested with dicotyledonous weeds, among which the following dominated: *Ch. album* (53 plants·m⁻², 23% of the total weed population), *Polygonum convolvulus* L. (64 plants·m⁻², 31% share), *Centaurea cyanus* L. (28 plants·m⁻², 14% share), and *Viola arvensis* Murr. (11 plants·m⁻², 5% share). To a lesser extent, also the species *Stellaria media* (L.) Vill. was present (11 plants·m⁻², 5% share). During growth, an increase in weed infestation was observed, especially compensation of *Ch. album* and *P. convolvulus* (during secondary weed infestation evaluation respectively to 32% and 36% share in the total weed number).

Herbicide effect

During growth, there were favourable conditions for maize growth and development, and also favourable for biological activity of herbicides. Therefore, high effectiveness of the preemergence treatment was found with the use of the mixture s-metolachlor + terbuthylazine + mesotrione applied at a full dose. Herbicide effectiveness evaluation showed 96% destruction of *Ch. album*, 93% of *P. convolvulus*, and 100% of *C. cyanus* and *S. media*. With strong pressure on the part of burdensome weeds, the application of a lowered dose of the mixture s-metolachlor + terbuthylazine + mesotrione (43% of the recommended dose) in the preemergence treatment (T₀) and subsequently carrying out the foliage treatments (T₂) with adjuvant and small herbicide doses did not protect sufficiently the maize plantation against weeds. In all the four treatment variants conducted in period T₂, the effect of the control of the most dominant weed species *P. convolvulus* was very small (29-52% destruction). In the case of *Ch. album*, foliage application of the mixture nicosulfuron and rimsulfuron or only rimsulfuron caused smaller herbicide effectiveness (respectively, 80% and 85% destruction). The remaining weed species in every variant were controlled satisfactorily.

In the second experiment in the village of Dąbrówka (Table 7), very strong plantation infestation was noted with the thermophilic species *S. nigrum* (152 plants·m⁻², 67% in the total weed population). To a smaller extent, such species were present as *Ch. album* (173 plants·m⁻², 7% share), *Polygonum lapathifolium* L. (11 plants·m⁻², 5% share) and less numerous weeds, such as *Mentha arvensis* L. (7 plants·m⁻², 3% share) and *G. tetrahit* (6 plants·m⁻², 3% of the total weed number). Two most frequently occurring species, *S. nigrum* and *Ch. album*, regardless of the application method and herbicide choice, were controlled almost in 100%. System of two separate treatments with smaller doses was characterized by a favourable effect on the control effectiveness of *P. lapathifolium*

and *M. arvensis*. Single preemergence treatment (To) with full dose of the mixture of s-metolachlor + terbuthylazine + mesotrione controlled the above two species very ineffectively (55%-69% destruction). Evaluation of secondary weed infestation showed a similar herbicide effect in the particular weeding systems.

Effect on the cultivated plant

In both experiments carried out in 2009, no symptoms of the phytotoxic effect of the applied herbicides were found in regard to maize plants (data not presented). High effectiveness of maize weeding with different systems of herbicide application affected favourably the yield size of this cultivated plant (results apply only to the experiment in Dąbrówka). The lowest grain yield was collected from the control plots (6.61 Mg·ha⁻¹). The highest yield was obtained in the combinations in which in the foliage treatment nicosulfuron or rimsulfuron were used in lowered doses and with addition of adjuvant Atpolan Bio 80 SL (respectively, 10.26 and 9.38 Mg·ha⁻¹). In this case, clear increase in the yield of maize grain in comparison with other combinations may be explained by, among others, significantly higher effectiveness of the destruction of burdensome and highly competitive species *P. lapathifolium*.

Impact of the weed control system on the herbicide effect in 2010

In the experiment carried out in the village of Gąsawy near Szamotuły (Table 8), in maize cultivation, dicotyledonous weeds dominated, such as *Ch. album* (86 plants·m⁻², 55% of the total weed population) and *V. arvensis* (27 plants·m⁻², 17% share) and the monocotyledonous species *E. cruss-galli* (15 plants·m⁻², 9% share in the total weed number). To a lesser extent, *P. convolvulus* occurred (7 plants·m⁻², 5% share). In 2010, like the year before, favourable weather conditions were observed for maize growth, which made it possible to carry out weed control treatments at different application times.

Herbicide effect

The best effect in the control of the dominant species *Ch. album* (100% destruction) was found in the system of two independent treatments with the use of herbicides at lowered doses. Application in the second treatment T2 of nicosulfuron or rimsulfuron, or the mixture of those active substances (Hector 53.6 WG), practically eliminated the above species from maize. Slightly smaller herbicide effect in regard to the above weed resulted from the application of the mixture of foramsulfuron and iodosulfuron (93% destruction). Highly effective in relation to all weed species in the entire maize growth period was the preemergence application of the mixture s-metolachlor + terbuthylazine + mesotrione at a full dose. After the application of that mixture, also the highest effectiveness of *E. cruss-galli* control was noted and in a longer period (100-97%). In the system of two treatments with lowered doses, the effectiveness of the destruction of this weed was significantly lower (60-82% after four weeks to 67-85% during the evaluation of secondary weed infestation) (Table 8).

Effect on the cultivated plant

In the experiment, no symptoms of the phytotoxic effect of the applied herbicides were found in regard to maize plants. Effective maize weeding with the use of different systems of herbicide application favourably affected the size of grain yield. The lowest grain yield was obtained from the unprotected control plots (4.20 Mg·ha⁻¹). The highest yield was obtained in combinations in which the system of two treatments was applied with herbicides at lowered doses (6.93-7.05 Mg·ha⁻¹). The yields were also significantly

higher from the grain yield collected from the untreated control plots, and also from the combinations where standard protection was applied, namely preemergence treatment with full dose of the mixture s-metolachlor + terbuthylazine + mesotrione.

Impact of the weeding system on the herbicide effect in 2011

Year 2011, due to drought, was unfavourable for proper maize growth and development. Lower effectiveness of herbicides used for preemergence treatments was also to be expected.

On maize plantations situated in the village of Gluchowo (Table 9), average intensification was noted of dicotyledonous weeds *Ch. album* (27 plants·m⁻², 40% of the total weed population), *P. persicaria* (10 plants·m⁻², 15% share in the total weed number), and *Amaranthus retroflexus* L. (10 plants·m⁻², 15% share). Occurrence of *E. crus-galli* during the evaluation four weeks after treatment was at a low level (8 plants·m⁻², 12% share). Weather conditions at the beginning of growth were a typical, as practically for three decades of May it was dry and relatively cold, and precipitation during five weeks after sowing amounted to nearly 10 mm. During growth, weed emergence was uneven and three to four weeks after sowing, an increase in the occurrence of thermophilic weeds was observed, particularly *A. retroflexus* (increase to 22% share) and *E. crus-galli* (increase by 10% to 22% share in the total weed population).

Herbicide effect

In spite of unfavourable weather conditions, effectiveness of a single preemergence treatment with the use of the mixture s-metolachlor + terbuthylazine + mesotrione applied at the full dose was satisfactory, especially in regard to *Ch. album* and *A. retroflexus* (respectively, 95% and 97% destruction). In the conditions of long-lasting drought and delayed emergence of *E. crus-galli*, lower impact activity of the mixture of the three active ingredients was found in regard to the above species (60% destruction). The best effects of the control of both *E. crus-galli* and the dicotyledonous species were noted in the system of two independent treatments, where for the foliage treatment nicosulfuron and rimsulfuron were used or nicosulfuron with adjuvant. In stressful conditions, the combination of two treatments with the foliage application of rimsulfuron (Titus 25 WG) at a dose lowered to 50% turned out relatively poor. The reason for poor herbicide effect was strong pressure on the part of burdensome weeds *Ch. album* and *E. crus-galli* (respectively, 65% and 70% destruction). During the evaluation of secondary weed infestation, very poor protection of maize plantation against weeds was found, especially against *Ch. album* (30% destruction).

Effect on the cultivated plant

The applied active ingredients and mixtures at various application dates did not damage maize. High effectiveness of weed control in maize with the use of different systems of herbicide application was reflected in the obtained grain yield. The lowest grain yield was collected from the control plots (4.93 Mg·ha⁻¹). In all combinations in which herbicide treatments were applied, very high grain yield was obtained, which exceeded twice the one from the untreated plots (with no weeding). The highest yield was found for combinations with foliage nicosulfuron application at a lower dose and with adjuvant Atpolan Bio 80 SL (13.59 Mg·ha⁻¹). Clear increase in maize grain yield on that plot was highly correlated with high effectiveness of the control of dominant weed species.

Table 6. Effectiveness of weed control in maize (preemergence To and foliage T2) (Nieczajna 2009)
 Tabela 6. Skuteczność zwalczania chwastów w kukurydzy (doglebowo To i nalistny T2) (Nieczajna 2009)

Combination – Kombinacja	Dose of a.i. Dawka s.a. g ha ⁻¹	Treatment time Termin zabiegu	Effectiveness of weed destruction – Skuteczność zniszczenia chwastów %											
			CHEAL		POLCO		CENCY		VIOAR		STEME			
			4 WAT*	SW*	4 WAT	SW	4 WAT	SW	4 WAT	SW	4 WAT	SW		
Control group – Kontrola plants m ² / % in total weed population szl. m ² / % w ogólnej populacji chwastów	–	–	53 / 26%	65 / 32%	64 / 31%	72 / 36%	28 / 14%	30 / 15%	11 / 5%	12 / 6%	5 / 3%	6 / 3%	–	
S-metolachlor- + terbuthylazine + mesotrione	1094 + 656 + 131	To	96	93	93	90	100	100	97	98	100	100	100	
S-metolachlor + terbuthylazine + mesotrione / nicosulfuron + rimsulfuron**	470 + 280 + 56 / 15 + 3.7	To/T2	80	82	29	25	91	90	90	98	100	100	100	
S-metolachlor + t terbuthylazine + mesotrione / nicosulfuron**	470 + 280 + 56 / 20	To/T2	95	92	52	40	99	99	100	100	100	100	100	
S-metolachlor + terbuthylazine + mesotrione / rimsulfuron**	470 + 280 + 56 / 7.5	To/T2	85	85	39	35	94	94	100	100	100	100	100	
S-metolachlor + terbuthylazine + mesotrione / foramsulfuron + iodosulfuron-methyl sodium**	470 + 280 + 56 / 15 + 0.5	To/T2	96	93	40	40	100	100	88	90	100	100	100	

treatment time – termin zabiegu: To – in-soil, before maize emergence – doglebowo, przed wschodami kukurydzy; T2 – foliage, maize at the 4-6 leaf stage – nalistnie, w fazie 4-6 liści kukurydzy

* 4 WAT – 4 weeks after treatment – 4 tygodnie po zabiegu, SW – secondary weed infestation – wtórne zachwaszczenie

** herbicides with the addition of adjuvant Apolan Bio 80 SL at the dose of 1.0 dm³·ha⁻¹ – herbicydy z dodatkami adiuwanta Apolan Bio 80 SL w dawce 1,0 dm³·ha⁻¹
 weeds – chwasty: CHEAL – *Ch. album*, POLCO – *P. convolvulus*, CENCY – *C. cyanus*, STEME – *S. media*, VIOAR – *V. arvensis*

Table 7. Effectiveness of weed control in maize (preemergence To and foliage T2) (Dąbrowka 2009)
 Tabela 7. Skuteczność zwalczania chwastów w kukurydzy (doglebowy To i nalistny T2) (Dąbrowka 2009)

Combination – Kombinacja	Dose of a.i. Dawka s.a. g·ha ⁻¹	Treatment time Termin zabiegu	Effectiveness of weed destruction – Skuteczność zniszczenia chwastów %												Yield Plon Mg·ha ⁻¹
			SOLNI		CHEAL		POLLA		MENAR		GALTE				
			4 WAT*	SW*	4 WAT	SW	4 WAT	SW	4 WAT	SW	4 WAT	SW	4 WAT	SW	
Control group – Kontrola plants m ⁻² / % in total weed population szt. m ⁻² / % w ogólnej populacji	–	–	152 / 67%	176 / 70%	17 / 7%	21 / 9%	11 / 5%	11 / 5%	11 / 5%	7 / 3%	9 / 4%	6 / 3%	7 / 3%	6.51	
S-metolachlor- + terbuthylazine + mesotrione	1094 + 656 + 131	To	99	100	98	100	55	50	69	70	85	80	80	8.86	
S-metolachlor + terbuthylazine + mesotrione / nicosulfuron + rimsulfuron**	470 + 280 + 56 / 15 + 3.7	To/T2	100	100	100	100	80	85	98	98	80	80	80	8.20	
S-metolachlor + t terbuthylazine + mesotrione / nicosulfuron**	470 + 280 + 56 / 20	To/T2	100	100	100	100	99	100	97	98	79	80	80	10.26	
S-metolachlor + terbuthylazine + mesotrione / rimsulfuron**	470 + 280 + 56 / 7.5	To/T2	100	100	100	100	98	100	87	90	79	80	80	9.38	
S-metolachlor + terbuthylazine + mesotrione / foramsulfuron + iodosulfuron- methyl sodium**	470 + 280 + 56 / 15 + 0.5	To/T2	100	100	100	100	93	100	91	90	99	100	100	8.42	
LSD _{0.05} – NIR _{0.05}														2.276	

treatment time – termin zabiegu: To – in-soil, before maize emergence – doglebowo, przed wschodami kukurydzy; T2 – foliage, maize at the 4-6 leaf stage – nalistnie, w fazie 4-6 liści kukurydzy

* 4 WAT – 4 weeks after treatment – 4 tygodnie po zabiegu, SW – secondary weed infestation – wtórne zachwaszczenie

** herbicides with the addition of adjuvant Atpolan Bio 80 SL at the dose of 1.0 dm³·ha⁻¹ – herbicydy z dodatkiem adiuwanta Atpolan Bio 80 SL w dawce 1,0 dm³·ha⁻¹
 weeds – chwasty: SOLNI – *S. nigrum*, CHEAL – *Ch. album*, POLLA – *P. lapathifolium*, MENAR – *M. arvensis*, GALTE – *G. tetrahit*

Table 8. Effectiveness of weed control in maize (preemergence To and foliage T2) (Gąsawy near Szamotuły 2010)
 Tabela 8. Skuteczność zwalczania chwastów w kukurydzy (doglebowy To i nalistny T2) (Gąsawy koło Szamotuł 2010)

Combination – Kombinacja	Dose of a.i. Dawka s.a. g·ha ⁻¹	Treatment time Termin zabiegu	Effectiveness of weed destruction – Skuteczność zniszczenia chwastów								Yield Plon Mg·ha ⁻¹
			CHEAL		VIOAR		ECHCG		POLCO		
			4 WAT*	SW*	4 WAT	SW	4 WAT	SW	4 WAT	SW	
Control group – Kontrola plants m ² / % in total weed population szl. m ² / % w ogólnej populacji chwastów	–	–	86 / 55%	27 / 17%	27 / 17%	15 / 9%	15 / 9%	7 / 5%	7 / 5%	4.20	
S-metolachlor- + terbuthylazine + mesotrione	1094 + 656 + 131	To	98	95	100	98	100	97	100	100	5.87
S-metolachlor + terbuthylazine + mesotrione / nicosulfuron + rimsulfuron**	470 + 280 + 56 / 15+3.7	To/T2	100	93	98	100	67	75	73	100	6.93
S-metolachlor + t terbuthylazine + mesotrione / nicosulfuron**	470 + 280 + 56 / 20	To/T2	100	100	100	100	77	85	95	100	6.97
S-metolachlor + terbuthylazine + mesotrione / rimsulfuron**	470 + 280 + 56 / 7.5	To/T2	100	100	100	100	60	67	88	100	6.46
S-metolachlor + terbuthylazine + mesotrione / foramsulfuron + iodosulfuron- methyl sodium**	470 + 280 + 56 / 15+0.5	To/T2	93	93	100	100	82	82	76	100	7.05
LSD _{0.05} – NIR _{0.05}										1.023	

treatment time – termin zabiegu: To – in-soil, before maize emergence – doglebowo, przed wschodami kukurydzy; T2 – foliage, maize at the 4-6 leaf stage – nalistnie, w fazie 4-6 liści kukurydzy

* 4 WAT – 4 weeks after treatment – 4 tygodnie po zabiegu, SW – secondary weed infestation – wtórne zachwaszczenie

** herbicides with the addition of adjuvant Atpolan Bio 80 SL at the dose of 1.0 dm³·ha⁻¹ – herbicydy z dodatkiem adiuwanta Atpolan Bio 80 SL w dawce 1,0 dm³·ha⁻¹
 weeds – chwasty: CHEAL – *Ch. album*, VIOAR – *V. arvensis*, ECHCG – *E. crus-galli*, POLCO – *P. convolvulus*

Table 9. Effectiveness of weed control in maize (preemergence To and foliage T2) at lowered doses (Głuchowo near Poznan 2011)
 Tabela 9. Skuteczność zwalczania chwastów w kukurydzy (doglebowy To i nalistny T2) w dawkach obniżonych (Głuchowo koło Poznania 2011)

Combination – Kombinacja	Dose of a.i. Dawka s.a. g·ha ⁻¹	Treatment time Termin zabiegu	Effectiveness of weed destruction – Skuteczność zniszczenia chwastów %								Yield Plon Mg·ha ⁻¹
			CHEAL		POLPE		AMARE		ECHCG		
			4 WAT*	SW*	4 WAT	SW	4 WAT	SW	4 WAT	SW	
Control group – Kontrola plants m ² / % in total weed population szl. m ² / % w ogólnej populacji chwastów	–	–	27 / 40%	27 / 40%	10 / 15%	8 / 12%	10 / 15%	10 / 15%	8 / 12%	15 / 22%	4.93
S-metolachlor- + terbuthylazine + mesotrione	1094+ 656 + 131	To	95	90	80	100	97	95	60	90	11.93
S-metolachlor + terbuthylazine + mesotrione / nicosulfuron + rimsulfuron**	470 + 280 + 56 / 15+3.7	To/T2	87	60	93	100	100	100	98	89	11.15
S-metolachlor + t terbuthylazine + mesotrione / nicosulfuron**	470 + 280 + 56 / 20	To/T2	95	80	100	100	100	100	99	88	13.59
S-metolachlor + terbuthylazine + mesotrione / rimsulfuron**	470 + 280 + 56 / 7.5	To/T2	65	30	87	100	100	95	70	92	8.93
S-metolachlor + terbuthylazine + mesotrione / foramsulfuron + iodosulfuron- methyl sodium**	470 + 280 + 56 / 15+0.5	To/T2	95	85	97	100	99	100	77	90	10.04
LSD _{0.05} – NIR _{0.05}											

treatment time – termin zabiegu: To – in soil, before maize emergence – doglebowo, przed wschodami kukurydzy; T2 – foliage, maize at the 4-6 leaf stage – nalistnie, w fazie 4-6 liści kukurydzy

* 4 WAT – 4 weeks after treatment – 4 tygodnie po zabiegu, SW – secondary weed infestation – wtórne zachwaszczenie

** herbicides with the addition of adjuvant Atpolan Bio 80 SL at the dose of 1.0 dm³·ha⁻¹ – herbicydy z dodatkiem adiuwanta Atpolan Bio 80 SL w dawce 1,0 dm³·ha⁻¹
 weeds – chwasty: CHEAL – *Ch. album*, POLPE – *P. persicaria*, AMARE – *A. retroflexus*, ECHCG – *E. crus-galli*

DISCUSSION

Results of the presented research show the need to adapt the weed control system in maize to the particular situation in the field, especially to the weather conditions at the beginning of growth. Choice of weed control methods must take into account changes in maize agrotechnics, particularly the simplifications of cultivation technology which lead to unfavourable changes in weed communities [Stupnicka-Rodzinkiewicz and Lepiarczyk 2004, Blecharczyk *et al.* 2007, Gołębiowska and Kaus 2009a]. Low herbicide effectiveness and the emergence of secondary weed infestation in the second half of growth are the negative effects of improper herbicide choice or their one-sided application [Gołębiowska and Kaus 2009b]. Therefore, the choice of herbicide mixtures is very important, alternatively of herbicides with a wide effect spectrum (for example, containing several active ingredients), which at the same time take into account the character of weed communities in the field [Skrzypczak *et al.* 2007]. In the case of unfavourable weather conditions, application of two independent treatments may be recommended with the use of herbicides in different trade formulas or system of split or lowered doses. This may alleviate the negative results of herbicide effects in relation to maize plants [Knezevic *et al.* 2002]. Advisability of such actions was proved in the present work and in other publications [Kierzek and Adamczewski 2008, Kierzek and Miklaszewska 2009, Kierzek *et al.* 2011].

Climate changes that have been taking place for several years contribute undoubtedly to the increase in maize infestation. Higher temperatures and increased insolation, particularly in May and June, significantly different from the many-years' average, as a consequence have been leading to earlier plant growth and weed quantitative and qualitative changes [Gołębiowska and Snopczyński 2008]. Earlier growth and favourable conditions stimulate the growth of many weed species, and at the same time pose a threat of strong competition to maize plants at the early stages of development. Early maize sowing on the one hand may partly protect against drought, although on the other hand it will not protect the plantation in the case of May ground frost. Situation of that sort took place in 2011. Maize plants, at the 1-2 leaf stage, were significantly damaged as a result of two- to three-day ground frost on the turn of April and May. Appearance of such unfavourable weather anomalies is a factor that delays foliage herbicide application. As far as the restoration of maize plant vigour and form takes place very slowly, at the same time the development of many weed species, for example *Ch. album* and those from the *Polygonum* kind, proceeds very intensely. Those weeds already at the beginning of growth are at more advanced developmental stages, and therefore it is harder to control them with herbicides used foliage. Thus, a very important element of proper strategy of foliage treatments is not only the application of proper chemical compounds, but also, as far as possible, the application of a safe and highly selective adjuvant with qualities that improve the applied fluid retention and biological activity of herbicides. In the present study, this sort of adjuvant was Atpolan Bio 80 SL, which added to significantly reduced herbicide doses (33%-50% of the recommended dose) significantly improved their herbicide effect. Information on the possibilities of obtaining better herbicide effects through joint application of herbicides with adjuvants can be found in many scientific publications [Skrzypczak *et al.* 1998, Woźnica and Skrzypczak 1998, Zabkiewicz 2000, Adamczewski and Matysiak 2005,

Woźnica 2005, Idziak and Woźnica 2008, Kierzek and Miklaszewska 2009, Drzewiecki and Pietryga 2011]. On the other hand, with unfavourable weather conditions (for example water stress), the addition of adjuvants prolongs the period of herbicide protection by improving the herbicide effect in regard to difficult to control weed species [Gołębiowska 2008, Drzewiecki and Pietryga 2010], as well as contributes to the increase in grain yield [Woźnica and Idziak 2010].

The conducted experiments on maize showed the advantages of the application of two treatments with the use of herbicides at lowered doses. One advantage of this sort of protection is undoubtedly the effective elimination of the competitive effect of weeds at the early developmental stages of maize, up to the stage of row-spacing covering. It was shown in the study that significant precipitation deviation from the many-years' average during the experiment affected negatively proper maize development and gave a lower herbicide effect. In unfavourable weather conditions (which, unfortunately, occur more and more frequently in May and early June), single herbicide application at a full dose (mainly preemergence treatment) does not eliminate infestation in the long time, particularly in the case of uneven emergence and compensation of burdensome species (for example *Ch. album* and *Polygonum* sp.). Particularly unfavourable situation takes place when, after a longer period of chill and lack of precipitation, sudden warming occurs, as well as the increase in soil moisture, as a result of regular precipitation. Several weeks after the preemergence treatment, intensive emergence on the maize plantation of the thermophilic species was observed (for example *E. crus-galli* and *A. retroflexus*). Too long period of waiting with a single treatment is irrational, since the transgression of the critical period of weed control takes place, the so-called „switch point”, after which maize yield potential decreases drastically. It has been proven that the borderline, depending on the conditions in the field, is at the 3-5-leaf stage of maize [Hall *et al.* 1992, Swanton *et al.* 1999, Dogan *et al.* 2004]. In this situation, the possibility of carrying out two independent treatments with lowered doses, on dates adapted to the current needs and situation in the field, makes it easier for the farmer to make the right decision in the choice of optimum maize protection strategy against weeds. Sufficient soil moisture during the first preemergence treatment was necessary for effective maize weed control with the use of the system based on preemergence and foliage (foliage) herbicide applications. In years with favourable precipitation balance, right before and after the preemergence treatment, it made effective action of the mixture s-metolachlor + terbuthylazine + mesotrione possible, applied at a significantly lowered dose.

The obtained maize grain yields after the application of one treatment with the full dose and in the system of two independent treatments with lowered doses were significantly higher as compared with untreated plots (no protection). This confirms good effectiveness of the studied weed control systems. Knezevic *et al.* [2003] demonstrated a significant yield increase thanks to the application of split and lowered doses. Similar results were obtained by Gołębiowska and Snopczyński [2008] in their studies on maize threat with secondary weed infestation under diversified weather conditions, as well as by Drzewiecki and Pietryga [2011] during the analysis of maize grain yield after the application of herbicide mixtures with the method of split doses with adjuvant Atpolan Bio 80 EC.

The presented chemical methods of weed control did not cause any negative effects on maize development, while they effectively eliminated competition of weeds. Those sorts of protection systems are the most effective and safer for the environment. Moreover, satisfactory economic effect is obtained, since the sums of herbicide doses are the same or slightly higher from the full herbicide dose applied a single time [Paradowski and Kierzek 2009]. Some solutions for herbicide application methods, at least in part, to the advantage of maize cultivators, could be put into practice. Proper choice of herbicide doses for the level of growth infestation, optimum date of treatment, and application of herbicide mixtures at lowered doses in order to eliminate a wide spectrum of weeds also correspond well with the implementation of integrated rules and methods of plant protection.

CONCLUSIONS

1. In unfavourable weather conditions at the early stages of maize growth, there is a possibility of effective plantation protection against weed infestation through the application of protection technology based on two treatments with lowered herbicide doses.

2. With very heavy plantation infestation with difficult to control species or compensation of weeds with strong competitive characteristics, in optimum humidity conditions, preemergence treatment with the full herbicide dose of Lumax 537.5 SE (s-metolachlor + terbuthylazine + mesotrione) guaranteed high herbicide effectiveness.

3. Prolonged and uneven weed emergence in diversified weather conditions (periods of drought, low temperatures, and sudden, intensive precipitation) caused a negative effect on the activity of herbicides applied preemergence. In those conditions, it was necessary to carry out an additional weed control treatment, particularly in relation to the later-emerging thermophilic species, such as *E. crus-galli* and *A. retroflexus*.

4. In the system of two independent treatments, the best maize weeding effects were obtained after the application in the preemergence treatment with lower dose of the mixture s-metolachlor + terbuthylazine + mesotrione, and subsequently the foliage treatment at the 4-6-leaf maize stage with nicosulfuron and adjuvant Atpolan Bio 80 SL, regardless of the different weather conditions during growth period in the evaluated research years.

5. On the plots free from weeds or effectively protected with the use of two independent herbicide treatments, high maize grain yield was obtained, which was significantly higher as compared with untreated plots – without weed control.

6. Threat of secondary weed infestation occurred only in the conditions of water stress and strong pressure on the part of weeds at the early stages of maize development, when the herbicide effect after treatments at lowered doses was poorer.

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CHEMICZNE METODY ODCHWASZCZANIA KUKURYDZY (*Zea mays* L.) W ZMIENNYCH WARUNKACH POGODOWYCH

Streszczenie. W latach 2009-2011 przeprowadzono 4 ścisłe doświadczenia polowe, których celem była ocena działania herbicydów zarejestrowanych w kukurydzy, stosowanych w obniżonych dawkach, na tle różnego przebiegu warunków pogodowych. Herbicydy stosowano w systemie: zabieg doglebowy z użyciem s-metolachlor + terbutoazyna + mezotrion oraz nalistny w fazie 4–6 liści kukurydzy z użyciem: nikosulfuron + rimsulfuron, nikosulfuron, rimsulfuron i foramsulfuron + jodosulfuron. Do herbicydów stosowanych nalistnie dodawano adiuwant Atpolan Bio 80 SL. Niezależnie od warunków pogodowych panujących w poszczególnych sezonach wegetacyjnych najlepsze efekty odchwaszczania kukurydzy uzyskano po zastosowaniu doglebowo mieszaniny s-metolachlor + terbutoazyna + mezotrion, a następnie nalistnie

nikosulfuronu z dodatkiem adiuwanta Atpolan Bio 80 SL. W warunkach opóźniających się i nierównomiernych wschodów chwastów (szczególnie ciepłolubnych) system dwóch zabiegów obniżonymi dawkami herbicydów najskuteczniej chronił plantację kukurydzy przed zachwaszczeniem wtórnym.

Słowa kluczowe: adiuwant, obniżone dawki herbicydów, systemy odchwaszczania, zabieg doglebowy, zabieg nalistny, zachwaszczenie wtórne

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