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APPLICATION OF HERBICIDES FOR WEED CONTROL BEFORE GERMINATION AND IN THE EARLY VEGETATION IN MAIZE

Mariyan YANEV

Agricultural University of Plovdiv, 12 Mendeleev Blvd, Plovdiv, Bulgaria

Corresponding author email: mar1anski@abv.bg

Abstract

In 2020 and 2021, a field trial with the maize hybrid P 9241 in the experimental field of the Agricultural University - Plovdiv, Bulgaria was conducted. The herbicidal products Stomp Aqua - 4.00 l ha^{-1} and Gardoprim Plus Gold - 3.50 l ha^{-1} applied to soil, as well as Adengo - 0.44 l ha^{-1} and Camix - 2.50 l ha^{-1} applied in the 1st - 2nd leaf stage of maize were evaluated. The efficacy of the studied products by the 10-score visual scale of EWRS was reported. Selectivity was also assessed using the 9-score scale of EWRS. The highest herbicidal efficacy against Amaranthus retroflexus L., Xanthium strumarium L., Abutilon theophrasti Medik., Solanum nigrum L., Sorghum halepense (L.) Pers. developed from seeds was reported after the application of Adengo. Of the studied herbicides, the highest control against Chenopodium album L. was reported for Camix. The biological yields of maize, as well as the structural elements of the maize yield were the highest after the application of Adengo and Camix applied in 1st - 2nd leaf stage of the crop.

Key words*: maize, herbicides, weeds, efficacy, yield's structural elements.*

INTRODUCTION

The growth of the world's population is insufficiently providing it with a sufficient amount of food products. This is possible through the implementation of output technologies, methods, and means leading to the sustainable production of agricultural products (Georgiev et al., 2019; Shopova & Cholakov, 2015; Shopova & Cholakov, 2014; Calkins & Swanson, 1995).

Maize (*Zea mays* L.) is one of the most widely spread and important cereal crops in the world (Ram et al., 2017). Its production is used in three directions - for grain, for green fodder, and for animal silage (Iken & Amusa, 2004). *Zea mays* L. is characterized by very good adaptability and high productive potential (Aldrich et al., 1975).

Weeds are the main limiting factor in maize cultivation, leading to a decrease in the yield and quality of the produced product (Tonev et al., 2019; Saleem et al., 2015; Arnold et al., 2013). Weeds have been found to consume a significant proportion of soil-applied fertilizers (Mundra et al., 2002).

Depending on the species composition and weed density, as well as the duration of the competitive relationship between maize and weeds, the grain yield of *Zea mays* L. can be reduced from 18% to 96.7% (Gharde et al., 2018; Dimitrova et al., 2018; Ehsas et al., 2016; Jagadish & Prashant, 2016; Kakade et al., 2016; Yakadri et al., 2015; Dimitrova et al., 2014a; Dimitrova et al., 2014b; Mukherjee & Puspajit, 2013; Jat et al., 2012; Oerke & Dehne, 2004; Khan et al., 2003; Zhalnov & Raikov, 1996).

Crop yield reduction, apart from the development of weeds in the crop, can also be caused by nutrient deficiency (Ivanov et al., 2019; Manolov & Neshev, 2017; Neshev & Manolov, 2016; Manolov et al., 2015; Neshev & Manolov, 2014; Neshev et al., 2014; Goranovska et al., 2014).

Depending on the latitude and agroecological conditions, maize may be infested by different types of weeds. In Bulgaria, the most common weeds in *Zea mays* L. are *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. (Mitkov et al., 2019; Hristova et al., 2012; Kalinova et al., 2012; Mitkov et al., 2009).

The weed association of maize fields in Kahramanmaras, Turkey is composed of

Amaranthus retroflexus L., *Convolvulus arvensis* L., *Solanum nigrum* L., *Chenopodium album* L., *Sorghum halepense* (L.) Pers., *Xanthium strumarium* L., *Cyperus rotundus* L., *Datura stramonium* L., *Portulaca oleracea* L., *Tribulus terrestris* L., and *Anagallis arvensis* L. (Tursun et al., 2016).

In Greece, *Amaranthus* spp. is most commonly found in maize crops (Vizantinopoulos & Katranis, 1998).

In Fundulea, Romania, maize is infested mainly by *Setaria viridis*, *Echinochloa crus-galli*, *Sorghum halepense*, *Chenopodium album*, *Xanthium strumarium*, and *Cirsium arvense* (Şerban et al., 2022).

Demjanová et al. (2009) and Týr & Vereš (2012) found that in Slovakia maize mainly infested by *Chenopodium album*, *Amaranthus* spp., *Echinichloa crus galli*, *Datura stramonium*, *Fallopia convolvulus*, *Persicaria* spp., *Convolvulus arvensis*, *Cirsium arvense*, *Elytrigia repens*, *Avena fatua*, and *Abutilon theophrasti*. According to Smatana et al. (2015), the dominant weeds in the crop were *Atriplex* spp. and *Setaria viridis*.

The most common weeds in Poznań, Poland are *Echinochloa crus-galli*, *Chenopodium album*, *Polygonum convolvulus*, *Polygonum aviculare*, *Geranium pusillum*, and *Viola arvensis* (Skrzypczak et al., 2011).

Weed infestation in the maize fields of India is presented by *Polygonum* spp., *Stellaria media, Stellaria aquatica, Oldelandia diffusa, Oldenlandia umbellate, Physalis minima, Solanum nigrum*. In the Belgaum district of Karnataka, India, the most common 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* (Soren et al., 2018; Mukherjee & Puspajit, 2013; Haji et al., 2012).

Weed control in agricultural crops (Mitkov, 2021; Mitkov, 2014; Tonev et al., 2010; Tityanov et al., 2010; Tityanov et al., 2009a; Tityanov et al., 2009b) and particularly in maize, is most often accomplished by herbicidal application (Mitkov, 2022; Mitkov, 2020; Goranovska & Kalinova, 2018; Goranovska et al., 2017; Janak & James, 2016; Sevov et al., 2015; Umesha & Sridhara, 2015; Goranovska & Kalinova, 2014; Dimitrova et al., 2013b; Skrzypczak et al., 2011; Pannacci & Covarelli, 2009, Tonev et al., 2009b).

According to Dimitrova et al. (2013a) efficient control of grass and broadleaf weeds was achieved with soil application of Gardoprim plus gold 500 SK at a rate of 4.00 l ha^{-1}, Lumax 538 SK at a rate of 4.00 l ha^{-1}, and Wing at a rate of 4.00 l ha^{-1}.

For the control of *Abuthilon theophrasti* L. and *Solanum nigrum* L. Mitkov et al. (2018) recommended Merlin Duo at rates of 1.00 l ha^{-1} to 2.00 l ha^{-1} after sowing before crop emergence.

Very good efficacy against *Amaranthus retroflexus* L., *Setaria viridis* (L.) Beauv., *Sinapis arvensis* L., and *Solanum nigrum* L. was found after treatment with foramsulfuron at a rate of 20.3 g ai ha^{-1}. At a higher dose of 20 to 50 g ai ha^{-1}, the herbicide also provides very good control against *Abutilon theophrasti* Medik., *Chenopodium album* L. and *Echinochloa crus-galli* (L.) Beauv. (Pannacci, 2016).

Kalinova et al. (2000) found that Stomp 33 EK + Mistral 4 SK in rates of 3.00 l ha^{-1}+1.30 l ha^{-1} controlled *Sorghum halepense* L., *Convolvulus arvensis* L., *Echinochloa crus gali* L., *Chenopodium album* L., *Amaranthus retroflexus* L., and *Abutilon theophrasti* L. in *Zea mays* L.

If there is mixed weed infestation, Kierzek et al. (2012), recommend the soil application of s-metolachlor + terbuthylazine + mesotrione in a tank mixture and nicosulfuron with adjuvant Atpolan Bio 80 SL.

Many scientists have studied the biological efficacy of atrazine in combination with other herbicides in maize (Acharya et al., 2022; Bottcher et al., 2022; Burhanuddin Wiqar et al., 2022; Choudhary et al., 2022; Jha et al., 2022; Khanna et al., 2022; Pinsupa et al., 2022; Wasnik et al., 2022). Soil application of atrazine followed by vegetational treatment with tembotrione vegetative was found to successfully control the weeds in maize (Arunkumar et al., 2019). Bada et al. (2022) also reported efficient weed control by the system involving soil application of atrazine followed by foliar treatment with tembotrione or topramezone.

Very good efficacy against *Xanthium strumarium*, *Amaranthus retroflexus*, *Datura stramonium*, and *Chenopodium album* in maize was observed after application of tembotrione at 100 g ai ha^{-1} and tembotrione at 100 g ai ha^{-1} in combination rimsulfuron at 10 g ai ha^{-1}, nicosulfuron at 40 g ai ha^{-1} and foramsulfuron at 60 g ai ha^{-1} (Damalas et al., 2018).

The present study aims to study the application of herbicides for weed control before germination and in the early vegetation in maize.

MATERIALS AND METHODS

In 2020 and 2021, a field trial with the maize hybrid P 9241 (370 FAO) in the experimental field of the Agricultural University - Plovdiv, Bulgaria was conducted.

The variants of the experiment were: 1. Untreated control; 2. Stomp Aqua (455 g/l pendimethalin) - 4.00 l ha^{-1} (BBCH 00); 3. Gardoprim Plus Gold (312.5 g/l S-metolachlor + 197.5 g/l terbutylazine) - 3.50 l ha^{-1} (BBCH 00); 4. Adengo (225g/l isoxaflutole + 90 g/l thiencarbazone-methyl + 150 g/l tsiprosulfamid - antidote) - 0.44 l ha^{-1} (BBCH 11-12); 5. Camix (60 g/l mesotrione + 500 g/l S-metolachlor) - 2.50 l ha^{-1} (BBCH 11-12).

The trial was performed by the randomized block design in 4 replications (Dimova and Marinkov, 1999) with a size of the experimental plot of 28 m^2.

The herbicidal products Stomp Aqua - 4.00 l ha^{-1} and Gardoprim Plus Gold - 3.50 l ha^{-1} were applied to the soil. Adengo - 0.44 l ha^{-1} and Camix - 2.50 l ha^{-1} were applied in the 1^{st} - 2^{nd} leaf stage of maize. The treatment was carried out via electrical backpack sprayer SOLO (model 417), with a size of the working solution 300 l ha^{-1}.

During the two experimental years, maize was grown as a monoculture under non-irrigated conditions. An experimental field was fertilized with 25 kg/da N:P:K (15:15:15) followed by deep plowing. Before sowing the maize, disking was carried out at 15 cm and two cultivations at 8 cm of depth. Sowing was carried out in the optimal period of the crop at a row spacing of 70 cm, with a density of 65000 plants per hectare. Spring dressing with 25 kg/da NH_4NO_3 was also carried out.

The experimental area was naturally infested with *Chenopodium album* L., *Amaranthus retroflexus* L., *Xanthium strumarium* L., *Abutilon theophrasti* Medik., *Solanum nigrum* L., and *Sorghum halepense* (L.) Pers. developed from seeds and rhizomes.

The biological efficacy was reported on the 14^{th}, 28^{th}, and 56^{th} day after the herbicide application. The efficacy against the weeds was evaluated by the 10-score visual scale of EWRS. The efficacy results were compared with the untreated control.

The selectivity of the studied herbicides was evaluated on the 7^{th}, 14^{th}, 28th, and 56^{th} day after the treatments by the 9-score visual scale of EWRS (at score 1 - there is no damage on the crop, and at score 9 there is complete death of the crop).

The following indicators of maize were evaluated and analyzed: ear length (cm); a number of grains per ear; ear diameter (cm); absolute seed mass of 1000 air-dry seeds (g), hectolitre seed mass (kg), and maize grain seed yield (t ha^{-1}).

Duncan's method with the SPSS 19 program (Duncan, 1955) was used for the statistical processing of the obtained data. Differences were considered significant at $p<0.05$.

RESULTS AND DISCUSSIONS

In 2020 and 2021, weed species belonging to only two biological groups were reported in the experimental area with maize. The species of the late-spring weeds were *Chenopodium album* L., *Amaranthus retroflexus* L., *Xanthium strumarium* L., *Abutilon theophrasti* Medik., and *Solanum nigrum* L. Species from the perennial group of weeds was *Sorghum halepense* (L.) Pers. developed from seeds and rhizomes.

On the 14^{th} day after applying the herbicides, the highest efficacy against *Ch. album* averaged over the two years was registered with Camix - 2.50 l ha^{-1} (BBCH 11-12) - 100%. Approximately excellent efficacy in the control of this weed was also registered with Adengo - 0.44 l ha^{-1} (BBCH 11-12) and Gardoprim Plus Gold - 3.50 l ha^{-1} (BBCH 00) - 97.5%. During the first reporting date, on average for the period, the lowest herbicide efficacy was registered with Stomp Aqua at a

dose of 4.00 l ha^{-1}, applied after sowing before emergence - 87.5%.

On day 28 after the treatment with Camix, the efficacy against *Ch. album* was again the highest compared to the other herbicides (Table 1). Gardoprim Plus Gold at a rate of 3.50 l ha^{-1}, applied after sowing before germination of the crop showed a higher efficacy against the weed compared to Adengo at a rate of 0.44 l ha^{-1}. The efficacy of the two products on the 28th day after treatment on average for the two experimental years was 87.5% and 77.5%, respectively.

Average for the two years, on the 56th day, the highest control of *Ch. album* - 82.5% was registered for Camix - 2.50 l ha^{-1} (BBCH 11-12). Gardoprim Plus Gold - 3.50 l ha^{-1} (BBCH 00) controlled the wed on average of 75%. Similar efficiency was reported for Adengo - 0.44 l ha^{-1} (BBCH 11-12) - 72.5%. During the third reporting date, the lowest herbicidal efficacy against *Ch. album* - 60%, for Stomp Aqua at a rate of 4.00 l ha^{-1} was found. Higher control of *Ch. album* - 99%. Şerban et al. (2022) found high control of the weed after the application of Diniro (40 g/kg prosulfuron + 400 g/kg dicamba + 100 g/kg nicosulfuron) at a rate of 500 g ha^{-1} + Trend (adjuvant) in dose 0.25 l ha^{-1}, applied in the 4th - 6th leaf stage of maize.

Table 1. Efficacy of the studied herbicides against *Chenopodium album* L. (%)

Variants	2020			2021			Average		
	14th	28th	56th	14th	28th	56th	14th	28th	56th
1. Untreated control	-	-	-	-	-	-	-	-	-
2. Stomp Aqua - 4.00 l ha^{-1} (BBCH 00)	90	75	65	85	70	55	87.5	72.5	60
3. Gardoprim Plus Gold - 3.50 l ha^{-1} (BBCH 00)	100	90	80	95	85	70	97.5	87.5	75
4. Adengo - 0.44 l ha^{-1} (BBCH 11-12)	100	80	75	95	75	70	97.5	77.5	72.5
5. Camix - 2.50 l ha^{-1} (BBCH 11-12)	100	95	85	100	90	80	100	92.5	82.5

Regarding the weed *Amaranthus retroflexus* L., on the 14th day after application of the herbicides, 100% efficacy of Camix - 2.50 l ha^{-1} (BBCH 11-12) and Gardoprim Plus Gold - 3.50 l ha^{-1} was recorded (BBCH 00). High efficiency was also reported for Adengo - 0.44 l ha^{-1} (BBCH 11-12) - 97.5%. On the first reporting date, the lowest efficacy against *A. retroflexus* after treatment with Stomp Aqua at a dose of 4.00 l ha^{-1} applied to the crop was observed (Table 2).

Table 2. Efficacy of the studied herbicides against *Amaranthus retroflexus* L. (%)

Variants	2020			2021			Average		
	14th	28th	56th	14th	28th	56th	14th	28th	56th
1. Untreated control	-	-	-	-	-	-	-	-	-
2. Stomp Aqua - 4.00 l ha^{-1} (BBCH 00)	90	80	70	85	75	65	87.5	77.5	67.5
3. Gardoprim Plus Gold - 3.50 l ha^{-1} (BBCH 00)	100	95	90	100	90	80	100	92.5	85
4. Adengo - 0.44 l ha^{-1} (BBCH 11-12)	100	100	100	95	100	100	97.5	100	100
5. Camix - 2.50 l ha^{-1} (BBCH 11-12)	100	100	100	100	100	100	100	100	100

On the 28th day after treatment, the efficacy of Adengo against *A. retroflexus* reached 100%. Camix at a dose of 2.50 l ha^{-1} on the 28th day maintains excellent control against *A. retroflexus* - 100%. In both experimental years, the foliar application of the herbicides was more effective than the application of soil herbicides applied after sowing before the germination of the crop (Table 2). On the second reporting date, the lowest control against the weed was observed for Stomp Aqua at a rate of 4.00 l ha^{-1} - 77.5%.

On the 56th day, the results for the *A. retroflexus* control showed that soil-applied herbicides were less effective than early-vegetation-applied herbicides. The highest efficacy against the weed was from Camix and Adengo - 100%. One hundred percent control against *A. retroflexus* can also be achieved after alone application of nicosuffuron (Dobbels & Kapusta, 1993).

Of the soil-applied herbicides, higher efficacy against *A. retroflexus* was obtained with Gardoprim Plus Gold - 85%. The control against this weed after the application of Stomp Aqua was significantly lower - 67.5% (Table 2).Results related to the control of *Xanthium strumarium* L. showed distinct differences between herbicides applied after sowing before crop emergence and in the early vegetation of maize. On average for the two experimental years, on the 14th day after the application of Adengo and Camix, 100% percent efficacy was recorded. With Stomp Aqua and Gardoprim Plus Gold, the efficacy against *X. strumarium* L. is unsatisfactory and is only 7.5% (Table 3).

On the 28th day after treatment, excellent control of *X. strumarium* L. was observed for the treatment with Adengo. The evaluation of the efficacy of Camix showed a decrease from 100% to 87.5% on the second reporting date. The Stomp Aqua and Gardoprim Plus Gold variants showed no efficacy against *X. strumarium.*

On the 56th day after treatment with Adengo – 0.44 l ha^{-1} (BBCH 11-12) the control against *X. strumarium* L. was excellent again. Satisfactory efficacy - 75% against the weed after application of Camix was also observed. Zero efficacy against weed was registered with the soil-applied herbicides Stomp Aqua and Gardoprim Plus Gold (Table 3).

Table 3. Efficacy of the studied herbicides against *Xanthium strumarium* L. (%)

Variants	2020			2021			Average		
	14th	28th	56th	14th	28th	56th	14th	28th	56th
1. Untreated control	-	-	-	-	-	-	-	-	-
2. Stomp Aqua - 4.00 l ha^{-1} (BBCH 00)	10	0	0	5	0	0	7.5	0	0
3. Gardoprim Plus Gold - 3.50 l ha^{-1} (BBCH 00)	10	0	0	5	0	0	7.5	0	0
4. Adengo - 0.44 l ha^{-1} (BBCH 11-12)	100	100	100	100	100	100	100	100	100
5. Camix - 2.50 l ha^{-1} (BBCH 11-12)	100	90	80	100	85	70	100	87.5	75

In contrast to *X. strumarium*, the studied herbicides showed higher efficacy against *Abutilon theophrasti* Medik. During the first reporting date, 100% control against *A. theophrasti* in the variants with Adengo at a dose of 0.44 l ha^{-1} (BBCH 11-12) and Camix at a dose of 2.50 l ha^{-1} (BBCH 11-12) was observed. In the variants with Gardoprim Plus Gold and Stomp Aqua the control of the weed was 92.5% and 87.5% respectively.

On the second reporting date, 100% control of *A. theophrasti* was again observed for variants 4 and 5 on average for the two years. In the variants with soil herbicides (3 and 2), good control of weeds was reported, respectively 87.5% and 82.5% (Table 4).

On the 56th day after treatment, the herbicides Adengo and Camix applied early in the growing season maintained 100% percent control of *A. theophrasti*. The efficacy of soil-applied Gardoprim Plus Gold and Stomp Aqua was lower, 77.5% and 72.5% respectively (Table 4).

Table 4. Efficacy of the studied herbicides against *Abutilon theophrasti* Medik., *(*%)

Variants	2020			2021			Average		
	14th	28th	56th	14th	28th	56th	14th	28th	56th
1. Untreated control	-	-	-	-	-	-	-	-	-
2. Stomp Aqua - 4.00 l ha^{-1} (BBCH 00)	90	85	75	85	80	70	87.5	82.5	72.5
3. Gardoprim Plus Gold - 3.50 l ha^{-1} (BBCH 00)	95	90	80	90	85	75	92.5	87.5	77.5
4. Adengo - 0.44 l ha^{-1} (BBCH 11-12)	100	100	100	100	100	100	100	100	100
5. Camix - 2.50 l ha^{-1} (BBCH 11-12)	100	100	100	100	100	100	100	100	100

The control results of *Solanum nigrum* L. in the trial area show the following. On the 14th day after treatment with Adengo - 0.44 l ha^{-1} (BBCH 11-12) and Camix - 2.50 l ha^{-1} (BBCH 11-12) the weed was controlled 100%. Very good efficiency after the treatment with Stomp Aqua - 4.00 l ha^{-1} (BBCH 00) and Gardoprim Plus Gold – 3.50 l ha^{-1} (BBCH 00) was also reported - 92.5% and 97.5%, respectively (Table 5).

It is noteworthy that during the second reporting date, the excellent efficacy against *S. nigrum* of Adengo and Camix was the same. Stomp Aqua and Gardoprim Plus Gold also

provided good control of the weed - 82.5% and 92.5%, respectively.

On the 56th day after treatment, average for the period 100% control of *S. nigrum* L. was observed only after the usage of Adengo. In second place in terms of effectiveness against the weed was Camix - an average of 92.5%. Of all the studied products, the lowest control of *S. nigrum* for Stomp Aqua - 67.5% was recorded (Table 5).

Table 5. Efficacy of the studied herbicides against *Solanum nigrum* L. (%)

Variants	2020			2021			Average		
	14th	28th	56th	14th	28th	56th	14th	28th	56th
1. Untreated control	-	-	-	-	-	-	-	-	-
2. Stomp Aqua - 4.00 l ha^{-1} (BBCH 00)	95	85	70	90	80	65	92.5	82.5	67.5
3. Gardoprim Plus Gold - 3.50 l ha^{-1} (BBCH 00)	100	95	90	95	90	85	97.5	92.5	87.5
4. Adengo - 0.44 l ha^{-1} (BBCH 11-12)	100	100	100	100	100	100	100	100	100
5. Camix - 2.50 l ha^{-1} (BBCH 11-12)	100	100	95	100	100	90	100	100	92.5

All treatments showed high efficacy against *Sorghum halepense* (L.) Pers. developed from seeds on the 14th day after treatment - from 97.5% to 100%.

On the 28th day, 100% control of *S. halepense* developed from seeds only at Camix - 2.50 l ha^{-1} (BBCH 11-12) was reported. For the other variants, the efficiency varied from 92.5% to 97.5%. On the 56th day for Adengo - 0.44 l ha^{-1} (BBCH 11-12) excellent control against *S. halepense* developed from seeds was found. Similar high efficiency (97.5%) was also observed for Camix - 2.50 l ha^{-1} (BBCH 11-12) and Gardoprim Plus Gold - 3.50 l ha^{-1} (BBCH 00) (Table 6).

Table 6. Efficacy of the studied herbicides against *Sorghum halepense* (L.) Pers. developed from seeds (%)

Variants	2020			2021			Average		
	14th	28th	56th	14th	28th	56th	14th	28th	56th
1. Untreated control	-	-	-	-	-	-	-	-	-
2. Stomp Aqua - 4.00 l ha^{-1} (BBCH 00)	100	95	90	95	90	85	97.5	92.5	87.5
3. Gardoprim Plus Gold - 3.50 l ha^{-1} (BBCH 00)	100	100	100	95	95	95	100	97.5	97.5
4. Adengo - 0.44 l ha^{-1} (BBCH 11-12)	100	100	100	95	95	100	97.5	97.5	100
5. Camix - 2.50 l ha^{-1} (BBCH 11-12)	100	100	100	100	100	95	100	100	97.5

The most difficult-to-control weed species in the study was *Sorghum halepense* (L.) Pers developed from rhizomes. The results for the herbicidal control of the weed are presented in Table 7. The soil-applied herbicides Stomp Aqua - 4.00 l ha^{-1} (BBCH 00) and Gardoprim Plus Gold - 3.50 l ha^{-1} (BBCH 00) showed no efficacy on the weed (0%). In the case of early vegetation herbicides, the efficacy is slightly higher but still insufficient.

Table 7. Efficacy of the studied herbicides against *Sorghum halepense* (L.) Pers. developed rhizomes (%)

Variants	2020			2021			Average		
	14th	28th	56th	14th	28th	56th	14th	28th	56th
1. Untreated control	-	-	-	-	-	-	-	-	-
2. Stomp Aqua - 4.00 l ha^{-1} (BBCH 00)	0	0	0	0	0	0	0	0	0
3. Gardoprim Plus Gold - 3.50 l ha^{-1} (BBCH 00)	0	0	0	0	0	0	0	0	0
4. Adengo - 0.44 l ha^{-1} (BBCH 11-12)	30	20	15	25	20	10	27.5	20	12.5
5. Camix - 2.50 l ha^{-1} (BBCH 11-12)	15	10	0	10	0	0	12.5	0	0

On the 56th day, 12.5% efficacy only with Adengo - 0.44 l ha^{-1} (BBCH 11-12) was observed, which is practically unsatisfactory. In the remaining variants, the control was 0% (Table 7).

Satisfactory efficacy against *S. halepense* from rhizomes in maize was observed after the application of nicosulfuron (Eleftherohorinos and Kotoula-Syka, 1995).

During the two experimental years, the selectivity of the applied products to maize hybrid P 9241 was also studied. Under the conditions of the experiment and during the four reporting dates of the two years, no visible

manifestations of phytotoxicity were found in all variants with herbicides - score 1 on the EWRS scale.

In addition to the biological efficacy and selectivity of the tested herbicides, the productivity of the maize hybrid P 9241 was also monitored during the experiment.

The comparative analysis of the ear length of maize, hybrid P 9241 showed that there are proven differences in all variants. It was statistically proven that the plants of treatment 4 (Adengo - 0.44 l ha^{-1} (BBCH 11-12) had the longest ears, with 20.43 cm in 2020 and 19.57 cm in 2021. It is also worth noting the variant with Camix - 2.50 l ha^{-1} (BBCH 11-12), where this indicator in 2020 is 19.36 cm and in 2021 - 18.42 cm. It was mathematically proven that of all variants, the shortest ear length in the untreated control was recorded, where in 2020 it was 11.22 cm, and in 2021 - 10.18 cm (Table 8).

Table 8. Maize ear length (cm)

Variants	2020	2021	Average
1.	11.22 e	10.18 e	10.70
2.	14.74 d	14.15 d	14.45
3.	18.23 c	17.50 c	17.87
4.	20.43 a	19.57 a	19.99
5.	19.36 b	18.42 b	18.89

Figures with different letters are with proved difference according to Duncan's multiple range test ($p < 0.05$).

Table 9. Number of seeds per maize ear

Variants	2020	2021	Average
1.	186.00 d	238.00 d	212.00
2.	394.00 c	322.00 c	358.00
3.	410.00 c	378.00 b	394.00
4.	608.00 a	532.00 a	570.00
5.	594.00 b	522.00 a	558.00

Figures with different letters are with proved difference according to Duncan's multiple range test ($p < 0.05$).

The results for the parameter number of seeds in a cob are presented in Table 9. The lowest number of seeds in a maize ear, on average for the period was recorded in the untreated control - 212.00. On average for the two experimental years, the highest number of seeds per ear after the application of Adengo - 0.44 l ha^{-1} (BBCH 11-12) - 570.00 was recorded (Table 9).

Regarding the ear diameter in 2020 and 2021, significant differences were recorded between the untreated control and all variants with herbicides. In 2020, the highest ear diameter (4.30 cm) was registered for Adengo - 0.44 l ha^{-1} and Gardoprim Plus Gold - 3.50 l ha^{-1}. With Camix - 2.50 l ha^{-1} and Stomp Aqua - 4.00 l ha^{-1}, the ear diameter was 4.20 cm. It is fair to note that there is no mathematically proven difference between these four treatments. The ear diameter was the lowest in the untreated control - 3.20 cm.

In 2021 the highest ear diameter after the application of Adengo - 0.44 l ha^{-1} (BBCH 11-12) (4.10 cm) was reported. In the remaining variants with herbicides, the ear diameter varied from 3.90 cm to 4.00 cm. There was no mathematically proven difference between variants 2, 3, 4, and 5. The maize ear diameter was the lowest in the untreated control (2.80 cm) in the second year as well (Table 10).

Table 10. Maize ear length (cm)

Variants	2020	2021	Average
1.	3.20 b	2.80 b	3.00
2.	4.20 a	4.00 a	4.10
3.	4.30 a	3.90 a	4.10
4.	4.30 a	4.10 a	4.20
5.	4.20 a	3.90 a	4.05

Figures with different letters are with proved difference according to Duncan's multiple range test ($p < 0.05$).

Absolute seed mass depends on the size and nutritional status of the seeds. On average for the two years, the highest results for this indicator for Adengo - 0.44 l ha^{-1} (BBCH 11-12) and Camix - 2.50 l ha^{-1} (BBCH 11-12) 279.15 g and 275.57 g, respectively were found. Both in 2020 and in 2021, there is no statistically proven difference between variants 4 and 5. A slightly lower absolute seed mass was registered in the variants with Stomp Aqua - 257.03 g and Gardoprim Plus Gold - 262.28 g. From all the treatments, the lowest values of the studied indicator for the untreated control were obtained, where in 2020 it was 244.33 g, and in 2021 - 223.50 g (Table 11). The significantly lower values of absolute seed mass in the untreated control compared to the herbicide variants were due to the high weed infestation. Bastegan et al. (2022) reported that weed development in sweet corn (*Zea mays* L. var. *saccharata*) resulted in a reduction of 1000 grain weight. Fang et al. (2022) found that successful weed control by mechanical

weeding combined with low doses of herbicide led to an increase in the 1000-grain weight.

Table 11. Absolute seed mass of maize (g)

Variants	2020	2021	Average
1.	244.33 c	223.50 c	233.92
2.	261.40 b	252.65 b	257.03
3.	267.12 b	257.43 b	262.28
4.	288.10 a	270.19 a	279.15
5.	283.44 a	267.69 a	275.57

Figures with different letters are with proved difference according to Duncan's multiple range test ($p < 0.05$).

The hectoliter mass is determined by the size and protection of the grain, by the presence of impurities, including weeds, etc. (Dimitrova et al., 2006). The highest values of hectoliter mass on average for the two years after the application of Adengo - 0.44 l ha^{-1} (BBCH 11-12) and Camix - 2.50 l ha^{-1} (BBCH 11-12) were registered - respectively 75.50 kg and 75.25 kg. For this indicator as well, the untreated control has the lowest values - 63.25 kg on average for the experimental period (Table 12).

Table 12. Hectolitre seed mass (kg)

Variants	2020	2021	Average
1.	65.50 d	61.00 d	63.25
2.	72.00 b	70.00 b	71.00
3.	74.00 a	72.50 ab	73.25
4.	76.00 a	75.00 a	75.50
5.	75.50 a	75.00 a	75.25

Figures with different letters are with proved difference according to Duncan's multiple range test ($p < 0.05$).

Table 13 shows the maize yield from the present study. The obtained results showed that there is a positive correlation between the effect of herbicides against the weeds and the structural elements of the maize yield and the biological yields of maize.

As a result of the weed infestation, the lowest maize yield was recorded in the untreated control, where in 2020 it was 4.11 t ha^{-1} and in 2021 it was 2.93 t ha^{-1}. Studies under different agrometeorological conditions show that maize grain yield can be reduced to varying degrees depending on the type and density of weeds (Choudhary et al., 2022; Wiqar et al., 2022; Mitkov, 2020; Dimitrova et al., 2018; Tursun et al., 2016; Skrzypczak et al., 2011; Walia et al., 2005).

The highest yield for Adengo - 0.44 l ha^{-1} (BBCH 11-12), and in 2020 it was 9.12 t ha^{-1}, and in 2021 it was 8.48 t ha^{-1} was reported. The other variant with early vegetation treatment is close to this yield. With Camix in a dose of 2.50 l ha^{-1}, applied in the 1st - 2nd leaf of the crop in 2020, the reported yield was 8.85 t ha^{-1}, and in 2021, 8.35 t ha^{-1}.

Compared to the variants with early vegetation application, lower yields were recorded when applying the herbicides to the soil. On average for the two experimental years, for Gardoprim Plus Gold at a rate of 3.50 l ha^{-1} (BBCH 00), a yield of 7.22 t ha^{-1} was reported, and with Stomp Aqua at a rate of 4.00 l ha^{-1} (BBCH 00), a yield of 6.17 t ha^{-1} (Table 13).

Table 13. Maize grain seed yield (t ha^{-1})

Variants	2020	2021	Average
1.	4.11 e	2.93 d	3.52
2.	6.23 d	6.10 c	6.17
3.	7.42 c	7.02 b	7.22
4.	9.12 a	8.48 a	8.80
5.	8.85 b	8.35 a	8.60

Figures with different letters are with proved difference according to Duncan's multiple range test ($p < 0.05$).

CONCLUSIONS

Adengo at a rate of 0.44 l ha^{-1} applied in the 1st - 2nd leaf stage of maize on the 56th day after treatment provides 100% control against *Amaranthus retroflexus* L., *Xanthium strumarium* L., *Abutilon theophrasti* Medik., *Solanum nigrum* L., and *Sorghum halepense* (L.) Pers. developed from seeds. However, none of the herbicides studied provided effective control against *Sorghum halepense* (L.) Pers. developed rhizomes. The highest control against *Chenopodium album* L. – 82.5% on average for the two years of the study for Camix at a dose of 2.50 l ha^{-1} was reported.

The herbicides applied early in the vegetation were more effective against existing weeds than herbicides applied after sowing before the germination of maize.

Under the conditions of the experiment, no visible signs of phytotoxicity were found on maize, hybrid P 9241 after the application of pendimethalin; S-metolachlor + terbutylazine; isoxaflutole + thiencarbazone-methyl; mesotrione + S-metolachlor.

The maize ear length, the number of seeds per ear, the ear diameter, absolute seed mass, hectolitre seed mass, and maize grain seed yield were the highest for the variants with Adengo - 0.44 l ha^{-1} (BBCH 11-12) and Camix - 2.50 l ha^{-1} (BBCH 11-12).

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MISCELLANEOUS