Scientific Papers. Series A. Agronomy, Vol. LXI, No. 1, 2018
ISSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785

BIOLOGICAL EFFICACY OF SOME SOIL HERBICIDES AT MAIZE (*Zea mays* L.)

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Abstract

Maize (Zea mays L.) is main grain, forage and strategical field crop in Bulgaria. One of the main negative factors for maize growing is the weeds. The aim of our study conducted in 2016 and 2017 is to evaluate the biological efficacy of some soil herbicides at maize hybrid P 1114. The experiment was stated on the experimental field of the base for training and implementation of the Agricultural University of Plovdiv, Bulgaria. The trial was conducted by the randomized block design in 4 replications, and the efficacy was recorded by the 10 score visual scale of EWRS. The herbicides Merlin® Duo (37.5 g/l isoxaflutole + 375 g/l terbutilazin), Adengo® 465 SC (225 g/l isoxaflutole + 90 g/l thiecarbazone-methyl + 150 g/l cyprosulfamide - antidote), Lumax® 538 SK (37.5 g/l mesotrione + 375 g/l s-metolachlor + 125 g/l terbutilazine) were examined. The herbicides were applied after sowing before germination of the crop (BBCH 00). The highest herbicide efficacy and the highest yields (11.86 t ha^{-1}) were obtained for the treatment with Merlin® Duo at rate of 2000 ml ha^{-1}. All evaluated herbicides were selective for the grown maize hybrid.

Key words: *maize, weeds, herbicides, efficacy.*

INTRODUCTION

Maize is the most common forage crop in Bulgaria that is grown for grain and silage (Yankov et al., 2013). According to data from the Ministry of Agriculture Food and Forestry in 2016 grain maize has harvested area of 406,942 ha with average yields of 5,470 kg ha^{-1} (www mzh.government.bg).

The weeds are one of the main yield limiting factors. They have high concurrence with the crop for water, light, space and nutrients (Tonev et al., 2007; Tonev, 2000). The maize grain yield can decrease from 24% to 96.7% (Mukherjee, Puspajit Debnath, 2013; Oerke, Dehne, 2004; Khan et al., 2003; Tonev et al., 2007; Zhalnov, Raikov, 1996). In Bulgaris economically most important weeds at this crop *Amaranthus retroflexus* L., *Datura stramonium* L., *Xanthium strumarium* L., *Solanum nigrum* L., *Chenopodium album*, *Abutilon theophrasti* L., *Sinapis arvensis* L., *Echinochloa crus-gali* L., *Setaria glauca* L., *Sorghum halepense* L., *Convolvulus arvensis* L, *Cinodon dactilon* L. and *Cirsium arvense* L. (Hristova et al., 2012; Kalinova et al., 2012; Tonev et al., 2010). Studies conducted in Slovakia showed that the most distributed weeds in maize fields are *Chenopodium album* L., *Amaranthus* spp., *Echinichloa crus-galli* (L.) P. Beauv, *Datura stramonium* (L.), *Fallopia convolvulus* (L.) A. Lôve, *Persicaria* spp., *Cirsium arvense* (L.) Scop, *Elytrigia repens* (L.) P. Beauv, *Avena fatua* (L.) and *Abutilon theophrasti* Medik. (Týrand Vereš, 2012). Smatana et al. (2015) reported that in the maize fields of the country the weeds *Atriplex* spp. and *Setaria viridis* (L.) P. Beauv. are found. In India the most aggressive weeds are *Polygonum* spp. (*P. pensylvanicum, P. persicaria, P. orientale*), *Stellaria media, Stellaria aquatica, Oldelandia diffusa, Oldenlandia umbellate, Physalis minima, Solanum nigrum*. In Belgaum district of Karnataka, India, the most distributed weeds are *Cynodon dactylon, Dinebra retroflexa, Echinochloa colonum, Eleusine indica, Cyperus rotundus, Parthenium hysterophorus, Commelina benghalensis, Portulaca oleracea, Cynotis cuculata, Phyllanthus niruri* and *Amaranthus viridis* (Mukherjee, Debnath, 2013; Haji et al., 2012). One of the main weed control methods is the herbicide application (Janak et al., 2016; Umesha et al., 2015; Noor Muhammd et al., 2012; Skrzypczak et al., 2011; Pannacci and Covarelli, 2009; Tonev, 1986). Against the annual grass and broadleaf weeds very high eficacy is found after the application of Gardoprim Plus Gold 500 SK -

4000 ml ha^{-1} (99%), Lumax 538 SK - 4000 ml ha^{-1} (97%), Wing - 4000 ml ha^{-1} (97%) and Merlinflex - 420ml ha^{-1} (94,6%) (Dimitrova et al., 2013). Pannacci (2016) established that the application offoramsulfuron had 95% efficacy against *Amaranthus retroflexus* L., *Setaria viridis* (L.) Beauv., *Sinapis arvensis* L. and *Solanum nigrum* L. Quddus et al. (2011) recorded that formasulfuron + isoxadifen-ethyl + Urea sucsessfully controleed *Cyperus rotundus* and *Achyranthus aspera* - 87% and 75%, respectively.

The aim of our study is to evaluate the efficacy of some soil herbicides at maize.

MATERIALS AND METHODS

The field experiment is carried out in 2016 - 2017 in the field of training and experimental base of the department of Agriculture and herbology. The trial was conducted by the randomized block design in 4 replications. The size of the experimental plot was 28 m². The maize hybrid P1114 (590 FAO from the latehybrid group) was grown in the experiment. Predecessor of maize during the experimental years was winter wheat. After predecessor's harvest, deep ploughing followed to disking tillage operations was performed. Fertilization with 500 kg ha^{-1}NPK (15:15:15) was done before sowing of maize and dressing with 300 kg ha^{-1} NH_4NO_3 during vegetation.

The reporting of the weeds was performed prior to treatment, on the 14th, 28th and 56th days after treatments. The efficiency against weeds was reported by the 10-score scale of EWRS. The results were compared with untreated control. The selectivity of the herbicides was reported by 9-score phytotoxicity scale of EWRS (0 - no damage, and 9 - complete crop destruction).

Variants of the trial were as follows: 1) Untreated control; 2) Merlin® Duo (37.5 g/l isoxaflutole + 375 g/l terbuthylazine) - 0.75 l ha^{-1}; 3) Merlin® Duo-1.00 l ha^{-1}; 4) Merlin® Duo - 1.25 l ha^{-1}; 5) Merlin® Duo - 1.50 l ha^{-1}; 6) Merlin® Duo - 2.00 l ha^{-1}; 7) Adengo® 465 SC (225 g/l isoxaflutole + 90 g/l thiencarbazone-methyl + 150 g/l cyprosulfamide-antidote) - 0.44 l ha^{-1}; 8) Lumax® 538 SC (37.5 g/l mesotrione + 375 g/l s-metolachlor + 125 g/l terbuthylazine) - 4.00 l ha^{-1}.

RESULTS AND DISCUSSIONS

The experimental field was infested with *Setaria viridis* (L.) P.Beauv., *Echinochloa crus-galli* (L.) Beauv., *Sorghum halepense* (L.) Pers. from seeds and rhizomes, *Chenopodium album* L., *Amaranthus retroflexus* L., *Xanthium strumarium* L., *Abutilon theophrasti* Medik., *Datura stramonium* L., *Solanum nigrum* L., *Portulaca oleracea* L., *Cynodon dactylon* (L.) Pers., *Convolvulus arvensis* L.

For control of *Sorghum halepense* L., *Convolvulus arvensis* L., *Echinochloa crus-gali* L., *Chenopodium album* L., *Amaranthus retroflexus* L. and *Abutilon theophrasti* L. in maize the combination of Stomp 33 EC + Mistral 4 SC could be applied (Kalinova et al., 2000). It is important to note that the use of pendimethalin has a lower risk of groundwater contamination than other herbicides such as alachlor (Brahushi et al., 2011).

The efficacy of the studied herbicides on the 14th day after treatment in 2016 and 2017 is presented on table 1. All annual broadleaf and grass weeds, except *X. strumarium*, were well controlled by Merlin® Duo in all the studied rates. Excellent efficacy against the weeds was also performed by Lumax® 538 SC and Adengo® 465 SC. Against the *S. halepense* from rhizomes, none of the tested products were able to control the weed, although on the 14th day after treatments, efficacy rates of 10 to 40% were reported. We did not expect any efficacy against the *C. dactylon* from the studied herbicides, irrespective of their application rate. Nevertheless, after the application of Adengo® 465 SC, on the 14th day after treatments light bleaching after the germination of the weed was observed. The symptoms disappeared very quickly and the weed completely restored. Against *C. arvensis* unsatisfactory efficacy of the examined herbicides was reported. The low efficacy of Merlin Duo (for treatments with rates of 1.25, 1.50 and 2.00 l ha^{-1}) and Adengo® 465 SC were expressed in a slight retention of weed growth and a decrease of the chlorophyll content in the leaves.

On the 28th day after treatments the efficacy against all annual weeds was kept or decreased from 5 to 15%, in comparison with the evaluation on the 14th day (Table 2). To a greater extent, herbicidal efficacy decreases for the perennial weeds - *S. helepense, C. dactylon* and *C. arvesnis*. According to Kierzek et al. (2012) the best control of mixed weed infestation in maize is achieved after soil application of s-*metolachlor* + *terbuthylazine* + *mesotrione*, followd by foliar application of *nicosulfuron* + adjuvant Atpolan Bio 80 SL.

In the maize fields Tonev et al. (2016) establish high efficacy against annual gass and broadleaf weeds, as well as *Sorghum halepense* L., *Convolvulus arvensis* L, and *Cirsium arvense* L. after application of Flurostar® 200 EC + Nishin® 4 ODat rates of 700 ml/ha + 1300 ml/ha. If there is high infestation with *Chenopodium album* L. tank mixture of Mustang® 306.25 SC+ Nishin® 4 ODat rates of 600 ml/ha + 1300 ml/ha (Tonev et al., 2016).

For both years of the study, on the 56th day after treatment with Merlin® Duo at rates of 0.75 l ha^{-1} and 1.00 l ha^{-1} and Adengo® 465 SC, due to a strong secondary weed infestation with *S. viridis* and *E. crus-gali* the efficacy decreases and reaches 65-80% (Table 3). For the herbicides Merlin® Duo applied at doses of 1.25 to 2.00 l ha^{-1} and Lumax® 538 S Cit was found to have very good results against these two weeds (56 days after herbicide application, 85% to 95% efficacy). All herbicides, except for the lowest dose of herbicide Merlin® Duo (0.75 l ha^{-1}), completely control (95-100%) the weed *S. halepense* developed from seeds. Against C. album, Merlin® Duo applied at doses of 1.25 l ha^{-1} to 2.0 l ha^{-1} had excellent efficacy - 95% to 100%. Efficacy is not satisfactory at the lowest tested rates of Merlin® Duo and from the herbicides Lumax® and Adengo® 465 SC (from 70% to 85%) against this weed. Independently of the herbicide and examined rates, in all variants, the herbicidal efficacy against the *A. retroflexus* was from 90% to 100%. From all annual broadleaf weeds, *X. strumarium* was the most resistant to evaluated herbicides and rates. In none of the variants, efficacy was satisfactory. For Merlin® Duo at all evaluated rates, the efficacy reported on the 56th day after treatment ranged from 55% to 85%. For the variants treated with Adengo® 465 SC and Lumax® 538 SC, the efficacy was 80% for both years of the experiment. These low results are most likely due to the fact that *X. strumarium* germinates unevenly in time and from different soil depths. This is also the reason for the late secondary infestation. From the herbicides Merlin Duo (at rates of 1.00, 1.25, 1.50 and 2.00 l ha^{-1}), Adengo® 465 SC and Lumax® 538 SC against *A. theophrasti*on the 56th day after the treatment 90% to 100 % efficacy was recorded. Against *D. stramonium* excellent efficacy from all herbicides and rates in the study was reported. All studied herbicidesexcept for the lowest rate of Merlin® (0.75 l ha^{-1}) excellently control *S. nigrum*. Against *P. oleracea*, excellent results were obtained with the highest evaluated rates of Merlin® Duo (2.00 l ha^{-1}) and Lumax®538 SC at a rate of 4.00 l ha^{-1}. The lower the Merlin® Duo rate was, the lower the efficacy on the 56th day after treatment was recorded (75% to 95%). From the product Adengo® 465 SC, on the third last efficacy reporting date, due to high secondary weed infestation, the efficacy gradually decreased to 85%. None of the herbicides in the trial were able to control *S. halepense* developed from rhizomes, *C. dactylon* and *C. arvensis*. On the 56th day after the treatments, the efficacy of all products against these weeds was 0%.

No visible signs of phytotoxicity were reported for any of the treatments.

The weeds decrease the yields and the quality of maize grain (Masqood et al., 1999). The results of the comparative analysis of the indicator yield per hectare showed that during the two years of the experiment, significant differences in the benefit of the individual treated variants compared to the untreated control were demonstrated (Table 4).

From the analysed data by Duncan's multiple range test it was found that for variant 6 (Merlin® Duo at rate of 2.00 l ha^{-1}) the highest maize grain yield was achieved - 11.85 t ha^{-1}average for the period. The lowest maize grain seed yield among the treated variants was obtained at variant 2 (Merlin® Duo at rate of 0.75 l ha^{-1}) - 7.84 t ha^{-1} average for the two experimental years. The yield from the untreated control (6.97 t ha^{-1}) was 34% lower than the yield of variant 6.

Table 1. Efficacy of the studied herbicides on the14th day after treatment (%)

Variants / Weeds	2016								2017							
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
	-	90	95	95	95	95	90	100	-	85	90	90	90	90	85	100
S. viridis	-	85	95	95	100	100	90	100	-	80	90	90	95	95	85	95
E. crus-galli	-	95	100	100	100	100	100	100	-	100	100	100	100	100	100	100
S. halepense (s)	-	85	95	100	100	100	85	100	-	80	90	95	95	95	80	95
C. album	-	100	100	100	100	100	100	100	-	100	100	100	100	100	100	100
A. retroflexus	-	70	80	80	90	90	90	90	-	65	75	75	85	85	90	90
X. strumariu	-	90	100	100	100	100	100	100	-	90	95	100	100	100	10	100
A. theophrasti	-	90	95	95	100	100	95	95	-	85	90	95	95	100	95	95
D. stramonium	-	90	100	100	100	100	100	100	-	90	95	100	100	100	100	100
S. nigrum	-	95	100	100	100	100	100	100	-	85	90	95	95	100	95	95
P. oleracea	-	10	30	40	40	40	40	30	-	10	25	35	40	40	40	35
S. halepense (r)	-	0	0	0	0	0	15	0	-	0	0	0	0	0	10	0
C. dactilon	-	0	5	10	15	20	20	0	-	0	0	5	10	15	20	0

Table 2. Efficacy of the studied herbicides on the 28th day after treatment (%)

Variants / Weeds	2016								2017							
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
S. viridis	-	80	90	95	95	95	80	100	-	70	80	85	85	85	75	95
E. crus-galli	-	80	85	95	95	100	80	95	-	75	80	90	90	90	75	90
S. halepense (s)	-	95	100	100	100	100	100	100	-	90	95	100	100	100	100	100
C. album	-	85	90	100	100	100	80	90	-	80	85	95	95	100	75	85
A. retroflexus	-	100	100	100	100	100	100	100	-	90	95	100	100	100	100	100
X. strumariu	-	65	80	80	80	85	80	85	-	60	75	75	80	80	75	80
A. theophrasti	-	85	100	100	100	100	100	100	-	80	90	95	100	100	100	100
D. stramonium	-	90	90	95	100	100	90	90	-	85	90	95	100	100	85	85
S. nigrum	-	90	100	100	100	100	100	100	-	85	90	95	100	100	100	100
P. oleracea	-	90	95	100	100	100	90	100	-	85	90	95	100	100	90	95
S. halepense (r)	-	0	5	15	15	15	20	15	-	0	0	10	10	10	15	10
C. dactilon	-	0	0	0	0	0	0	0	-	0	0	0	0	0	0	0
C. arvensis	-	0	0	0	0	5	5	0	-	0	0	0	0	0	0	0

Table 3. Efficacy of the studied herbicides on the 56th day after treatment (%)

Variants / Weeds	2016								2017							
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
S. viridis	-	70	80	90	90	90	75	90	-	65	75	85	90	90	70	90
E. crus-galli	-	70	80	90	95	95	75	90	-	65	75	85	90	95	75	90
S. halepense (s)	-	90	100	100	100	100	100	100	-	85	95	95	100	100	100	100
C. album	-	80	90	100	100	100	75	85	-	75	85	95	95	100	70	80
A. retroflexus	-	100	100	100	100	100	100	100	-	90	90	95	100	100	100	100
X. strumariu	-	60	75	75	80	85	80	80	-	55	70	75	80	80	80	80
A. theophrasti	-	85	100	100	100	100	100	100	-	80	90	95	100	100	100	100
D. stramonium	-	85	90	95	95	100	90	90	-	80	85	90	90	95	90	90
S. nigrum	-	90	100	100	100	100	100	100	-	85	100	100	100	100	100	100
P. oleracea	-	80	90	95	95	100	85	100	-	75	85	90	95	100	85	95
S. halepense (r)	-	0	0	0	0	0	0	0	-	0	0	0	0	0	0	0
C. dactilon	-	0	0	0	0	0	0	0	-	0	0	0	0	0	0	0
C. arvensis	-	0	0	0	0	0	0	0	-	0	0	0	0	0	0	0

Table 4. Maize grain seed yield, t ha^{-1}

Treatments	Rates l ha^{-1}	2016		2017		Average	
		yield	Duncan	yield	Duncan	yield	Duncan
1. Untreated control	-	7.03	a	6.90	a	6.97	a
2. Merlin®Duo	0.75	7.90*	b	7.78*	b	7.84*	b
3. Merlin®Duo	1.00	8.10*	b	8.01*	b	8.05*	b
4. Merlin®Duo	1.25	8.89*	c	8.88*	c	8.89*	c
5. Merlin®Duo	1.50	9.50*	d	9.45*	d	9.48*	d
6. Merlin®Duo	2.00	11.90*	f	11.81*	f	11.85*	f
7. Adengo® 465 SC	0.44	11.01*	de	10.99*	de	11.00*	de
8. Lumax® 538 SC	4.00	11.06*	e	11.05*	e	11.05*	e

All variants with a star have significant difference with the untreated control. The values in a column, followed by different letters (a, b, c etc.), differ significantly in $P < 0.05$.

CONCLUSIONS

The herbicide product Lumax® 358 SC at rate of 4.00 l ha^{-1} is superior in efficiency to Merlin® Duo at rates of 0.75 and 1.00 l ha^{-1} and Adengo 465 CK at rate of 0.44 l ha^{-1} against *Setaria viridis* L.

The highest efficacy against *Echinochloa crus-galli* L. and *Datura stramonium* L. for Merlin® Duo at rate of 2.00 l ha^{-1} was recorded.

In all variants, with the exception of the lowest tested Merlin® Duo rate, 90% to 100% efficacy against *Sorghum halepense* L. from seeds, *Abuthilon theophrasti* L. and *Solanum nigrum* L. was found.

The highest efficacy against *Chenopodium album* L.was observed after the treatment of Merlin® Duo at rates of 1.25, 1.5 and 2.00l ha^{-1}. The most resistant annual broadleaf weed in the experiment was *Xanthium strumarium* L.

Visible signs of phytotoxicity were not observed for any of the treatments in the study. The highest maize grain yield was achieved for the treatment of Merlin® Duo at rate of 2.00 l ha^{-1}.

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