EFFICIENCY AND SELECTIVITY OF HERBICIDES IN MAIZE (*ZEA MAYS* L.)

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ABSTRACT

The action, efficiency and selectivity of the herbicides acetochlor, isoxafluthol, oxadiargyl, thifensulphuron-methyl, atrazine, dicamba, nicosulphuron, rimsulphuron, and their combinations in maize were investigated in experiments conducted in Pančevo and Zemun in 1997-1999. After several consecutive years of herbicide application, changes in the floristic composition and structure of the weed community, and an increase in the resistant weed species were observed. The dominant weed species in maize were: *Polygonum persicaria*, *Datura stramonium*, *Xantium strumarium*, *Abutilon theophasti, Ambrosia artemisifolia, Stachys annua, Chenopodium album, Solanum nigrum, Setaria spp., Sorghum halepense* and *Echinochloa crus-galli*. After several consecutive years of acetochlor application an over multiplication of *Polygonum persicaria* and *Xanthium strumarium* was observed, while the application of isoxafluthol led to an increase of *Datura stramonium* in maize fields.

Key words: crop rotation, herbicides, maize.

INTRODUCTION

The total herbicide consumption in the world in 1994 cost a total of $ 13 billion (Wrubel and Gressel, 1995). About ¾ of this was used for weed control in maize, rice (*Oryza sativa* L.) soybean (*Glycine max* (L.), Merr), vegetables and fruit trees. The key herbicidal groups are triazine, amides, carbamates ureas, toluidines, diazines, diphenyl ethers and 2.4-D herbicides. In recent years a large increase in the application of sulphonylurea, imidazolinone, aryloxypropionate, glyphosate and paraquat has been observed, amounting to as much as 14% (Wood Machensi, 1995). These were introduced as selective herbicides for simultaneous control of annual and perennial, grass and broad-leaf weed species in maize (Kimura et al., 1989; Marković, 1988, 1992). Maurer et al. (1987) reported high efficiency of these herbicides in controlling resistant weed species in maize, such as wild sorghum and spear grass.

Weed control management is closely connected with social and economic factors. Late weed removal because of manpower shortages provokes yield losses of more than 25% (Parker and Fryer, 1975). If manual and animal work is used for weed control, than 45-60 % of total work before harvest is spent just for controlling weeds (Akobundu, 1987).

Weed control management should include careful herbicide selection, use of active agent mixtures, alternation of herbicides with different modes of action, and adaptation to the cultivated crop, with the aim to improve efficiency, selectivity and persistency. Simultaneous control of *Sorghum halepense, Elymus repens, Cirsium arvense, Abutilon theophrasti, Ambrosia* spp., and other dominant weeds in maize was achieved together with the use of residuals of alachlor and metolachlor for weed control in following crops, such as soybean and sunflower (Palm et al., 1989; Marković, 1988; Marković and Marković, 1989).

Herbicide requires a wise choice in application, because the enlargement of the spectrum of action to the dominant weed species, at same time accelerates weed resistance and harmful effect of residuals to the environment (Wrubel and Gressel, 1995). Besides, alternation of active herbicidal groups during and between seasons, delays the occurrence of resistant weeds populations. Alternative means of controlling resistant biotypes are crop rotation, mechanical cultivation, tillage and hoeing.

During three year study, the control of dominant weed species, the appearance of resistant weeds and the choice of selective herbicides for maize were investigated. This paper presents the results of herbicide efficiency and selectivity, as well as the influence of herbicides and weeds on the biological characteristics of maize, such as plant height structure and yield.

MATERIAL AND METHODS

Investigations on weed control through herbicide application were conducted in 1997 at a location in Pančevo and in 1998-1999 in Zemun. The experiments were set up on plots

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infested with *Stachys annua* as the dominant weed and with annual mono- and dicotyledonous weed species in Zemun (*Setaria* spp., *Echinochloa crus-galli, Ambrosia* spp., *Datura stramonium, Solanum nigrum, Polygonum persicaria, Abutilon theophrasti, Chenopodium album, Xanthium* spp.) (Table 1).

Table 1. Weed species in maize during season of 1997-1999 years (No/m^2)

Weed species	Locations and years			Average	
	Pančevo	Zemun			
	1997	1998	1999	m^2	%
Stachys annua	83	-	-	27.7	18.3
Polygonum persicaria	1	3	67	23.7	15.7
Echinochloa crus-galli	-	58	-	17.0	11.2
Solanum nigrum	2	12	24	12.6	8.4
Setaria spp.	-	35	-	11.7	7.7
Hibiscus trionum	-	14	13	9.0	6.0
Datura stramonium	-	16	9	8.3	5.5
Xantium spp.	5	1	19	8.3	5.5
Ambrosia artemisifolia	-	20	3	7.7	5.2
Chenopodium album	-	7	14	7.0	4.6
Amaranthus retroflexus	-	6	7	4.3	2.9
Sorghum halepense	-	-	9	4.0	2.6
Helianthus annuus	7	-	-	2.3	1.6
Abutilon theophrasti		2	4	2.0	4.0
Other	14	-	2	4.3	2.8
Total	112	174	171	149.9	100

The efficacy and selectivity of herbicides based on acetochlor (Acenit 880), isoxaflutholе (Merlin 750 WG), atrazine (Sutrazin 50 SC), acetochlor-atrazine (Erunit), dicamba (Banvel 480 S), oxadiargyl (Raft 800 WG), nicosulphuron (Motivell), rimsulphuron (Tarot 25 DF), and ready-made mixtures of rimsulphuron and thiphensulph uronmethyl (Grid 75), were investigated in a maize - sunflower - soybean crop rotation.

The experimental plots were arranged in a random block design, in four replications with an elementary plot size of 25 m^2. Treatments were done immediately after sowing and after emergence in the 2 and 4-5 leaf stages of maize hybrid ZPSC 633, using CP-3 sprayers with 400 l/ha of water. The efficiency was recorded as the number of weeds per square metre. Evaluations were done one month after treatment and then every 15 days, with simultaneous observation of herbicide persistency and resistant weed appearance. The last evaluation was done immediately before the maize harvest. The degree of herbicide selectivity was judged on the basis of the occurrence of phytotoxic symptoms, plant height and yield levels of maize.

RESULTS AND DISCUSSION

For many years maize producers in Yugoslavia have mainly relied on triazine and chloracetanilide as standard herbicides for the control of broadleaf and grassy weeds before crop emergence. If these herbicides are applied at higher rates, they endanger the safety of the environment and the toxicological justification of application, which lead to a limitation of their use. As a consequence, there is a shortage of effective herbicides which can be applied before emergence and at the same time weeds resistant to triazines have developed, further limiting the efficacy of herbicides in maize.

Herbicides based on acetochlor and isoxafluthole provide excellent grass and broad-leaved weed control in maize, if applied before and after crop emergence. Herbicide mixtures improve both reliability and spectrum of action. At the same time they have more favourable toxicological and ecotoxicological characteristics, thus avoiding disturbances of the environment. In the field they provide appropriate residual activity. Being decomposed during vegetation, they do not transmit harmful residuals to following crops, eliminating problems related to wrong application. Mono- and dicotyledonous weeds provoke economic losses through reducing the yield and quality. By one application of herbicide mixture of acetochlorine with atrazine, isoxafluthol, dicamba and oxadiargil, a wide spectrum of weeds is controlled. This is an important advantage, as it decreases extra work cost, time and fuel. Crop and herbicides rotation, enables the use of herbicides of different ways of action, providing reliable selectivity to the crop (Wrubel and Gressel, 1995) and synergistic action (Gressel and Segel, 1990). On this way, through the management and integrate production and crop protection, a model for weed control is treated at global and regional plan, if the association is taken for a region, field or plot, for longer time interval (Table 2).

Herbicide isoxaflutole (Merlin) provides solid grass and broad-leaved weed control in corn. Applied immediately after sowing, before emergence and after emergency of crops in relatively small dosages (75-100 g a.i./ha), it controls important weed species, including *Abutilon theophrasti* and *Ambrosia artemisifolia*. It prevents the biosynthesis of enzymes by phydroxsyphenil piruvatdioxsyqenesis inhibition in susceptible plant species.

Table 2. Percentage control of weeds during vegetation time of maize (*CE %)

Herbicides rate (kg/ha)	Evaluation date					Average
	01.06.	15.06.	19.07.	15.08.	30.08.	
a) Preemergence						
Acetochlor + AD-67 (2.4 + 0.16)	90	78	65	68	75	74
Acetochlor + Atrazine (1.6 + 1.0)	100	100	100	100	100	100
Acetochlor + Isoxafluthol (1.6 + 0.07)	100	100	100	100	100	100
Acetochlor + Oxadiargyl (1.6 + 0.24)	100	95	90	90	90	93
Isoxafluthol (0.09)	100	100	100	100	100	100
Average	98	94	91	92	93	93
b) Early postemergence (2-3 leaves maize)						
Acetochlor + AD-67 (2.2 + 0.16)	80	85	89	88	80	85
Acetochlor + Atrazine (1.6 + 0.75)	100	100	100	87	99	99
Acetochlor + Dicamba (1.6 + 0.24)	100	100	100	96	95	98
Isoxafuthol (0.075)	100	100	100	100	100	100
Oxadiargyl (0.27)	100	100	100	95	84	96
Isoxafluthol + Rimsulfuron (0.07 + 0.025)	100	100	100	100	100	100
Average	97	98	98	96	93	96
c) Second postemergence (4-5 leaves maize)						
Acetochlor + Atrazine (1.6 + 0.75)		97	90	90	90	92
Acetochlor + Dicamba (1.6 + 0.24)		90	91	90	90	90
Isoxafluthol + Nicosulfuron (0.09 + 0.5)		100	100	95	90	96
Thifensulfuthol-metyl + Rimsulfuron (0.09 + 0.5)		91	90	81	78	85
Thifensulfuthol-metyl + Rimsulfuron + Dicamba (0.005 + 0.01 + 0.24)		100	100	98	91	97
Thifensulfuthol-metyl + Rimsulfuron + Atrazine (0.005 + 0.01 + 0.75)		100	100	100	100	100
Average		96	95	92	89	93

*CE = Coefficient of efficiency

Mixtures with other herbicides improve reliability and spectrum of action. It has a relatively short half-life period in soil, with final mineralization in carbon dioxide. It is dissociated by hybrolysis and microbiologically. In rainy years it is poorly mobile, residues stay in surface horizon and already after four months there are no residues in the soil profile. Persistency is 6-8 weeks. It shows systemic action, being absorbed by plants through roots and leaves. The key stop of isoxsaflutole action is biosynthesis in „plastoquinovin" and its inhibition of chlorophyll and carrotenoide in meristemic tissue, what leads to albinism or bleatching symptoms in new growth and to weed dying. It is unreliable in control of *Datura stramonium, Sorghum halepense* and *Bilderdykia convolvulus*, so application with complementary herbicides as acetochlor, alachlor, metolachlor, dimetenamid, rimsulfuron and nicosulfuron is recommended (Table 3). Today, in regions free of resistant weeds, the most reliable is a mixture of acetochlore with atrazine, and in arid conditions of acetochlor with dicamba, with application immediately after crop emergency (2-leaf stage of maize).

Our model of weed control in maize is based on optimal quantities of herbicides for every plot, to control all weed individuals in which there is no resistance gene, or if already resistance gene has accumulated in the weed population. In this case, by using tank-mix herbicides, resistance appearance will be delayed for longer periods of time, than if lower or higher dosages of individual herbicides are used. The best is to postpone the appearance of resistance, in time as well as in space, through crop rotation, agro measures and herbicides, to prevent weed seed development.

Table 3. Efficiency of herbicides in controlling dominating weeds in maize, during vegetation season (CE%)

	Herbicides (kg/ha)	*Stachys annua*	*Polygonum persicaria*	*Echinochloa crusgalli*	*Solanum nigrum*	*Setaria* spp.	*Hibiscus trionum*	*Datura stramonium*	*Xantium* spp.	*Ambrosia artemisifolia*	*Chenopodium album*	*Amaranthus retroflexus*	*Sorghum halepense*	*Abutilon theophrasti*
	a) Preemergence													
1.	Acetochlor + AD-67 (2.4-0.16)	99	0	5	100	95	40	45	0	71	80	95	65	95
2.	Acetochlor + Atrazine (1.6 + 1.0)	100	90	90	100	92	100	96	100	100	100	100	60	90
3.	Acetochlor + Isoxafluthol (1.6 + 0.02)	100	92	90	100	94	100	100	95	100	100	100	72	100
4.	Acetochlor + Oxadiargyl (1.6 + 0.24)	100	75	90	100	95	100	100	100	100	100	100	41	100
5.	Isoxafluthol (0.09)	96	75	75	100	61	100	47	100	89	100	100	48	90
	b) Early postemergence (2-3 leaves maize)													
1.	Acetochlor + AD-67 (2.2 + 0.16)	100	0	90	100	90	75	50	0	69	100	100	42	45
2.	Acetochlor + Atrazine (1.6 + 0.75)	100	100	92	100	89	100	69	100	90	100	100	41	89
3.	Acetochlor + Dicamba (1.6 + 0.24)	100	100	89	100	87	100	100	100	100	100	100	30	100
4.	Isoxafluthol (0.075)	89	100	75	100	69	100	65	100	89	100	87	34	100
5.	Oxadiargyl (0.27)	89	89	45	100	41	100	100	100	87	100	86	0	86
6.	Isoxafluthol + Rimsulfuron (0.07 + 0.025)	100	100	100	100	100	100	100	100	100	100	100	100	100
	c) Second postemergence (4-5 leaves maize)													
1.	Acetochlor + Atrazine (1.6 + 0.75)	100	100	92	100	87	100	100	100	100	100	100	44	100
2.	Acetochlor + Dicamba (1.6 + 0.24)	100	100	89	100	85	100	100	100	100	100	100	29	100
3.	Isoxafluthol + Nicosulfuron (0.9 + 0.5)	100	89	100	90	100	49	100	100	100	100	100	100	100
4.	Thifensulfuron-metyl + Rimsulfuron (0.006 + 0.012)	100	100	100	0	100	100	100	100	100	100	100	100	100
5.	Thifensulfuron-metyl + Rimsulfuron + Dicamba (0.005 + 0.75)	100	100	100	100	100	100	100	100	100	100	100	100	100
6.	Thifensulfuron-metyl + Rimsulfuron + Atrazine (0.005 + 0.01+0.75)	100	100	89	100	87	100	100	100	100	100	100	28	100

Combinations of herbicides of different ways of action and of reliable selectivity to crop, such as acetohlor + atrazine, thypensulfuron methyl + rimsulfuron with atrazine or dicamba, acetochlor + dicamba and acetochlor + isoxafluatole, should be used. This recommendation might be sometimes difficult to implement in some agroecological systems, because of monoculture introduction and of the mechanism of herbicide detoxication. Because of that, management and integrated systems of production and weed control should be created on country and/or regional level, taking into account longer time intervals. Crops or varieties must be tolerant or resistant to diseases and pests, or appropriate measures of protection must be taken for preventing yield losses (Table 4).

If however only single individual herbicides are used, the result is the over-multiplication of *Sorghum halepense* and other resistant weed species in fields treated with atrazine, of *Datura stramonium* after herbicide isoxsaflufole and oxadiargil or of *Polygonum persicaria* and *Xanthium strumarium* on plots where herbicides on the basis of acetochlore, dimetenamide and fluorochloridone are applied.

Table 4. Comparison of the herbicidal selectivity and efficacy in maize

Herbicides (kg/ha)			Plant density (%)	Plant height		Yield	
				m	%	t/ha	%
a) Preemergence							
1.	Acetochlor + Ad-67 (2.4 + 0.16)		90	2.4	225	6.7	1340
2.	Acetochlor + Atrzine (1.6 + 1.0)		100	2.6	255	8.5	1700
3.	Acetochlor + Isoxafluthol (1.6 + 0.24)		81	2.4	240	8.0	1600
4.	Acetochlor + Oxadiargyl (1.6 + 0.24)		80	2.4	235	7.0	1400
5.	Isoxafluthol (0.09)		84	2.4	235	6.9	1300
b) Early postemergence (2-3 leaves maize)							
1.	Acetochlor + AD-67 (2.2 + 0.16)		94	2.3	230	7.1	1420
2.	Acetochlor + Atrazine (1.6 + 0.75)		100	2.5	250	8.3	1700
3.	Acetochlor + Dicamba (1.6 + 0.24)		100	2.3	235	8.0	1600
4.	Isoxafluthol (0.075)		89	2.5	250	7.5	1500
5.	Oxadiargyl (0.27)		89	2.2	235	7.5	1500
6.	Isoxafluthol + Rimsulfuron (0.07 + 0.025)		68	1.8	180	6.5	1300
c) Postemergence (4-5 leaves maize)							
1.	Acetochlor + Atrazine (1.6 + 0.75)		100	2.4	240	8.5	1700
2.	Acetochlor + Dicamba (1.6 + 0.24)		100	2.3	235	8.5	1700
3.	Isoxafluthol + Nicosulfuron (0.09 + 0.5)		10	0.9	90	0.1	20
4.	Thifensulfuron-methyl + Rimsulfuron (0.006 + 0.012)		100	2.3	230	7.2	1440
5.	Thifensulfuron-methyl + Rimsulfuron + Dicamba (0.005 + 0.01 + 0.24)		100	2.5	250	8.5	1700
6.	Thifensulfuron-methyl + Rimsulfuron + Atrazin (0.005 + 0.01 + 0.75)		100	2.6	255	8.6	1700
7.	Control untilled		56	0.8	100	0.5	100
8.	Control tilled		100	2.2	219	7.01	14.23
LSD		5%	15.1	0.7		1.1	
		1%	12.0	0.4		0.7	
Control = 64.120 plants/m^2 = 100%							

CONCLUSIONS

In maize, weeds can be successfully controlled by herbicides and by using herbicide residues in the system of maize rotation with the other field crops.

Investigated herbicides on the basis of acetochlorate (Acetin 9009) in mixture with atrazine and isoxsaflutrul (Merlin 75) or with addition of dicamba are the most reliable solution in solving the weed control in maize and in preventing the spread of resistant weeds.

The problem is simplified by the system of crop rotation and by the use of herbicides mixtures, such as rimsulfphuron or nicosulphuron with dicamba, atrazine and type ensulphuron methyl, depending on the appearance of problem weeds.

The system of management and the integrated system of protection and weed control in maize should be based on a model of weed control on global and regional plan, for longer periods of time. This is a fundamental change, involving the introduction of new technologies, varieties and herbicides, and leading to the elimination of susceptible weeds, poorer weed associations, decrease of competitive relations of weeds and prevention of spreading resistant weeds in the maize crop.

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