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EVALUATION OF SOME SOIL HERBICIDES AND THEIR COMBINATIONS IN MAIZE

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Abstract

In the growing seasons of 2020 and 2021, a field plot trial with the maize hybrid P 9241 (FAO 370) was conducted. The trial was performed on the experimental field of the department of "Agriculture and herbology" at the Agricultural University - Plovdiv, Bulgaria. The evaluated herbicidal products were Aspect® T (200 g/l flufenacet + 333 g/l terbuthylazine), Adengo® 465 SC (225 g/l isoxaflutol + 90 g/l thiencarbazone-methyl + 150 g/l cyprosulfamide (antidote)), and Merlin® Flexx SC 480 (240 g/l isoxaflutole + 240 g/l cyprosulfamide (antidote)). The herbicidal products were applied alone and in combinations after sowing before germination of the crop. The natural weed infestation of the experimental field was presented by the following late spring weed species: Setaria viridis L., Digitaria sanguinalis (L.) Scop., Chenopodium album L., Amaranthus retroflexus L., Xantium strumarium L., Abutilon theophrasti Medic, Datura stramonium L., Solanum nigrum L., and Portulaca oleracea L. The highest herbicidal efficacy, as well as the highest seed yields after the alone application of Adengo® 465 SC, was recorded.

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

INTRODUCTION

One of the factors limiting the development of cultivated plants is the annual ubiquity and development of weeds and nutrient availability in soil (Yanev, 2015; Yanev et al., 2014a).

There is a large number of literature sources that prove both the harmful effects of weeds and the great possibilities for chemical control over them. Weeds are a very limiting factor for realizing the potential of crops (Tonev, 2000; Kostadinova et al., 2016; Tonev et al., 2019; Dimitrova et al., 2020). Studies by several authors show that depending on the type and degree of weeding, corn yield can be reduced from 24.0 to 96.7% (Mukherjee and Debnath 2013; Dimitrova et al., 2013; Najafi and Tollenar, 2005; Oerke and Dehne, 2004; Khan et al., 2003). A wide range of weed species may be infesting the maize fields. Some of them are *Amaranthus* spp., *Chenopodium album* L., *Abutilon theophrasti* Medik., etc. (Tonev et al., 2011; Tonev, 2008; Nikolov et al., 2005; Mousavi, 2001).

Chemical weed control is the most common weed control (Yanev 2021; Yanev 2020). The method is highly efficient, fast, and easy. Proper use of herbicides reduces weed control costs by up to 60%, reduces fuel and energy costs, and soil erosion (Valcheva, 2011). The proper herbicide must meet the following requirements - to be selective for the crop; to be highly effective against the existing weeds; its application rates should not lead to the accumulation of residues in plant production and soil; should not deteriorate the quality of production ad should be harmless to soil microorganisms and the environment (Yanev and Kalinova, 2020; Goranovska and Yanev, 2016; Hristeva et al., 2015; Yanev and Kalinova, 2015; Semerdjieva et al., 2015; Hristeva et al., 2014; Yanev et al., 2014b; Rao, 2000).

According to Kalinova et al. (2000) for control of late-spring weeds in maize, the application Stomp 33 EC + Mistral 4 SC may be accomplished. It is important to note that the use of pendimethalin has a lower risk of groundwater contamination compared to other herbicides such as alachlor (Brahushi et al., 2011). In areas infested with light-preferable weeds, tall and fast-growing hybrids should be grown (Tonev, 2013). For control of grass weeds mainly, after sowing before germination of the crop, the herbicides S-metolachlor, Isoxaflutol, Pendimethalin, Dimethenamid-P may be applied. Also, for broadleaf weeds, soil-applicable herbicides such as

Terbuthylazine; Mesotrione; Flumioxazine, etc. may be sprayed (Tonev et al., 2019).
The aim of the study is to evaluate the efficacy of soil herbicides and combinations in maize.

MATERIALS AND METHODS

In 2020 and 2021 a field experiment with the maize hybrid P 9241 was conducted. The trial was situated in the Training and Experimental Field of the Department of Agriculture and Herbology at the Agricultural University – Plovdiv, Bulgaria.
The experiment is based on the block method in 4 repetitions with a total size of the working plot of the four repetitions 112 m².
A preliminary inspection of the experimental field was performed. In the reporting field nine types of weeds, typical for the crop were identified. The average weed density in the two experimental years, per 1 m^2 was as follows: *Setaria viridis* L. - 12.5 specimens; *Digitaria sanguinalis* (L.) Scop. - 5.5 specimens; *Chenopodium album* L - 18 specimens; *Amaranthus retroflexus* L. - 8 specimens; *Xantium strumarium* L. - 6 specimens; *Abutilon theophrasti* Medic. - 5 specimens; Datura stramonium L. - 5.5 specimens; *Solanum nigrum* L. - 59.5 specimens; *Portulaca oleracea* L. - 11 specimens.
The study included the following treatments: 1. Untreated control; 2. Aspect T (200 g/l flufenacet + 333 g/l terbuthylazine) - 1.5 l ha^{-1}; 3. Aspect T - 1.0 l ha^{-1}; 4. Aspect T - 0.75 l ha^{-1}; 5. Aspect T - 0.4 l ha^{-1}; 6. Aspect T + Adengo 465 SC - 1.0 l ha^{-1} + 0.22 l ha^{-1} (in tank mixture); 7. Aspect T + Adengo 465 SC (225 g/l isoxaflutole + 90 g/l thiencarbazone-methyl + 150 g/l ciprosulfamide - antidote) - 0.75 l ha^{-1} + 0.22 l ha^{-1} (in tank mixture); 8. Aspect T + Merlin Flexx 465 SC (240 g/l isoxaflutole + 240 g/l ciprosulfamide - antidote) - 1.0 l ha^{-1} + 0.21 l ha^{-1} (in tank mixture); 9. Aspect T + Мерлин Флекс 465 СК - 0.75 l ha^{-1} + 0.21 l ha^{-1} (in tank mixture); 10. Adengo 465 SC - 0.44 l ha^{-1}.
All treatments were performed after sowing before germination of maize (BBCH 00).
The herbicide spraying was accomplished via electrical backpack sprayer SOLO model 417 (Solo, Germany) with a volume of the working solution of 300 l ha^{-1}.
Maize was grown as a mono-cropping system under drop irrigation conditions.
The soil preparation before sowing of the crop included deep autumn ploughing in 30-35 cm of depth. Also, two disking operations were performed. Pre-sowing fertilization with NPK 15:15:15 at the rate of 300 kg ha^{-1} was accomplished. Sowing was carried out in the optimal time for the crop at a spacing of 25 x 70 cm. Spring dressing with NH_4NO_3 at the rate of 300 kg ha^{-1} was also done.
The herbicide efficacy evaluations were performed 14, 28, and 56 days after herbicidal application. The 10-score scale of EWRS (European Weed Research Society) for visual rating was used.
For herbicidal selectivity, the 9-score scale of EWRS was used.
The results of the conducted research with the software package of SPSS 17 program of one- and two-factorial analysis of variance were processed.

RESULTS AND DISCUSSIONS

On Table 1 is shown the obtained efficacy against the weed *S. viridis* L average for both experimental years. At treatments 2, 6, 8, and 10 the herbicidal efficacy on the 14th day after application varies from 90 to 100%.
On the 56th day, the efficacy decreased. The highest and long-lasting efficacy to the 56th day after treatments after the application of Aspect T + Merlin Flexx - 1.00 + 0.21 l $ha^{-1}$and Adengo - 0.44 l ha^{-1} was recorded - 90%.

Table 1. Efficacy of the studied herbicides against *S. viridis* average fort the period (%)

Treatments	Days after treatments		
	14	28	56
1. Untreated control	-	-	-
2. Aspect T - 1.50 l ha^{-1}	95	90	80
3. Aspect T - 1.00 l ha^{-1}	70	65	55
4. Aspect T - 0.75 l ha^{-1}	50	40	20
5. Aspect T - 0.40 l ha^{-1}	20	10	0
6. Aspect T + Adengo - 1.00 + 0.22 l ha^{-1}	90	85	75
7. Aspect T + Adengo - 0.75 + 0.22 l ha^{-1}	70	60	40
8. Aspect T + Merlin Flexx - 1.00 + 0.21 l ha^{-1}	100	100	90
9. Aspect T + Merlin Flexx - 0.75 + 0.21 l ha^{-1}	85	80	65
10. Adengo - 0.44 l ha^{-1}	100	100	90

The efficacy results regarding the weed *D. sanguinalis* are presented on Table 2. Despite the high efficacy (85-95%) of treatments 2, 6, 8 and 10 against this weed, excellent efficacy was not recorded from any treatment. After the last reporting date (56 days after treatments) severe decrease of the herbicidal efficacy was found (55-80%).

Table 2. Efficacy of the studied herbicides against *D. sanguinalis*, average fort the period (%)

Treatments	Days after treatments		
	14	28	56
1. Untreated control	-	-	-
2. Aspect T - 1.50 l ha^{-1}	90	80	70
3. Aspect T - 1.00 l ha^{-1}	65	55	45
4. Aspect T - 0.75 l ha^{-1}	40	30	5
5. Aspect T - 0.40 l ha^{-1}	15	0	0
6. Aspect T + Adengo - 1.00 + 0.22 l ha^{-1}	85	75	55
7. Aspect T + Adengo - 0.75 + 0.22 l ha^{-1}	65	55	30
8. Aspect T + Merlin Flexx - 1.00 + 0.21 l ha^{-1}	95	90	80
9. Aspect T + Merlin Flexx - 0.75 + 0.21 l ha^{-1}	80	75	55
10. Adengo - 0.44 l ha^{-1}	95	90	80

The efficacy of the studied herbicides against the broadleaf weed Срешу *Ch. album* is presented on Table 3. On the 14th day, the efficacy of treatments 2, 6, and 8 was 100% but decreased in time. The highest results for treatment 10 (Adengo - 0.44 l ha^{-1}) were recorded. The efficacy of this treatment was 100% from the 14th till the 56th day after the treatments. It is noteworthy that in variants 6 and 8 the efficacy is also high - in the range of 90-95% reported on the 56th day after treatment. The herbicidal effect of the product Aspect T applied at a dose of 1.50 l ha^{-1} (85%) was also satisfactory.

Table 3. Efficacy of the studied herbicides against *Ch. album*, average fort the period (%)

Treatments	Days after treatments		
	14	28	56
1. Untreated control	-	-	-
2. Aspect T - 1.50 l ha^{-1}	100	95	85
3. Aspect T - 1.00 l ha^{-1}	80	70	50
4. Aspect T - 0.75 l ha^{-1}	50	40	20
5. Aspect T - 0.40 l ha^{-1}	20	5	0
6. Aspect T + Adengo - 1.00 + 0.22 l ha^{-1}	100	100	95
7. Aspect T + Adengo - 0.75 + 0.22 l ha^{-1}	75	70	60
8. Aspect T + Merlin Flexx - 1.00 + 0.21 l ha^{-1}	100	95	90
9. Aspect T + Merlin Flexx - 0.75 + 0.21 l ha^{-1}	80	70	55
10. Adengo - 0.44 l ha^{-1}	100	100	100

The highest average efficacy results against the weed *A. retroflexus* for the treatments with Aspect T - 1.50 l ha^{-1} (variant 2) and Adengo - 0.44 l ha^{-1} (variant 10) were recorded. Also, the use of Aspect T (1.0 l ha^{-1}) in a tank mix with the products Adengo and Merlin Flexx showed high herbicidal efficacy on the three reporting dates. A satisfactory effect against weed *A. retroflexus* was also obtained from the lower tested dose of 1.0 l ha^{-1} of Aspect T.

Against the weed species *Xa. strumarium,* 100% efficacy after the application of the tank mixture of Aspect T + Merlin Flexx - 1.00 + 0.21 l ha^{-1}, as well as for the alone application of Adengo - 0.44 l ha^{-1} was recorded on the 14th day after application (Table 4). On the 14th day after applying the product Aspect T - 1.50 l ha^{-1} led to 90%, and the tank mixture of Aspect T + Adengo - 1.00 + 0.22 l ha^{-1} to 95% efficacy. At the last reporting date, 90% control over the weed from the product Adengo applied alone was found. In all other variants of the experiment on the 56th day after treatments satisfactory control of weed was not reported.

Table 4. Efficacy of the studied herbicides against *Xa. strumarium,* average fort the period (%)

Treatments	Days after treatments		
	14	28	56
1. Untreated control	-	-	-
2. Aspect T - 1.50 l ha^{-1}	90	80	60
3. Aspect T - 1.00 l ha^{-1}	65	50	30
4. Aspect T - 0.75 l ha^{-1}	40	20	0
5. Aspect T - 0.40 l ha^{-1}	10	0	0
6. Aspect T + Adengo - 1.00 + 0.22 l ha^{-1}	95	85	70
7. Aspect T + Adengo - 0.75 + 0.22 l ha^{-1}	75	60	30
8. Aspect T + Merlin Flexx - 1.00 + 0.21 l ha^{-1}	100	90	75
9. Aspect T + Merlin Flexx - 0.75 + 0.21 l ha^{-1}	75	60	35
10. Adengo - 0.44 l ha^{-1}	100	95	90

From the data presented on Table 5 it is seen that the herbicidal efficacy of the products Aspect T - 1.50 l ha^{-1} T, Adengo - 0.44 l ha^{-1}, as well the tank mixture of Aspect T + Merlin Flexx - 1.00 + 0.21 l ha^{-1} against the broadleaf weed *A. theophrasti* was high on the three reporting dates. The efficacy of the tank mixture of Aspect T + Adengo - 1.00 + 0.22 l ha^{-1} against the weed was also high. The efficacy of the other treatments against the weed *A. theophrasti* was unsatisfactory.

Table 5. Efficacy of the studied herbicides against *A. theophrasti,* average fort the period (%)

Treatments	Days after treatments		
	14	28	56
1. Untreated control	-	-	-
2. Aspect T - 1.50 l ha^{-1}	100	95	90
3. Aspect T - 1.00 l ha^{-1}	80	70	60
4. Aspect T - 0.75 l ha^{-1}	50	35	20
5. Aspect T - 0.40 l ha^{-1}	10	5	0
6. Aspect T + Adengo - 1.00 + 0.22 l ha^{-1}	95	90	85
7. Aspect T + Adengo - 0.75 + 0.22 l ha^{-1}	80	70	60
8. Aspect T + Merlin Flexx - 1.00 + 0.21 l ha^{-1}	100	95	90
9. Aspect T + Merlin Flexx - 0.75 + 0.21 l ha^{-1}	90	80	65
10. Adengo - 0.44 l ha^{-1}	100	100	100

The herbicidal efficacy against the weed *D. stramonium* was very good to excellent at treatments 2, 6, 8, and 10 (Table 6) on the three reporting days. In the other variants of the experiment, an unsatisfactory herbicidal effect against weeds was observed. The efficacy of the lowest evaluated rate of Aspect T (0.40 l ha^{-1}) at the last reporting date (56th day after application of the products) reached 10% only.

Table 6. Efficacy of the studied herbicides against *D. stramonium,* average fort the period (%)

Treatments	Days after treatments		
	14	28	56
1. Untreated control	-	-	-
2. Aspect T - 1.50 l ha^{-1}	100	100	95
3. Aspect T - 1.00 l ha^{-1}	90	80	70
4. Aspect T - 0.75 l ha^{-1}	70	50	30
5. Aspect T - 0.40 l ha^{-1}	50	30	10
6. Aspect T + Adengo - 1.00 + 0.22 l ha^{-1}	100	100	95
7. Aspect T + Adengo - 0.75 + 0.22 l ha^{-1}	90	80	70
8. Aspect T + Merlin Flexx - 1.00 + 0.21 l ha^{-1}	100	95	90
9. Aspect T + Merlin Flexx - 0.75 + 0.21 l ha^{-1}	95	85	75
10. Adengo - 0.44 l ha^{-1}	100	100	100

The only excellent efficacy (100%) from the 14th till the 56th day after treatments against the weed *S. nigrum* after the application of Adengo - 0.44 l ha^{-1} was recorded (Table 7). The alone application of the product Aspect T at the rate of 1.50 l ha^{-1} showed 100% efficacy on the 14th day after treatments. The efficacy of the treatment decreased to 80% in time.

The combined application of Aspect T at the rate of 1.0 l ha^{-1} in tank mixture with Merlin Flexx and Adengo showed 95% on the first reporting date. For the other variants in the experiment on the 56th day after treatment, the efficacy was extremely low and ranged from 0 to 50%. It is correct to note that the density of the weed *S. nigrum* was the highest compared to other weeds species in the experiment (over 70 specimens per m² was reported).

Table 7. Efficacy of the studied herbicides against *S. nigrum,* average fort the period (%)

Treatments	Days after treatments		
	14	28	56
1. Untreated control	-	-	-
2. Aspect T - 1.50 l ha^{-1}	100	90	80
3. Aspect T - 1.00 l ha^{-1}	70	55	40
4. Aspect T - 0.75 l ha^{-1}	40	20	5
5. Aspect T - 0.40 l ha^{-1}	10	0	0
6. Aspect T + Adengo - 1.00 + 0.22 l ha^{-1}	95	85	70
7. Aspect T + Adengo - 0.75 + 0.22 l ha^{-1}	75	60	45
8. Aspect T + Merlin Flexx - 1.00 + 0.21 l ha^{-1}	95	85	75
9. Aspect T + Merlin Flexx - 0.75 + 0.21 l ha^{-1}	70	60	50
10. Adengo - 0.44 l ha^{-1}	100	100	100

The recorded efficacy against the weed *P. oleracea* is shown on Table 8. High efficacy is observed when using the herbicidal product Aspect T 1.50 l ha^{-1} alone - 100% on the first reporting date. The application of Adengo - 0.44 l ha^{-1} showed the highest results - 100% on the three evaluation dates.

Table 8. Efficacy of the studied herbicides against *P. oleracea,* average fort the period (%)

Treatments	Days after treatments		
	14	28	56
1. Untreated control	-	-	-
2. Aspect T - 1.50 l ha^{-1}	100	95	85
3. Aspect T - 1.00 l ha^{-1}	70	55	35
4. Aspect T - 0.75 l ha^{-1}	40	20	0
5. Aspect T - 0.40 l ha^{-1}	10	0	0
6. Aspect T + Adengo - 1.00 + 0.22 l ha^{-1}	100	90	80
7. Aspect T + Adengo - 0.75 + 0.22 l ha^{-1}	80	60	40
8. Aspect T + Merlin Flexx - 1.00 + 0.21 l ha^{-1}	100	95	85
9. Aspect T + Merlin Flexx - 0.75 + 0.21 l ha^{-1}	85	65	45
10. Adengo - 0.44 l ha^{-1}	100	100	100

Visible signs of phytotoxicity were not observed in any of the variants.

The disperse analyses of the obtained data for the maize grain seed yields showed proved differences among the treatments (Table 9). The average yields obtained for the period are shown. The maize productivity is determined by the differences in the herbicidal efficacy differences. The lowest results for the untreated control were obtained (6.56 t ha^{-1}). According to the degree of mathematical proof, seven separate groups are distinguished (a, b, c, d, e, f, g). It was found that treatment 10 (Adengo - 0.44 l ha^{-1}) is from the group (g) - the most distanced group from the untreated control (a) and respectively treatment 10 showed the highest grain yield - 13.45 t ha^{-1}. After the decrease of the Aspect T rates, the productivity also decreased. At the lowest Aspect T rate of 0.40 l ha^{-1}, the yields of 6.72 t ha^{-1} were comparable to those of the untreated control.

Table 9. Maize grain seed yield, t ha^{-1}

Treatments	Yields
1. Untreated control	6.56 a
2. Aspect T - 1.50 l ha^{-1}	10.00* e
3. Aspect T - 1.00 l ha^{-1}	8.72* c
4. Aspect T - 0.75 l ha^{-1}	8.16* b
5. Aspect T - 0.40 l ha^{-1}	6.72 a
6. Aspect T + Adengo - 1.00 + 0.22 l ha^{-1}	9.52* d
7. Aspect T + Adengo - 0.75 + 0.22 l ha^{-1}	8.88* c
8. Aspect T + Merlin Flexx - 1.00 + 0.21 l ha^{-1}	12.24* f
9. Aspect T + Merlin Flexx - 0.75 + 0.21 l ha^{-1}	8.89* c
10. Adengo - 0.44 l ha^{-1}	13.45* g

All results with a * have significant differences with the untreated control. The values with different letters have significant differences at $p < 0.05$.

CONCLUSIONS

The herbicidal product Adengo 468 SC applied at a rate of 0.44 l ha^{-1} alone and the tank mixture of Aspect T (1.00 l ha^{-1}) + Merlin Flexx (0.21 l ha^{-1}) showed the highest efficacy results against the weeds *S. viridis* and *D. sanguinalis.*

Excellent (100%) herbicidal efficacy against *Ch. album, A. retroflexus, A. theophrasti, D. stramonium,* and *S. nigrum* after the application of Adengo 468 SC - 0.44 l ha^{-1} was recorded.

The lowest herbicidal efficacy against all weeds in the experiment from the product Aspect T applied alone at a rate of 0.40 l ha^{-1} was reported.

No visible signs of phytotoxicity were observed in either variant throughout the maize vegetation.

The highest maize grain seed yield after the application of Adengo 468 SC - 0.44 l ha^{-1} was found (13.44 t ha^{-1}).

Of all the herbicide-treated variants, the lowest yields after the treatment with Aspect T at a rate of 0.40 l ha^{-1} were obtained.

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