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Weed chemical control in grain sorghum at the steppe zone of Ukraine

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Abstract. The highest control of ragweed (*Ambrosia artemisiifolia* L.) in the field experiments was provided by the herbicide Primekstra TZ Gold (effect – 83%; dose – 4.5 l/ha), bent sedum (*Amaranthus retroflexus* L.) with herbicide Mastak (effect – 88%; dose – 0.5 l/ha), chicken millet (*Echinochloa crus-galli* L.) using the herbicides Varyag and Datonit Gold (effect – 57%, dose – 4.5 and 2.5, respectively), white quinoa (*Chenopodium album* L.) – herbicide Datonite Gold with surfactant (effect – 85%; dose – 2.5 l/ha). The greatest chemical control was provided by the application options of herbicides Varyag – 4.5 l/ha and Agent – 0.6 l/ha in the phase of 3-5 leaves of the crop in June. This treatment provide the Ponki sorghum hybrid grain yield increase 24-27% compared to the control.

Keywords: sorghum, grain yield, weeds, herbicides.

1. Introduction

Global warming may be one of the reasons for the decline in yields of many field crops (Schroetter, 2013). Weeds are an additional factor that limits the increase in grain productivity (Tsyliuryk et al., 2017, 2018; Tkalich et al., 2020). Grain sorghum is characterized by high yielding capacity and drought resistance. This crop doesn't recuire special care, is able to produce high yields under different climatic conditions in various soils thanks to a powerful root system deeply penetrating into soil (Kovtunov, 2018; Kovtunova & Koltunov, 2018; Thompson et al., 2016; Correia & Gomes, 2015).

One of the main factors limiting the increase in sorghum productivity is weed vegetation. The spreading of weeds has become threatening and the issue of weed control is extremely relevant (Pimentel et al., 2019; Maciel et al., 2017; Machado et al., 2016). It should be noted that at the beginning of the growing season sorghum grows slowly. The increase in aboveground mass is small and it is easily suppressed by faster-growing weeds. Therefore, sorghum weeds control is one of the most important elements of receiving of high productivity. Investigation of the effect of herbicide application on the most dangerous weeds is the main requirement for the development of a chemical protection system in local conditions (Furquim et al., 2019; Galon et al., 2016; Takano et al., 2016). Meanwhile, some herbicides and their decay products can adversely affect crops and at sometime not completely inhibit the weed growth (Werle et al., 2017; Metlina & Vasilchenko, 2021). The modern herbicide testing is an urgent task to provide environmental safety weed control.

The main objective of this study was to determine the individual and overall effectiveness of herbicides for weed control in grain sorghum crop in the northern steppe of Ukraine.

2. Materials and Methods

This investigation was carried out on the research field of the educational and research center of the Dnipro State Agrarian and Economic University during 2018-2020 on black soil. Soil samples are characterized by high content of humus 3.9%.

Hydrothermal conditions of 2018-2020 in the area of carrying out of experiments are characterized as unstable and complicated with uneven distribution of weather elements over time. The peculiarity of the weather during the study period should be considered the increased temperature regime of air in autumn (by 1.4-2.3°C relative to the norm), which led (except for 2018) to the late cessation of plant vegetation. The total amount of atmospheric moisture received during the summer was in 2018 – 129.8 mm, 2019 – 147.3 mm, 2020 – 90.9 mm, which had amounted to 85, 97 and 60% of the rate, respectively. The timing of their fallout in most cases coincided with the critical phases of grain sorghum water consumption, which had the positive effect on its yielding capacity. At the same time, the temperature regime in the summer of 2018-2020 exceeded the long-term indicators by 1.7-2.1°C. Every year during the summer there were several periods of hot weather, when the air temperature reached from +35 to +38°C, the soil from +55 to +65°C. The driest were August 2018, June 2019, July 2020. In general, the weather conditions of 2018-2020 were favorable for the growth and development of sorghum plants, especially in June and July, when torrential rains fell steadily, which coincided with the critical period of water consumption. The complex of soil tillage was carried out in time and corresponded to the generally accepted agricultural technique in the Steppe zone. Soil herbicides were applied at covering their by means of spike-tooth harrows. The grain sorghum predecessor was winter wheat. Herbicides in the experiment were applied with a small-sized sprayer. The Ponki hybrid from American company Raelin SE was sown with a SUPN-6 seeder.

The scheme of the experiment trials to study the effectiveness of herbicides active substances in grain sorghum crops is shown in Table 1.

The scheme of the experiment include the most common and modern herbicides with different doses of active substances. Weediness of crops was determined by overlapping on the largest diagonal of plots at 3 points of the accounting framework (0.25 m^2) with the determination of weeds number, species composition and subsequent recalculation of abundance per 1 m^2 of field. Finally all weeds from the accounting frameworks were teared off, labeled, and dried up to an air-dry state to determine their aboveground biomass (Tribel et al., 2001). General research methods had been used to study the interaction of sorghum crops with biological and abiotic factors. Crop capacity was determined using method of mathematical statistics (dispersion method and correlation method).

Table 1. The scheme of the experiment to study the effectiveness of active substances of herbicides in sorghum crops

No	Trial	Rate, l/ha	Phenological Stage
1	Control (without processing)	-	-
2	Variag (Metallochlor, 315 g/l +Terbuthylazine, 190 g/l)	4.0	before-emergence of seedlings
3	Varyag (Metallochlor 315 g/l + Terbuthylazine, 190 g/l)	4.5	before-emergence of seedlings
4	Varyag (Metallochlor 315 g/l + Terbuthylazine, 190 g/l)	4.0	3-5 leaves
5	Varyag (Metallochlor 315 g/l + Terbuthylazine, 190 g/l)	4.5	3-5 leaves
6	Primextra TZ Gold 500 S (Metallochlor, 312.5 g/l + Terbuthylazine, 187.5 g/l) standard	4.5	before-emergence of seedlings
7	Datonite Gold (Chloroacetanilide, 960 g/l)	2.0	3-5 leaves
8	Datonite Gold (Chloroacetanilide, 960 g/l)	2.5	3-5 leaves
9	Datonite Gold (Chloroacetanilide, 960 g/l + surfactant)	2.5	3-5 leaves
10	Agent (2,4-D 2 ethylhexyl ether, 452 g/l, in acid equivalent, 300 g/l + Floraculam, 6.25 g/l)	0.6	3-5 leaves
11	Mastak (Clopyralide, 300 g/l)	0.5	3-8 leaves

3. Results and Discussion

The degree of weediness of the experimental plot (trial 2, 3 and 6) – after the application of soil herbicides was very high, as the number of weeds in accordance with the scale exceeded 50 pcs/m² and was – 922-1133 pcs/m² (Table 2).

This can be explained by the significant potential weedness of the soil (creeping-rooted weeds – 100-120 thousand pieces/m² (i.e. average), annual weeds 700-800 million pieces/ha in the arable layer (high). The soil surface temperature was often very high even in the morning in May. Thus, the effectiveness of soil herbicides reduced because of high temperature, wind and lack of precipitation**.**

In the structure of the weed grouping was dominated the dicotyledons: Common ragweed (*Ambrosia artemisiifolia* L.), Lamb's-quarters (*Chenopodium album* L.), Redrout amaranth (*Amaranthus retroflexus* L.) and monocotyledonous weeds Japanese barnyard millet (*Echinochloa crus-galli* L.). These weeds posed the greatest potential threat to grain loss and therefore needed to be exterminated as a matter of priority. Trailing bindweed (*Convolvulus arvensis* L.) was also found in sorghum crops.

Table 2. Weediness of sorghum crops in 15 days after application of soil herbicides in May for 2018-2020, pcs/m²

No.	Trial	Rate, l/ha -	Botanical name of weeds						
			Common ragweed	Japanese barnyard millet	Lamb's-quarters	Redrout amaranth	Trailing bindweed	Other species	In total
1	Control (without processing)	-	240.0	650.0	160.0	80.0	3.0	0.0	1133.0
2	Varyag (May)	4.0	130.0	480.0	290.0	60.0	6.0	0.0	966.0
3	Varyag (May)	4.5	220.0	380.0	220.0	100.0	2.0	0.0	922.0
4	Varyag (June)	4.0	weed accounting in June						
5	Varyag (June)	4.5	weed accounting in June						
6	Primextra TZ Gold 500 S	4.5	260.0	390.0	230.0	120.0	2.0	0.0	1002.0
7	Datonite Gold	2.0	weed accounting in June						
8	Datonite Gold	2.5	weed accounting in June						
9	Datonite Gold + Surfactant	2.5	weed accounting in June						
10	**Agent**	0.6	weed accounting in June						
11	Mastak	0.5	weed accounting in June						
Least significant difference (LSD) p = 0.05			20.1	30.4	40.3	17.2	1.8	-	-

The use of soil herbicides based on Metallochlor, as well as Terbuthylazine in different doses slightly reduced weeds in 15 days after application of herbicides to 922.0-1002.0 pcs/m², or 133-211.0 pcs/m² (14.4-21.0%). The active substances Metallochlor and Terbuthylazine block the germination of weeds (Queiros et al., 2018). S-metollochlor inhibit the biosynthesis of lipids and fatty acids, flavonoids and protein and sulfur-hydryl-containing biomolecules and acetylcoenzyme A. This mechanism of action inhibits the development of weed resistance to herbicides. Terbuthylazine inhibits electron transport in photosystem II during photosynthesis.

At the soil tillage before-emergence of seedlings, sensitive weed species do not germinate or non-viable seedlings with pronounced signs of chlorosis or leaf necrosis appear. They quickly stunt and terminate a competition with sorghum just after appearance of weeds seedlings as soon herbicide was applied. Complete death of sensitive dicotyledonous species occurs within 10-20 days. In our case, dry conditions at the time of application of the preparations caused the low efficiency of herbicides, as a result of which a protective screen against weeds was not formed on the soil surface.

Due to the low effectiveness of soil herbicides, post-emergence ("insurance") herbicides based on such substances as Chloroacetanilide, Ethylhexyl ester, Floraculum, Clopyralid were used. The greatest weeds number was recorded in the control (1297 pcs/m^2) before application of post-emergence herbicides. There were less weeds in the Varyag plots (4.5 l/ha) – 855 pcs/m^2 and Agent plots (0.6 l/ha) – 823 pcs/m^2 (Table 3).

The active substance of 2.4-D – auxin type block the action of plant growth hormone and affects the growth processes of

Table 3. Weediness of crops before the application of post-emergence herbicides in June for 2018-2020, pcs/m²

No.	Trial	Rate, l/ha -	Botanical name of weeds						
			Common ragweed	Japanese barnyard millet	Lamb's-quarters	Redrout amaranth	Trailing bindweed	Other species	In all
1	Control (without processing)	-	320.0	670.0	210.0	90.0	7.0	0.0	1297
2	Varyag (May)	4.0	weed count was carried out in May						
3	Varyag (May)	4.5	weed count was carried out in May						
4	Varyag (June)	4.0	250.0	460.0	165.0	75.0	2.0	0.0	952
5	Varyag (June)	4.5	230.0	420.0	143.0	60.0	2.0	0.0	855
6	Primextra TZ Gold 500 S	4.5	weed count was carried out in May						
7	Datonite Gold	2.0	248.0	660.0	153.0	90.0	8.0	0.0	1159
8	Datonite Gold	2.5	240.0	510.0	160.0	80.0	3.0	0.0	993
9	Datonite Gold + Surfactant	2.5	200.0	530.0	180.0	70.0	0.0	0.0	980
10	**Agent**	0.6	190.0	603.0	190.0	40.0	0.0	0.0	1023
11	Mastak	0.5	206.0	590.0	230.0	90.0	0.0	0.0	1116
Least significant difference (LSD) p = 0.05		-	14.3	50.2	33.6	13.8	1.4	-	-

cells in weeds (Todd et al., 2020). It is known that florasulam is an acetolactate synthase inhibitor that is a major enzyme in the biosynthesis of amino acids such as Isoleucine, Leucine and Valine. The combination of two active substances with different mechanisms of action prevents the emergence of resistance (insensitivity) in weeds.

Weed counts after 30 days showed that the part of dicotyledonous weeds decreased significantly (Fig. 1).

Thus, we can distinguish trials 5, 6, 10 (Varyag – 4.5 l/ha, the standard Primextra Gold 500 and Agent – 0.6 l/ha). In terms of dynamics, the reduction in the proportion of weeds was in almost all variants except control. It was also noted that bluegrass weeds (Japanese barnyard millet (*Echinochloa crus-galli* L.) predominated in the total share of all weeds, especially in the variants using Mastak – 0.5 l/ha – 410 pcs/ha and Datonite Gold – 2 l/ha – 423 pcs/ha.

The visual post-emergence herbicides effect on weeds was noted on the 30th day after application. In particular, weak visual whitening of rosettes and growth tips of dicotyledonous weeds was fixed for Common ragweed (*Ambrosia artemisiifolia* L.), Lamb`s quarters (*Chenopodium album* L.), Redrout amaranth (*Amaranthus retroflexus* L.). Trailing bindweed (*Convolvulus arvensis* L.) in trials 9, 10, 11 was not detected.

Phytotoxic effects of herbicides on grain sorghum plants were not fixed. The effect of herbicides on all trials was slow. The reason for this process was the significant drought in May, which complicated the contact of active substances with the soil.

The best results in Common ragweed, Japanese barnyard millet and Redrout amaranth control were provided by herbicides in trials 5, 6 and 10 (Fig. 2).

The technical efficiency Varyag was 69.5% for the Common ragweed (*Ambrosia artemisiifolia* L.) destruction (trial 5) and 57.1% against Japanese barnyard millet (*Echinochloa crus-galli* L.). The herbicide Primextra TZ Gold 500 (S-Metallochlor, 312.5 g/l + terbuthylazine, 187.5 g/l) proved to be more effective against Common ragweed (*Ambrosia artemisiifolia* L.) and Redrout amaranth (*Amaranthus retroflexus* L.). Technical efficiency was 83 and 55% respectively. Herbicides Datonite Gold – 2 l/ha, Varyag – 4.5 l/ha and Agent – 0.6 l/ha was more effective against Lamb`s quarters (*Chenopodium album* L.) and Redrout amaranth (*Amaranthus retroflexus* L.). Their technical efficiency was 76%, 79 and 77%, respectively. Chloroacetanilide acts on weed seedlings for a long time (10-12 weeks) until the sorghum rows close. The soil must be sufficiently moist for the manifestation of herbicidal properties. The mechanism of action of Chloroacetanilide is based on the inhibition of the biosynthesis of gibberellins at the stage of oxidation of kaur to kaurenol (Breaux, 1987). Blocking of enzymes containing sulfohydryl groups leads first to the suppression of oxidative phosphorylation, and then to a violation of protein synthesis (nitrogen metabolism). Mitosis is slowed

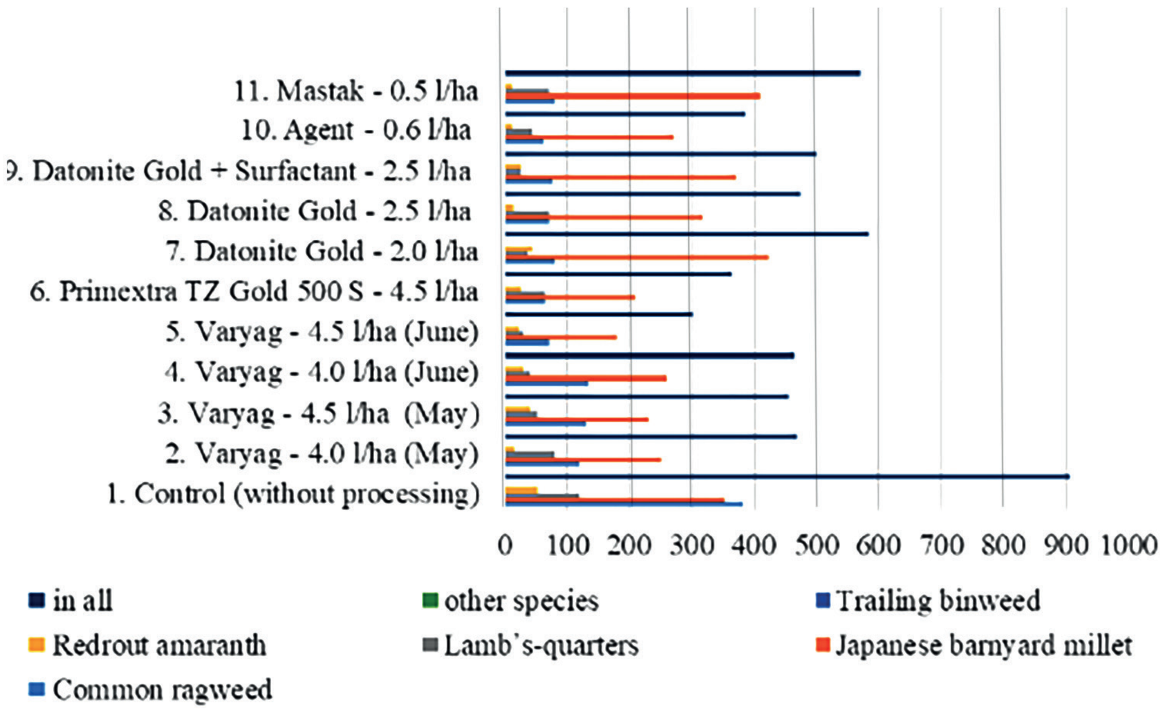

Figure 1. Weediness of sorghum crops in 30 days after application of herbicides for 2018-2020, pcs/m²

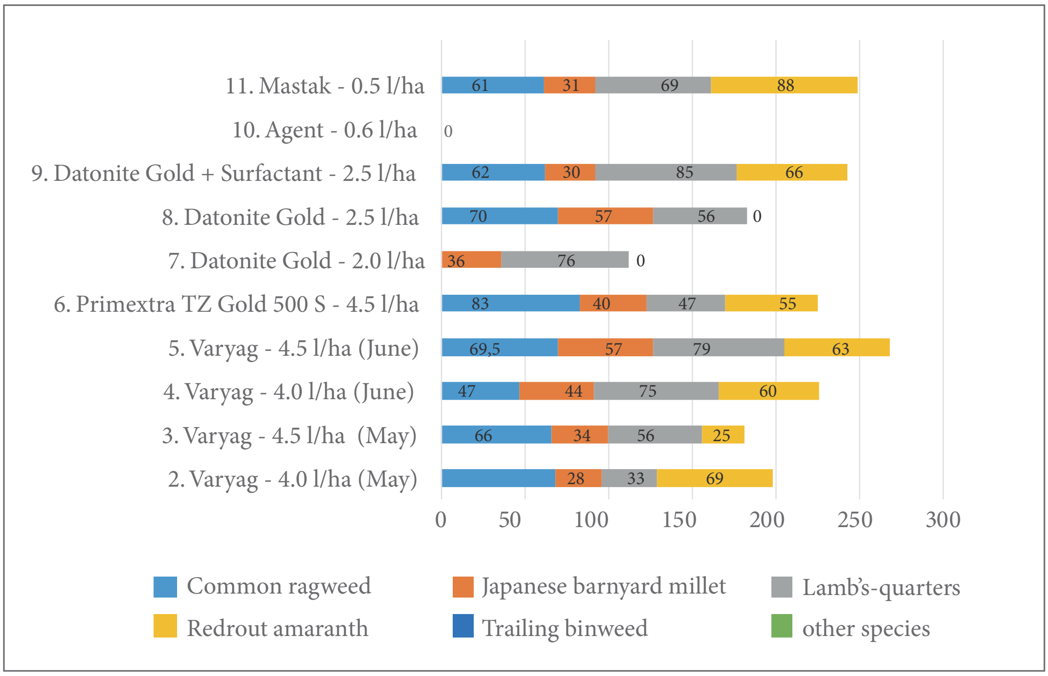

Figure 2. Efficiency of herbicides in 30 days after introduction in 2018-2020, %

down. The processes of root growth and cell growth are suppressed (Fuerst, 1987). The supply of potassium to the plant is weakened. In addition, the transport of auxins and amino acids into the coleoptile is stopped, the osmotic pressure is reduced, as a result of which the embryo dies. It is well known that Agent and Mastak preparations are highly effective in controlling dicotyledonous weeds, and do not act on cereals (Fig. 3).

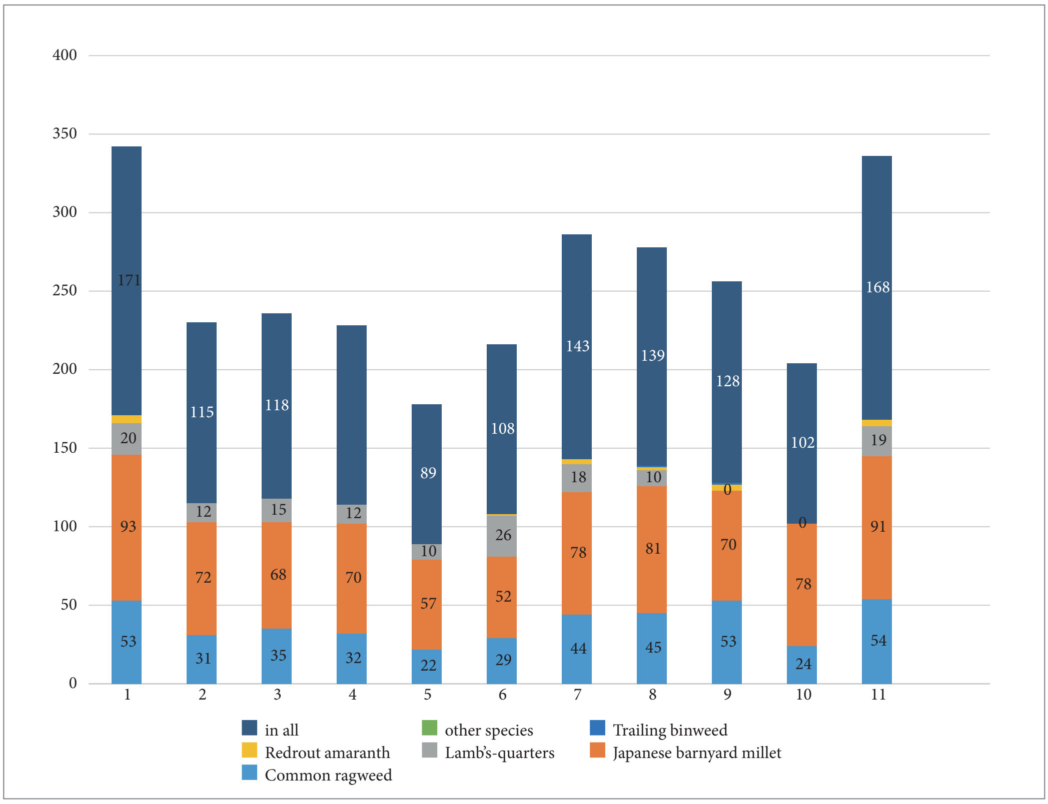

Figure 3. Weediness of sorghum crops before harvest for 2018-2020, pcs/m²

Clopyralid is a herbicide with high herbicidal activity against weeds and easily penetrates into the root system (Bukun et al., 2009). Due to its systemic action, Alpha-Pyralide easily penetrates the plant, mainly through the leaves (partly through the roots), spreads rapidly throughout the plant, including the root system, blocks the growth points of meristematic tissues, stops weed growth and further causes their complete death.

In our case, there was a decrease in the number of Japanese millet (*Echinochloa crus-galli* L.), which was the most numerous in the experiment. This is probably due not only to the action of the herbicide, but also to dry conditions, under which highly developed weeds withered from soil and air drought and died from lack of moisture.

The significant reduction in the weediness of grain sorghum crops was due to their destruction by herbicides and interspecific competition, when more developed weeds suppressed less developed ones (Rad et al., 2020). The weight of weeds in the air-dry state was the maximum in the control – 430.0 g/m² (Table 4). The minimum number was in the trials with Varyag (4.5 l/ha) – 214 g/m², Primextra TZ Gold 500 (4.5 l/ha) – 246 g/m². The highest technical efficiency was recorded at application preparations Varyag (4.5 l/ha) – 64.7%, Primextra TZ Gold 500 (4.5 l/ha) – 63.8% and Agent (0.6 l/ha) – 62.3%.

Table 4. Dynamics of weediness of grain sorghum crops on average for 2018-2020

No.	Trial	Rate, l/ha	Weight, g/m²	Efficiency, %
1	Control (without processing)	-	430	-
2	Varyag (May)	4.0	341	51.4
3	Varyag (May)	4.5	308	50.6
4	Varyag (June)	4.0	323	51.2
5	Varyag (June)	4.5	214	64.7
6	Primextra TZ Gold 500 S	4.5	246	63.8
7	Datonite Gold	2.0	341	50.0
8	Datonite Gold	2.5	389	52.4
9	Datonite Gold + Surfactant	2.5	364	49.0
10	**Agent**	0.6	226	62.3
11	Mastak	0.5	360	49.0

The lack of weed control measures led to a minimum grain yield of 1.2 t/ha in the trial without any treatment (Table 5).

The greatest effect from herbicides with high technical efficiency, which reduced weediness of crops and promoted the formation of the maximum grain yield, were the trials with the application of preparations Varyag (4.5 l/ha) and Agent (0.6 l/ha). Weeds control with application of Varyag (4.5 l/ha) and Agent (0.6 l/ha) provide sorghum grain **y**ield

Table 5. Sorghum grain yielding capacity on average for 2018-2020, t/ha

No.	Trial	Rate, l/ha	Years of research			Average value
			2018	2019	2020	
1	Control (without processing)	-	1.16	1.18	1.16	1.2
2	Varyag (May)	4.0	1.90	2.01	2.06	1.9
3	Varyag (May)	4.5	2.02	2.07	2.03	2.0
4	Varyag (June)	4.0	1.94	2.11	2.05	2.1
5	Varyag (June)	4.5	3.03	2.92	2.77	2.9
6	Primextra TZ Gold 500 S	4.5	2.18	2.21	2.62	2.4
7	Datonite Gold	2.0	1.59	1.68	1.76	1.7
8	Datonite Gold	2.5	1.59	1.55	1.57	1.6
9	Datonite Gold + Surfactant	2.5	1.48	1.51	1.51	1.5
10	**Agent**	0.6	3.08	2.94	3.01	3.0
11	Mastak	0.5	2.02	2.12	2.01	2.1
Least significant difference (LSD) p = 0.05		0.16		0.16	0.17	-

up to 2.5 time higher comparative control. Other trials of the experiment to study the effectiveness of herbicides provided slightly worse results. The use of herbicides in general allowed to save from 1.7 to 2.1 t/ha of sorghum grain. Herbicide preparations differed insignificantly in effect on the sorghum grain yield.

4. Conclusion

The size of the obtained yield and its quality is determined by the combined action of many factors, including moisture conditions, nutrient regime, features of agrophysical properties of soils, climatic conditions, productive properties of the crop, as well as the weediness. No phytotoxic effect of herbicides on sorghum plants was detected. Unfavorable weather conditions (drought) reduce the efficiency of the applied herbicides..

Maximum results in the Common ragweed (*Ambrosia artemisiifolia* L.) control were obtained using Varyag (4.5 l/ha), Agent (0.6 l/ha) and Primextra TZ Gold 500 (4.5 l/ha). Varyag (4.5 l/ha) and Datonite Gold (2.5 l/ha) were effective against Lamb`s quarters (*Chenopodium album* L.), 79% and 85% respectively. The best herbicides against Redrout amaranth (*Amaranthus retroflexus* L.) were Datonite Gold (2.5 l/ha) – 84% and Mastak (0.5 l/ha) – 88%. The application of Varyag (4.5 l/ha) and Agent (0.6 l/ha) reduced the weediness of crops and contributed to the maximum grain yield formation. The yielding capacity reached 3.0 t/ha.

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