

APPLICATION OF FOLIAR HERBICIDES TO CONTROL BROADLEAF WEEDS IN RYE (*Secale cereale* L.)

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Abstract

Rye (*Secale cereale* L.) is an important crop used for food, animal feed and bioenergy. Weeds are one of the main factors limiting the growth and development of the crop. The aim of the present study was to determine the efficacy of foliar herbicides against broadleaf weeds and the treatments' influence on growth and reproductive performance of rye, "Millennium" cultivar. During the period 2021/2022 and 2022/2023, a field experiment with rye was carried out on the experimental field of the Agricultural University of Plovdiv, Bulgaria. The herbicidal products Sekator OD - 0.15 l ha⁻¹, Axial One - 1.00 l ha⁻¹, Biathlon 4D - 55 g ha⁻¹, Granstar 75 DF - 15 g ha⁻¹, and Aminopielik 600 SL - 2.00 l ha⁻¹ applied in tillering stage of rye (BBCH 29) were evaluated. The efficacy of the studied products by the 10-score visual scale of EWRS was reported. The application of Biathlon 4D - 55 g ha⁻¹ provides the best control against *Papaver rhoeas* L., *Descurainia sophia* L., *Consolida orientalis* J. Gay, *Capsella bursa-pastoris* L., *Lamium purpureum* L. and *Fumaria officinalis* L. At the same treatment rye yields as well as accompanying biometric indicators were the highest.

Key words: rye, herbicides, weeds, efficacy, biometry.

INTRODUCTION

One of the main challenges facing humanity is to provide enough raw materials for the population's nutrition. This requires the use of arable land to be rational, through the implementation of new technologies in the cultivation of crops, leading to an increase in their yield. In addition, it is necessary to find solutions to the problems related to the lack of water and nutrients, the competition between plants, the control of pests, especially weeds, etc. (Shopova, 2023; Suryawanshi & Patil, 2023; Grzebisz et al., 2022; Neshev, 2022; Neshev, 2021; Neshev, 2020; Petkova et al., 2020; Veeck et al., 2020; Dimitrova et al., 2019; Georgiev et al., 2019; Matev et al., 2017; Mitkov et al., 2017; Pereira, 2017; Petrova et al., 2017; Neshev & Manolov, 2016; Shopova & Cholakov, 2015; Neshev et al., 2014; Neshev & Manolov, 2014; Shopova & Cholakov, 2014; Bernstein et al., 2011; Calkins & Swanson, 1995).

The main food providing sources for people and livestock around the world are the cereal crops. In Europe, the cultivation of rye (*Secale cereale* L.) dates back to ancient times. In the global aspect, the largest producers of rye are the countries of the European Union and

specifically Germany, Poland, Russia and Denmark (Orhun et al., 2023).

One of the main uses of rye is as a raw material for the food industry. The grain is used for flour, from which rye bread is made, as well as pumpnickel. The flour is characterized by a high percentage of gliadin and a low percentage of glutenin. Unlike wheat flour, the amount of gluten in rye is lower (Clifton & Keogh, 2016). In addition, rye grain contains arabinoxylan, which determines the water binding properties of the flour (Poutanen et al., 2014). In addition, rye can be used in fermented beverages such as kvass, whiskey, vodka and beer (Heiniö et al., 2003; Wang et al., 1999).

Secale cereale L. develops well on almost all types of soil and shows little sensitivity to soil reaction. Compared to other winter cereals, rye has a higher cold resistance. The root system of the plant is more developed than that of wheat, which determines the higher drought resistance. As a result of the better adaptability of rye to low fertility soils and unfavorable climatic conditions, the cultivation of rye instead of wheat is preferred (Orhun et al., 2023; Ivanova et al., 2019)

Rye has no high preceding crop demands. It can be grown after itself for several years, as well as after wheat, barley and oats. The most suitable

preceding crops for rye are legumes, field crops, flax and oilseed rape. Compared to wheat, rye is a better preceding crop for other crops because it depletes the soil less and leaves it cleaner of weeds (Ivanova et al., 2019).

Currently, rye is widely used as a cover crop due to its valuable qualities. Walters et al. (2008) reported the potential of winter rye as a cover crop for integrated no-till weed control in cucurbits with the use of herbicides. Liebl et al. (1992) reported that rye mulch can be used as an alternative for weed control in soybean. Yadav et al. (2023) found that growing *S. cereale* as a soybean cover crop in combination with narrow crop rows reduced the density of *Amaranthus tuberculatus*. According to Shilling et al. (1985), removal of tillage and incorporation of rye mulch in tobacco, sunflower and soybean cropping technology reduced the biomass of *Chenopodium album* L. and *Amaranthus retroflexus* L.

Some authors found that rye has an allelopathic effect on weeds. According to Barnes and Putnam (1987) and Przepiorkowski and Gorski (1994), benzoxazinoids suppress *Coryza canadensis* and *Amaranthus* spp. In addition, Rice et al. (2012) reported that benzoxazinoids contained in rye residues are released in small concentrations and slowly into the soil. The authors also found that these compounds persist for a short time in the soil – up to one day, which is insufficient to cause damage to weeds. According to Hovary et al. (2016), Reberg-Horton et al. (2005) and Macías et al. (2014) weed toxicity caused by these compounds depends on cultivar, developmental phenophase and density of the rye plants.

Despite the rapid growth *S. cereale* and the allelopathic potential of the crop against the weeds, if some agrotechnical measures are violated in its cultivation technology, the weeds can cause serious damage. In the conditions of a poorly garnished crop, weeds quickly develop and occupy the free area, and can take the upper hand over cultivated plants. In this early phase, the crop is sensitive to weed infestation, which can lead to a severe yield reduction (Tonev et al., 2007).

Weed development may be favored by increased seed bank in the soil as a result of wrong crop rotations. Every crop is weed infested with species that coincides with the growing season

of the crop plants. Winter-spring weeds find the best conditions in winter cereal crops. Therefore, if correct crop rotations are not performed on an area infested with winter-spring weeds, if winter-cereal crops are sown successively, the density of these weeds rapidly increases, especially if herbicides are not applied (Tonev et al., 2019).

There are many studies related to the spread of weeds in wheat crops and the possibilities of their control (Mitkov, 2023; Yanev, 2022; Yanev et al., 2021; Shaban et al., 2021; Mitkov, 2014; Tityanov et al., 2010; Mitkov et al., 2009a; 2009b; Tityanov et al., 2009). It is noteworthy that, on a national and global scale, information on the weed composition in rye, as well as the chemical control of weeds, is very limited. Moyer et al. (2002) found that the fields of perennial cereal rye were infested by *Avena fatua* L., *Setaria viridis* (L.) P. Beauv., *Chenopodium album* L., *Malva rotundifolia* L., *Cirsium arvense* (L.) Scop., and *Sonchus asper* (L.) Hill.

Gar'kova et al. (2011) study the short- and long-term effects of Granstar on the physiological and biochemical indicators related to the development of oxidative stress in winter rye, winter wheat, maize and common wild oat. The authors found that more tolerant to Granstar were winter rye and winter wheat in comparison to maize and common wild oat. In 2013, a similar experiment was conducted with the herbicidal product Topik (Lukatkin et al., 2013). The studied crops were winter rye, winter wheat and maize. It was found that in winter rye and winter wheat the antioxidant enzymes are the most active, which indicates a better protective mechanism compared to that of maize. Studies related to the efficacy of amidosulfuron + iodosulfuron (Sekator OD) in rye are not found. In addition, many scientists have reported successful broadleaf weeds control after application of amidosulfuron + iodosulfuron in wheat (Kotelnikova et al., 2022; Yanev, 2022; Petrova & Nankova, 2018). Georgiev (2020) investigated the influence of Secator OD and Granstar 75 DF on structural elements of yield and quality parameters of wheat's grain.

No studies were found on the biological efficacy of Axial One in rye. The herbicidal efficacy of Axial One was studied in winter wheat (Dospatliev et al., 2015; Reisinger et al., 2012).

The control of broadleaf weeds in wheat and barley after application of florasulam + tritosulfuron has been studied by many researchers (Mitkov, 2023; Sevov et al., 2023; Yanev, 2022; Yanev et al., 2021; Brathuhn & Petersen, 2014), but by this moment there are not studies found in the literature for the application of Biathlon 4D in winter rye.

The aim of the present study was to determine the efficacy of foliar herbicides against broadleaf weeds and the influence of the treatments on growth and reproductive performance of rye, cultivar Millennium.

MATERIALS AND METHODS

During the period 2021/2022 and 2022/2023, a field experiment with rye was carried out on the experimental field of the Agricultural University of Plovdiv, Bulgaria. The experiment was carried out according to the randomized block method in 3 replications. The size of the working plot was 20 m². For the purpose of the experiment, the Bulgarian rye variety Millennium was grown. The preceding crop of rye in both experimental years was winter oilseed rape (*Brassica napus* L., hybrid PT 228 CL).

The trial included the following variants: 1. Untreated control; 2. Sekator OD (25 g/l iodosulfuron + 100 g/l amidosulfuron) - 0.15 l ha⁻¹; 3. Axial One (45 g/l pinoxaden + 5 g/l florasulam) - 1.00 l ha⁻¹; 4. Biathlon 4D (54 g/kg florasulam + 714 g/kg tritosulfuron) - 55 g ha⁻¹; 5. Granstar 75 DF (750 g/kg tribenuron-methyl) - 15 g ha⁻¹; 6. Aminopielik 600 SL (600 g/l 2.4 D amine salt) - 2.00 l ha⁻¹. The herbicides were applied in the phenophase end of tillering of rye (BBCH 29) with spraying solution 250 l ha⁻¹.

The efficacy of the studied herbicides was evaluated by the 10-score scale of EWRS (European Weed Research Society) on the 14th, 28th, and the 42th day after treatments. The selectivity of the herbicides was evaluated by the 9-score scale of EWRS on the 14th, 28th, and the 42th day after application (Zhelyazkov et al., 2017).

The following parameters of the *S. cereale* L. were determined: plant height at the end of the vegetation (m); rye ear length (cm); absolute seed mass (g) (Tonev et al., 2018), and hectolitre

seed mass (kg) (Tonev et al., 2018). During the two trila years, rye grain yields (t ha⁻¹) of all variants were reported. Harvesting was done with a Wintersteiger® field trial harvester.

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

During the two years of growing rye in the experimental field of the Agricultural University, only broadleaf weeds, represented by three biological groups, were recorded. With the most representatives is the group of winter-spring weeds: *Papaver rhoeas* L., *Descurainia sophia* L., *Consolida orientalis* J.Gay, *Capsella bursa-pastoris* L. The other two groups were represented by one weed species each, respectively *Lamium purpureum* L. from the early-spring group and *Fumaria officinalis* L. from the ephemeral group. It is correct to note that the development of weeds is favored by the not well garnished sowing of the crop.

The results related to weed control show that the lowest herbicidal efficacy was recorded on the 14th day after application of the herbicide products, and the highest was on the 42nd day after treatment.

Table 1 shows the efficacy of the examined herbicides against *Papaver rhoeas* L. On average for the period, on the 14th day after treatment, an efficacy ranging from 45% for variant 2 (Sekator OD - 0.15 l ha⁻¹) to 70% for varaint 4 (Biathlon 4D - 55 g ha⁻¹). On the next evaluation date, the efficacy increased and reached 65-82.5% between variants on average over the experimental years. On the 42nd, on average for the conditions of the experiment, the efficacy against the weed reached 97.5% in variant 4. For the other treatments the efficiency was 92.5% (Table 1).

The biological efficacy of the studied herbicidal products against *Descurainia sophia* L. is shown on table 2. On average for the period, on the 14th day after treatment, efficacy ranging from 55% with Sekator OD - 0.15 l ha⁻¹ to 70% with Biathlon 4D - 55 g ha⁻¹ was found. At the next reporting date, the efficiency increases and reaches 75-85% between the variants on average over the experimental years. On the 42nd day

after treatment, the efficacy against *D. sophia* reached 100% at variant 4 (Biathlon 4D - 55 g ha⁻¹), 97.5% in variants 3 (Axial One - 1.00 l ha⁻¹) and 6 (Aminopielik 600 SL - 2.00 l ha⁻¹), and

for variants 2 (Sekator OD - 0.15 l ha⁻¹) and 5 (Granstar 75 DF - 15 g ha⁻¹) the average efficacy was 87.5% (Table 2).

Table 1. Efficacy of the studied herbicides against *Papaver rhoeas* L., %

Variants	2022			2023			Average		
	14 th day	28 th day	42 th day	14 th day	28 th day	42 th day	14 th day	28 th day	42 th day
1. Untreated control	-	-	-	-	-	-	-	-	-
2. Sekator OD - 0.15 l ha ⁻¹	50	60	90	40	70	95	45	65	92.5
3. Axial One - 1.00 l ha ⁻¹	60	80	90	65	85	95	62.5	82.5	92.5
4. Biathlon 4D - 55 g ha ⁻¹	65	85	100	75	80	95	70	82.5	97.5
5. Granstar 75 DF - 15 g ha ⁻¹	60	80	90	70	80	95	65	80	92.5
6. Aminopielik 600 SL - 2.00 l ha ⁻¹	50	70	90	45	80	95	47.5	75	92.5

Table 2. Efficacy of the studied herbicides against *Descurainia sophia* L., %

Variants	2022			2023			Average		
	14 th day	28 th day	42 th day	14 th day	28 th day	42 th day	14 th day	28 th day	42 th day
1. Untreated control	-	-	-	-	-	-	-	-	-
2. Sekator OD - 0.15 l ha ⁻¹	50	70	85	60	80	90	55	75	87.5
3. Axial One - 1.00 l ha ⁻¹	60	80	95	65	75	100	62.5	77.5	97.5
4. Biathlon 4D - 55 g ha ⁻¹	65	85	100	75	80	100	70	82.5	100
5. Granstar 75 DF - 15 g ha ⁻¹	55	75	85	65	80	90	60	77.5	87.5
6. Aminopielik 600 SL - 2.00 l ha ⁻¹	60	80	95	65	90	100	62.5	85	97.5

Table 3. Efficacy of the studied herbicides against *Consolida orientalis* J. Gay, %

Variants	2022			2023			Average		
	14 th day	28 th day	42 th day	14 th day	28 th day	42 th day	14 th day	28 th day	42 th day
1. Untreated control	-	-	-	-	-	-	-	-	-
2. Sekator OD - 0.15 l ha ⁻¹	45	65	80	55	75	90	50	70	85
3. Axial One - 1.00 l ha ⁻¹	55	75	85	65	70	90	60	72.5	87.5
4. Biathlon 4D - 55 g ha ⁻¹	60	80	95	65	85	90	62.5	82.5	92.5
5. Granstar 75 DF - 15 g ha ⁻¹	45	65	85	55	75	95	50	70	90
6. Aminopielik 600 SL - 2.00 l ha ⁻¹	55	75	80	65	75	95	60	75	87.5

Table 4. Efficacy of the studied herbicides against *Capsella bursa-pastoris* L., %

Variants	2022			2023			Average		
	14 th day	28 th day	42 th day	14 th day	28 th day	42 th day	14 th day	28 th day	42 th day
1. Untreated control	-	-	-	-	-	-	-	-	-
2. Sekator OD - 0.15 l ha ⁻¹	55	75	90	65	80	100	60	77.5	95
3. Axial One - 1.00 l ha ⁻¹	60	80	95	70	80	100	65	80	97.5
4. Biathlon 4D - 55 g ha ⁻¹	65	85	100	75	90	100	70	87.5	100
5. Granstar 75 DF - 15 g ha ⁻¹	50	70	85	60	80	95	55	75	90
6. Aminopielik 600 SL - 2.00 l ha ⁻¹	60	80	100	70	90	100	65	85	100

Table 3 shows the efficacy of the evaluated herbicides against *Consolida orientalis* J. Gay. Average for the period, on the 14th day after spraying, the highest efficiency of 62.5% after the application of Biathlon 4D - 55 g ha⁻¹ was reported. Approximately the same control - 60% was obtained after the usage of Axial One - 1.00 l ha⁻¹ and Aminopielik 600 SL - 2.00 l ha⁻¹. On the next reporting date, the efficiency increases and reaches 70-82.5% between variants. On the 42nd day after treatment, the efficacy against the weed reached 92.5% at variant 4, where was the highest control against *C. orientalis*. Reports related to the efficacy of applied herbicides against *Capsella bursa-pastoris* L.

showed that on average for the period, on the 14th day after treatment the efficacy ranged from 55% for Granstar 75 DF - 15 g ha⁻¹ to 70% for Biathlon 4D - 55 g ha⁻¹. On the next reporting date, the efficiency increased and reached average values from 75 to 87.5%. On the 42nd day after spraying the efficacy against the weed reached 100% for Biathlon 4D - 55 g ha⁻¹ and Aminopielik 600 SL - 2.00 l ha⁻¹. The efficacy of Sekator OD - 0.15 l ha⁻¹ reached 95% on the last evaluation, and that of Axial One - 1.00 l ha⁻¹ - 97.5%. On the last reporting date, the lowest efficacy was recorded for Granstar 75 DF - 15 g ha⁻¹ - 90% (Table 4).

Table 5. Efficacy of the studied herbicides against *Lamium purpureum* L., %

Variants	2022			2023			Average		
	14 th day	28 th day	42 th day	14 th day	28 th day	42 th day	14 th day	28 th day	42 th day
1. Untreated control	-	-	-	-	-	-	-	-	-
2. Sekator OD - 0.15 l ha ⁻¹	60	80	100	70	85	100	65	82.5	100
3. Axial One - 1.00 l ha ⁻¹	65	85	100	70	85	100	67.5	85	100
4. Biathlon 4D - 55 g ha ⁻¹	70	90	100	75	95	100	72.5	92.5	100
5. Granstar 75 DF - 15 g ha ⁻¹	60	80	100	70	90	95	65	85	97.5
6. Aminopielik 600 SL - 2.00 l ha ⁻¹	60	85	100	75	90	100	67.5	87.5	100

Under the conditions of the experiment the weed species *Lamium purpureum* L. was the most easy-to-control (Table 5). On average for the period, on the 14th day after treatment, efficacy ranging from 65% for Sekator OD - 0.15 l ha⁻¹ and Granstar 75 DF - 15 g ha⁻¹ to 72.5% for Biathlon 4D - 55 g ha⁻¹ was found. On the second reporting date, efficacy varied from 82.5% to 92.5% between variants. On the 42nd day after spraying the efficacy against *L. purpureum* reached 100% in all variants treated with herbicides except for Granstar 75 DF - 15 g ha⁻¹ where it was 97.5 %.

Of all the weeds developing in the trial area the control of *Fumaria officinalis* L. was the most difficult. On average for the period during the first reporting date, the highest efficacy was reported after the treatment with Biathlon 4D

and Aminopielik 600 SL - 45%. In the other treatments the control was unsatisfactory and varied from 32.5% to 35% (Table 6). On the 28th day after application, the efficacy against the weed weeds increased, being the highest with Aminopielik 600 SL - 2.00 l ha⁻¹ - 72.5%. On the 42nd day after spraying, the efficacy against *F. officinalis* was the highest for variant 4 - 87.5%, followed by that of variant 6 - 82.5%. An efficiency of 75% was reported for Axial One - 1.00 l ha⁻¹. The efficiency of the variant Sekator OD - 0.15 l ha⁻¹ reached 52.5%, and that of Granstar 75 DF - 15 g ha⁻¹ was the lowest - 50%. In a previous study similar herbicidal efficacy against *F. officinalis* after the application of Sekator OD in winter wheat was found (Yanev, 2022).

Table 6. Efficacy of the studied herbicides against *Fumaria officinalis* L., %

Variants	2022			2023			Average		
	14 th day	28 th day	42 th day	14 th day	28 th day	42 th day	14 th day	28 th day	42 th day
1. Untreated control	-	-	-	-	-	-	-	-	-
2. Sekator OD - 0.15 l ha ⁻¹	35	45	50	30	40	55	32.5	42.5	52.5
3. Axial One - 1.00 l ha ⁻¹	40	60	80	30	50	70	35	55	75
4. Biathlon 4D - 55 g ha ⁻¹	50	70	85	40	60	90	45	65	87.5
5. Granstar 75 DF - 15 g ha ⁻¹	30	40	45	35	45	55	32.5	42.5	50
6. Aminopielik 600 SL - 2.00 l ha ⁻¹	50	70	80	40	75	85	45	72.5	82.5

Under the conditions of the experiment, all studied herbicides in the applied doses were selective for rye, cultivar “Millennium”.

Tables 7 and 8 present the established results for vegetative and productive indicators of rye in 2022 and 2023. In all variants with herbicides applied, higher values for plant height were recorded. On average for the period, the tallest plants at Biathlon 4D (55 g ha⁻¹) - 1.80 m and Sekator OD (0.15 l ha⁻¹) - 1.78 m were measured. The lowest plants were registered in the untreated control - 1.39 m. (Table 7) The reason for this is the competition of weeds on the crop. The plants from the untreated control have the shortest ears - 10.58 cm on average. All variants that received herbicide spraying had longer spikes, with spike lengths ranging from 13.49 to

14.03 cm on average over the two-year period. The longest ears were measured from the plants treated with Biathlon 4D - 55 g ha⁻¹ (Table 7). Marczevska-Kolasa and Kieloch (2009) and Yanev (2022) reported that successful weed control significantly increased absolute seed mass compared to untreated control. The highest absolute seed mass was reported for variant 4 (Biathlon 4D - 55 g ha⁻¹) - an average of 30.80 g. In the other treatments with herbicides, the studied indicator varied from 29.25 g to 30.56 g. The lowest absolute seed mass was recorded for the control - 26.31 g (Table 8).

All variants in which weed control was performed had higher values for hectoliter seed mass compared to the untreated control. In the herbicide-treated variants, the average hectoliter

mass for varied from 68.38 kg for Aminopielik 600 SL to 69.85 kg for Granstar 75 DF. The

seeds of the untreated control had an average hectoliter weight of 64.85 kg (Table 8).

Table 7. Plant height at the end of the vegetation and ear length of rye, cultivar Millennium

Variants	Plant height, m			Ear length, cm		
	2022	2023	Average	2022	2023	Average
1. Untreated control	1.37 c	1.41 c	1.39	10.27 c	10.89 c	10.58
2. Sekator OD - 0.15 l ha ⁻¹	1.75 a	1.80 a	1.78	13.46 b	13.52 b	13.49
3. Axial One - 1.00 l ha ⁻¹	1.69 b	1.69 b	1.69	13.48 b	13.53 b	13.51
4. Biathlon 4D - 55 g ha ⁻¹	1.79 a	1.81 a	1.80	13.95 a	14.10 a	14.03
5. Granstar 75 DF - 15 g ha ⁻¹	1.70 b	1.72 b	1.71	13.83 a	13.99 a	13.91
6. Aminopielik 600 SL - 2.00 l ha ⁻¹	1.65 b	1.70 b	1.68	13.54 b	13.61 b	13.58

Values with different letters are significantly different according to Duncan's test ($p < 0.05$).

Table 8. Absolute and hectoliter seed mass of rye, cultivar Millennium

Variants	Absolute seed mass, g			Hectoliter seed mass, kg		
	2022	2023	Average	2022	2023	Average
1. Untreated control	26.29 c	26.33 c	26.31	64.89 c	64.80 c	64.85
2. Sekator OD - 0.15 l ha ⁻¹	30.29 a	30.31 ab	30.30	69.26 a	69.35 ab	69.31
3. Axial One - 1.00 l ha ⁻¹	30.50 a	30.57 a	30.54	69.45 a	69.70 a	69.58
4. Biathlon 4D - 55 g ha ⁻¹	30.84 a	30.75 a	30.80	69.40 a	69.60 a	69.50
5. Granstar 75 DF - 15 g ha ⁻¹	30.55 a	30.56 a	30.56	69.89 a	69.80 a	69.85
6. Aminopielik 600 SL - 2.00 l ha ⁻¹	29.14 b	29.35 b	29.25	68.36 b	68.40 b	68.38

Values with different letters are significantly different according to Duncan's test ($p < 0.05$).

Table 9. Rye grain yield, cultivar Millennium

Variants	2022	2023	Average
1. Untreated control	2.56 c	2.21 d	2.38
2. Sekator OD - 0.15 l ha ⁻¹	3.32 a	3.52 a	3.42
3. Axial One - 1.00 l ha ⁻¹	3.35 a	3.46 b	3.41
4. Biathlon 4D - 55 g ha ⁻¹	3.40 a	3.58 a	3.49
5. Granstar 75 DF - 15 g ha ⁻¹	3.43 a	3.27 c	3.35
6. Aminopielik 600 SL - 2.00 l ha ⁻¹	3.27 b	3.40 b	3.34

Values with different letters are significantly different according to Duncan's test ($p < 0.05$).

A high average yield was reported for all variants with controlled weeds, by application of herbicides (Table 9). The highest yield of rye grain was found at variant 4 (Biathlon 4D - 55 g ha⁻¹) - 3.49 t ha⁻¹. In the other variants with herbicides, the yields varied from 3.34 t ha⁻¹ to 3.42 t ha⁻¹. Touahar et al. (2021), Yanev et al. (2021), and Al-Khazali et al., 2020 also found an increase in yield after successful weed control. The lowest yields were recorded in the untreated control - 2.38 t ha⁻¹.

CONCLUSIONS

Of all herbicides studied, the highest control against *Papaver rhoeas* L., *Descurainia sophia* L., *Consolida orientalis* J.Gay, *Capsella bursa-pastoris* L., *Lamium purpureum* L., and *Fumaria officinalis* L. after the application of Biathlon 4D at the rate of 55 g ha⁻¹ was provided. Under the conditions of the study, all studied herbicides in the applied rates were selective for rye, variety "Millennium". The lowest values of

the studied indicators as plant height, ear length, absolute and hectoliter seed mass, as well as grain yield for the untreated control were recorded. The differences were proved mathematically in favor of the herbicide-treated variants. The highest rye grain yield and highest biometric parameters after the application of Biathlon 4D at were recorded.

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