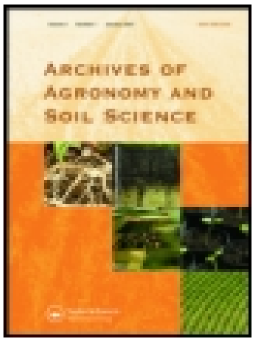

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POST herbicide programs utilizing tribenuron for cleavers (*Galium aparine* L.) control in winter wheat cultivars

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ABSTRACT

Cleavers (*Galium aparine* L.) causes severe problems in winter wheat (*Triticum aestivum*). Four field experiments were performed at Kayakenstky and Stalskiy regions, southern Russia over two growing winter seasons 2015 and 2016 to evaluate postemergence (POST) applications of herbicides (Flucarbazone, metsulfuron, 2,4-D, fluroxypyr, tribenuron, pyroxsulam and sulfosulfuron) applied alone or in tank mixtures on winter wheat cultivars. Wheat injury from herbicide application was minor, with the exception of pyroxsulam + sulfosulfuron in 2015, and tribenuron + pyroxsulam in 2016 at Kayakenstky. Best cleavers control was observed in treatments containing tribenuron. Cleavers were controlled least by metsulfuron (study 1) and flucarbazone (study 2), whereas cleavers had intermediate growth inhibitory responses to the other treatments. Tribenuron + fluroxypyr applied in wheat 'Krasnodar 99', and tribenuron + pyroxsulam in wheat 'Gerda' resulted in enhanced grain yield with the value of 60% and 45.7%, respectively. Overall, tribenuron and herbicides containing tribenuron provided the most efficient control compared to the other herbicides and consistently maintained optimal grain yields in all cases. To improve weed control and to prevent a rapid development of herbicide resistance, tribenuron should be applied in combination with either fluroxypyr, pyroxsulam or metsulfuron.

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Cleavers; winter wheat; weed control; postemergence herbicides

Introduction

Winter wheat (*Triticum aestivum* L.) has higher production than spring wheat in the Russian prairies; nevertheless, several agronomic and marketing challenges restrict its broad adoption by farmers. The major difficulty towards expansion of winter wheat cultivation is the application of better agronomic practices and techniques that produce healthy plants and provide good production of winter wheat, a phenomenon that is influenced by various environmental and management factors (Johnson et al. 2018).

Profitable winter wheat production in the Russia prairies depends on direct sowing of cultivars into standing stubble in late summer (Zargar et al. 2017a). Beres et al. (2010) stated that winter wheat is competitive against summer annual weeds. However, there is potential that winter annual weeds can highly compete with winter wheat (Johnson et al. 2018). Cleavers (*Galium aparine* L.) is a problematic broadleaved weed in winter wheat and other winter produced crops in Eurasia and North America (Defelice 2002; Mennan and Zandstra 2005). Cleavers species included in top 10 most dominant weeds across the prairie region of Sothern Russia. Therefore, in Southern Russia, cleavers poses as an obstacle in winter wheat production due to its negative interaction with the crop (Poska 2018). This weed is highly adapted to the environment due to its inherent characteristics such as flexibility in the timing of

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seed germination, variable growth forms, multiple annual lifecycles, freezing tolerance, high dispersal ability and high genetic diversity (Hubner et al. 2003; Mennan et al. 2011).

Cleavers probably originated from southwest Asia, and then it is distributed throughout Eurasia and North America (Defelice 2002). It is capable of causing severe problems in different environment conditions but is largely dangerous in winter wheat fields and other winter-cultivated crops (Mennan et al. 2011). Moreover, it can also cause significant crop yield loss (Beckie et al. 2012).

It has been reported by Glazunova et al. (2015) that in the last two decades, cleavers have become one of the most important weeds of wheat fields in Russia, because of it is resistant to 2,4-D and MCPA, which are commonly used herbicides for weed control in the wheat crop. The timely use of inputs such as herbicides, high yielding varieties and tolerant varieties of crops may reduce the yield losses. Hence, herbicides application has now become an integral part of Russian agriculture (Zargar et al. 2017b). Tribenuron is a postemergence (POST) herbicide (2-[4-methoxy-6-methyl-1,3,5-triazin-2-yl(methyl)-carbamoylsulfamoyl] benzoic acid) belongs to the class of sulfonylurea herbicides.

A wide range of broad-leaf weeds in cereal crops such as winter wheat, barley, oats, rye and triticale are controlled by applying tribenuron (Irani et al. 2015). Efficiency and efficacy of different POST herbicides on cleavers were evaluated for instance for mesosulfuron (Mennan et al. 2011), tribenuron (Vencill 2002) and dicamba (Grossman 2000). Combinations mixture of POST herbicides are recommended to sustain season long-term control of cleavers. According to Beckie and Harker (2017), herbicide rotation and tank-mixing can be a key component of an integrated weed management program, as repeated herbicide application with the same mode of action can result in herbicide-resistant biotypes. However, few studies have been reported on POST herbicide program for cleavers management in winter wheat in Russia. Experiments were organized and carried out to determine the level of control of cleavers and the tolerance of winter wheat cultivars ('Krasnodar 99' and 'Gerda') when treated with POST herbicides and herbicide tank-mixes containing tribenuron.

Materials and methods

Site description, experimental procedures and site management

This research consisted of four experiments that were conducted in two fields, in 2015 and 2016. Experimental fields were established at two locations in southern Russia, namely Stalskiy region, Zardian (40°56′ N, 39°38′ E and 151 m altitude) for study 1, and Kayakenstky region, Kaspi (42°56′ N, 46°28′ E and 140 m altitude) for study 2. The winter wheat cultivar 'Krasnodar 99' was sown in experiments 1 & 2 (study 1) and 'Gerda' in experiments 3 & 4 (study 2). The key soil parameters and climate conditions at both sites are summarized in Tables 1 and 2, respectively.

The experimental design used for all experiments was a randomized complete block design with three blocks, with net plot size of 20 × 3 m, comprising 12 crop rows (row to row distance = 33 cm). The four central crop rows were used to investigate the differences in crop yields between experimental treatments. Seven herbicides were used in all experiments: flucarbazone, metsulfuron, 2,4-D, fluroxypyr, tribenuron, pyroxsulam and sulfosulfuron. Detailed treatment description is given in Table 3.

Table 1. Summary of experiment establishment and soil parameters 2015–2016.

Location – year	Latitude/longitude	Soil organic matter	Sowing date	pH	Soil texture
Stalskiy region	40°56′ N, 39°38′ E	1.9%		6.3	Loamy sand
2015			Sept. 9		
2016			Sept. 1		
Kayakenstky region	42°56′ N, 46°28′ E	1.6%		6.6	Clay loam
2015			Sept. 10		
2016			Sept. 7		

Table 2. Average precipitation (mm on monthly basis) and average maximum (Max.) and minimum (Min.) temperatures (°C on monthly basis) in Kayakenstky and Stalskiy over two growing seasons.

	Kayakenstky				Stalskiy			
	2014–2015		2015–2016		2014–2015		2015–2016	
Mean temperatures	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
September	24	15	23	14	27	16	25	15
October	17	10	17	11	20	11	21	13
November	12	6	13	6	14	8	15	7
December	7	2	7	3	9	4	8	4
January	5	−1	3	−1	6	1	5	0
February	6	0	6	1	8	2	7	2
March	11	5	12	5	13	6	13	5
April	17	7	16	6	20	9	18	8
May	22	14	23	13	24	15	23	13
June	26	21	27	22	30	23	29	23
Average precipitation								
September	26		24		21		20	
October	13		14		12		14	
November	15		17		15		14	
December	18		21		25		34	
January	24		30		35		40	
February	14		20		18		25	
March	15		14		28		22	
April	10		17		15		17	
May	34		30		41		32	
June	14		17		20		18	

Table 3. Herbicide treatment descriptions.

Active ingredients	Trade name	Rate (g ai ha^{-1})	Concentration/ formulation	Manufacturer
Flucarbazone	Everest®	35	700 g/kg WDG	Arysta LifeScience, http://www.arysta-na.com
Metsulfuron	Innova®	13	600 g/kg WDG	Syngenta, http://www.syngenta.com.au
2,4-D	Esteron®	360	600 g/L EC	Dow Agro Sciences, https://www.dowagro.com
Fluroxypyr	Demeter^{EC}	150	350 g/L EC	Avgust, http://www.pesticidy.ru
Tribenuron	Express ™	20	750 g/kg WDG	DuPont, http://www.dupont.com.au
Pyroxsulam	Pallas™ 45	15	45 g/L OD	Dow Agro Sciences, https://www.dowagro.com
Sulfosulfuron	Sulfos®	30	750 g/kg WDG	Cheminova, https://www.cheminova.com.au

Abbreviations: WDG, water-dispersible granules; EC, emulsion concentrate; OD, oil dispersion.

POST herbicides were applied early in April when the winter wheat plants were at the tillering stage and the cleavers plants were 4–10 cm tall with 4–6 leaves. CO_2 pressurized knapsack sprayer calibrated to spray at a rate of 220 L ha^{-1} at 207 kPa through four Hypro ultra-low drift 120-02 nozzles (Hypro, New Brighton, MN, USA) spaced 60 cm apart was used to spray herbicides in experiments.

The dominant weed in our experimental fields was cleavers, but little amount of some other weed species was also there and they were removed through hand-weeding during experiments. Weedy and weed-free control was involved in each block of each experiment. No weeding practices were performed in weedy-control, but in weed-free control hand – weeding were done every week until the starting of wheat florescent stage. The application time and the weather condition during the experiments are summarized in Table 4.

Each year at the beginning of September winter wheat was direct seeded using a tractor-mounted drill at 200–220 kg ha^{-1} at a depth of 3.5 cm. Sowing date for each site-year is described in Table 1.

Table 4. The application schedule, cleavers height and the weather condition descriptions during herbicide application.

Location – year	Sunlight %	Temperature °C	Relative humidity %	Wind speed km h^{-1}	Cleavers density plants m^{-2}	Cleavers height cm
Stalskiy region						
2015	90	15	70	4	36–85	4–6
2016	85	13	65	5	31–79	6–8
Kayakenstky region						
2015	100	16	75	4	45–92	4–10
2016	90	14	65	3	38–86	5–8

Nitrogen, phosphorus and potassium fertilizers were applied with the recommended doses to all plots prior to sowing based on soil test results. The fertilizer application rate for all plots was 220 kg ha^{-1}, the formulation applied was $N_{20}P_{20}K_{20}$ that was applied in the rows, and a top dressing of 140 kg N ha^{-1} was added when the winter wheat was at the tillering stage. Fertilizer application in experimental fields was based on soil characteristics, as recommended for winter wheat cultivation (Russian Academy of Science/http://www.agroacadem.ru).

Weed control was evaluated at 1 to 3 weeks after herbicide applications (WAA) in all experiments. Winter wheat and cleavers were randomly chosen from two sampling area based on the plant maturity level (2 rows by 1 m) were selected in each plot. Weed density in these areas was counted each year at 1 WAA, 2 WAA and 3 WAA. In addition, weed samples were dried at 70°C in the oven for dry matter (biomass) assessment. Herbicide effect on winter wheat was visually evaluated 2 and 4 weeks after POST herbicide application by assigning notes of a percentage scale from 0% to 100%, with zero denoting no visual effect and 100 meaning complete wheat plant death proposed by Hulting et al. (2012).

Statistical analysis

Collected data were examined for normality and constant variance. Data analyses were conducted using the GLIMMIX procedure of SAS (Version 9.4, SAS Institute Inc., Cary, NC, USA) using the mixed procedure with block as the random factor. Each season was analyzed individually. The least squares mean statement in SAS with the Tukey adjustment at $P = 0.05$ was used for comparison of means. Data obtained from several dates, such as winter wheat and cleavers counts were analyzed using the repeated measure.

Results and discussion

Cleavers control

Study 1. Cleavers control attained from 57% to 87% at 1 WAA. At 2 WAA, 3 WAA and 4 WAA the efficacy of herbicides tested for cleavers control ranged from 52% to 91%, 58% to 93% and 60% to 85%, respectively, for all the experiments, with all the treatments being statistically different from the weedy control (Table 5). Removing the weed-free and weedy control treatments help us to clearly recognize the differences. The tank mixture of tribenuron + fluroxypyr (20 + 150 g ai ha^{-1}) and tribenuron + metsulfuron (20 + 13 g ai ha^{-1}) postemergence herbicides were the most effective with >83% control at all periods in winter wheat cultivar 'Krasnodar 99'. The lowest cleavers control with a value of 52% was observed at 2 WAA with the application of metsulfuron (13 g ai ha^{-1}) and was similar to fluroxypyr (150 g ai ha^{-1}).

The tank mixtures consist of tribenuron + metsulfuron and tribenuron +2,4-D at 3 WAA; tribenuron + fluroxypyr at 2 WAA showed a control range of cleavers statistically similar to the weed-free control plots (Table 5). These results were in agreement with those of Johnson et al. (2018), who reported that a POST herbicide combinations including tribenuron provided >80%

Table 5. Control (%) of cleavers (*Galium aparine*) that was infesting the wheat, Krasnodar 99, in study 1 due to the application of POST herbicides at the Stalskiy region, Zardian, in 2015–2016.

Active ingredients	Rate (g ai ha^{-1})	Control of cleavers (%) 1 WAA	2 WAA	3 WAA	4 WAA
Weedy	–	0.0g[a]	0.0f	0.0f	0.0f
Tribenuron	20	87.9b	87.8b	80.9bc	79.9c
Metsulfuron	13	61.2e	52.9e	60.8de	71.2cd
2,4-D	360	79.1c	75.5c	66.6d	60.9de
Tribenuron + metsulfuron	20 + 13	83.2bc	88.8b	93.8a	83.0bc
Fluroxypyr	150	57.3ef	60.0de	58.8e	61.5de
Tribenuron + fluroxypyr	20 + 150	85.9b	91.8ab	88.1b	85.5b
Fluroxypyr + metsulfuron	150 + 13	70.5d	68.4d	73.3cd	71.8cd
Tribenuron + 2,4-D	360 + 20	78.5c	84.4bc	90.8ab	80.5c
Weed-free	–	100.0a	100.0a	100.0a	100.0a
P value	–	0.052	0.0082	0.0002	0.0033
Coefficient of variation (%)	–	9.9	12.8	17.8	3.3

[a]Means followed by different letters are significantly different by Tukey's protected LSD ($P \leq 0.05$).
Abbreviation: WAA, weeks after application.

weed control in wheat. The 80% control range is regarded as a reference. Weed reduction >80% can be recommended towards the use of a special herbicide (Oliveira et al. 2009; Maciel et al. 2013); hence, the mixtures used in our study can be suggested to be efficient or beneficial for the management of cleavers. Other authors have reported similar POST herbicide combinations efficacy on cleavers in winter annual crops (Ferhatoglu and Barrett 2006; Shimi et al. 2007).

Study 2. Postemergence application of tribenuron (20 g ai ha^{-1}) reduced the weed density as the same as weed-free control at 3 WAA in winter wheat 'Gerda' with a value of 90% (Table 6). Also, the effect of tank mixture of tribenuron + pyroxsulam (20 + 15 g ai ha^{-1}) being assessed did not differ from the weed-free control at 2 and 4 WAA with the cleavers control rate >91%. Herbicide treatments that constituted tribenuron showed high effectiveness at almost all the periods compared with other treatments. The same results were observed in the first study, hence reducing the cleavers population in winter wheat.

The treatments consisting of tribenuron (20 g ai ha^{-1}), tribenuron + pyroxsulam (20 + 15 g ai ha^{-1}) and tribenuron + flucarbazone (20 + 35 g ai ha^{-1}) showed an average control range of cleavers greater than 78% in all periods. The least effective treatment, besides the weedy control, was the flucarbazone treatment, with a control average of 62% in all the observation dates (Table 6). Use of herbicides is the most effective technique for controlling cleavers in annual cropping systems, allowing for short-term management. Spiridonov and Shestakov (2013) reported that cleavers was favorably controlled using POST herbicides in wheat field in southern parts of Russia.

Table 6. Control (%) of cleavers (*Galium aparine*) that was infesting the wheat, Gerda, in study 2 due to the application of POST herbicides at the Kayakenstky region, Kaspi, in 2015–2016.

Active ingredients	Rate (g ai ha^{-1})	Control of cleavers (%) 1 WAA	2 WAA	3 WAA	4 WAA
Weedy	–	0.0f[a]	0.0f	0.0e	0.0e
Tribenuron	20	80.8c	86.5b	90.7ab	81.8b
Pyroxsulam	15	50.9e	65.8d	72.8c	65.1d
Sulfosulfuron	30	80.5c	79.5bc	65.2d	69.6cd
Flucarbazone	35	59.1e	57.8e	62.8d	70.0c
Tribenuron + pyroxsulam	20 + 15	88.8b	94.4a	82.8b	91.8ab
Pyroxsulam + sulfosulfuron	15 + 30	66.8d	72.9c	80.7b	79.5bc
Tribenuron + flucarbazone	20 + 35	81.8c	79.9bc	80.6b	78.8bc
Weed-free	–	100.0a	100.0a	100.0a	100.0a
P value	–	0.0054	0.0011	0.0250	0.0001
Coefficient of variation (%)	–	2.8	9.8	11.5	5.1

[a]Means followed by different letters are significantly different by Tukey's protected LSD ($P \leq 0.05$).
Abbreviation: WAA, weeks after application.

Wheat grain yield and injury

The results of the combination of tribenuron + metsulfuron (20 + 13 g ai ha^{-1}) and tribenuron + fluroxypyr (20 + 150 g ai ha^{-1}) in winter wheat 'Krasnodar 99' indicated that the interaction of these active ingredients is effective on weed reduction percentage and on the improvement of winter wheat 'Krasnodar 99' yield simultaneously. The highest grain yield was achieved with the combination of tribenuron + metsulfuron (20 + 13 g ai ha^{-1}) (60% over the weedy control). The lowest increase in grain yield compared to control was observed in the plots sprayed with fluroxypyr (150 g ai ha^{-1}) because of lower level of weed control in winter wheat 'Krasnodar 99' (Table 7). Mentioned results were consistent with Curran et al. (2015) who reported that treatments including tribenuron resulted in greater wheat yields (about 500–700 kg ha^{-1}) after weed control. The increase in wheat yields after spring applications can be attributed to the optimum control of cleavers.

The productivity of the mixture of tribenuron + flucarbazone (20 + 35 g ai ha^{-1}) for winter wheat 'Gerda' was 45% higher than the weedy control. The lowest grain yield except the weedy control was observed in plots treated with the POST application of sulfosulfuron (30 g ai ha^{-1}). This result is associated with less effective weed control in winter wheat 'Gerda' (Table 7). Increase in cleavers shoot could cause the relative yield losses in winter wheat (Challaiah et al. 1986; Roberts et al. 2001). Mennan and Zandstra (2005) and Wright and Wilson (1987) revealed that cleavers reduced winter wheat yield to various extents, depending upon the year. They also stated that winter wheat density decreased as cleavers density increased in all the years. Thus, cleavers indirectly reduced winter wheat yield through the reduction of wheat density.

Herbicide application displayed some level of winter wheat injury from 1% to 10% in all treatments at all site-years when assessed 2–4 weeks after POST application (Table 8). At Kayakenstky in 2015 and 2016, the injury assessment at 4 WAA was higher (up to 10%) compared to the assessment at 2 weeks after application (less than 6%) (Table 8).

Table 7. Effect of herbicides that were applied alone or in tank mixtures on the grain yield of the winter wheat cultivar 'Krasnodar' in Study 1 and cultivar 'Gerda' in Study 2 in 2015 and 2016.

Study	Active ingredients	Rate (g ai ha^{-1})	2015	2016	Increase kg ha^{-1}[b]	Increase %[c]
			Krasnodar 99 grain yield (kg ha^{-1})			
1	Weedy	–	5020f[a]	5348e	–	–
	Tribenuron	20	8655a	8312a	3299	63.6
	Metsulfuron	13	7760c	7280c	2336	45.0
	2,4-D	360	6998d	7876bc	2253	43.4
	Tribenuron + metsulfuron	20 + 13	8280b	7998b	2955	57.0
	Fluroxypyr	150	5980e	6854d	1233	23.7
	Tribenuron + fluroxypyr	20 + 150	7988bc	8621a	3120	60.0
	Fluroxypyr + metsulfuron	150 + 13	6670d	8023b	2162	41.7
	Tribenuron + 2,4-D	360 + 20	7973bc	8185b	2895	55.8
	Weed-free	–	8685a	8300a	–	–
	P value	–	0.0121	0.0004	–	–
	Coefficient of variation (%)	–	8.9	17.1	–	–
			Gerda grain yield (kg ha^{-1})			
2	Weedy	–	5813ef	5246e	–	–
	Tribenuron	20	7810bc	6655d	1710	30.9
	Pyroxsulam	15	7650c	8208a	2400	43.4
	Sulfosulfuron	30	5980e	6990c	956	17.2
	Flucarbazone	35	7805bc	6580d	1663	30.0
	Tribenuron + pyroxsulam	20 + 15	8214ab	7861b	2508	45.3
	Pyroxsulam + sulfosulfuron	15 + 30	6980d	7190c	1556	28.1
	Tribenuron + flucarbazone	20 + 35	8108b	8005a	2527	45.7
	Weed-free	–	8450a	7990a	–	–
	P value	–	0.0050	0.0008	–	–
	Coefficient of variation (%)	–	11.6	5.5	–	–

[a]Means followed by different letters are significantly different by Tukey's protected LSD ($P \leq 0.05$).
[b]Wheat yield increase over weedy control in average of both years.
[c]Increase percent of wheat yield over weedy control in average of both years.

Injury ratings of 10% were recorded at Kayakenstky with POST applications of pyroxsulam + sulfosulfuron (15 + 30 g ai ha^{-1}) in 2015, and tribenuron + pyroxsulam (20 + 15 g ai ha^{-1}) in 2016 (Table 8). The reason for the higher injury recorded at Kayakenstky is not fully understood; nonetheless, Kayakenstky region has generally a harsher environment than Stalskiy region for winter wheat production. Hence, the harsher winter environment at Kayakenstky region (Table 2) could have reduced the crop's ability to tolerate herbicides. Despite slightly higher injury at Kayakenstky in 2015 and 2016, minor injury at Stalskiy was also observed (Table 8). Similar results have been reported by Johnson et al. (2018) who noted that pyroxsulam applied at a rate of 15 g ai ha^{-1} resulted in higher than 10% injury in winter wheat. Generally, winter wheat injury is more likely to be observed when herbicides are sprayed during spring using higher labeled rates (Derksen et al. 1989; Curran et al. 2015). This study showed that tribenuron was very effective in controlling broadleaved weeds in winter wheat. Wheat plants without weed competition are capable of producing enhanced grain yields and consequently increase the farmer's income.

Those producers who use the appropriate herbicides and at the recommended rates are advantageously positioned to obtain a better grain yield. According to findings from this study sulfonylurea group of herbicides is more suitable to control weeds in the wheat crops. Tribenuron with its short soil residual activity (Samtani et al. 2014) and POST application pattern would appear to be compatible for use in wheat cropping region like the southern Russia. Wheat grain yield was obviously affected by the presence of cleavers at both sites. A study by Mennan and Zandstra (2005) revealed that cleavers reduced the wheat yield from 11.6% to 31.5% in Bezostaja depending on weed density at the standard seed rate.

Unfortunately, regardless of the favorable weed control percentage, there was still a number of weeds that managed to survive and continued to produce seed, thus augmenting the weed seed bank, the fact that may complicate weed control systems in the future, particularly for the application of herbicides with a single mode of action. Cleavers has been recorded as resistant to different types of herbicide such as 'synthetic auxins herbicides' fluroxypyr in China, and 2,4-D & MCPA in Iran; resistant to 'ALS inhibitors herbicides'

Table 8. Visual winter wheat injury assessed 2–4 weeks after POST herbicide treatments at the Stalskiy region, Zardian (study 1, wheat cultivar Krasnodar 99), and the Kayakenstky region, Kaspi (study 2, wheat cultivar Gerda) in 2015 and 2016.

			Visible injury %			
			2015		2016	
Study	Active ingredients	Rate (g ai ha^{-1})	2 WAA	4 WAA	2 WAA	4 WAA
				Stalskiy region		
1	Weedy	–	0.0[a]	0.0	0.0	0.0
	Tribenuron	20	0.0	0.0	0.0	0.0
	Metsulfuron	13	1.0	0.0	2.0	0.0
	2,4-D	360	2.0	2.0	0.0	0.0
	Tribenuron + metsulfuron	20 + 13	0.0	1.0	2.0	0.0
	Fluroxypyr	150	1.0	0.0	1.0	0.0
	Tribenuron + fluroxypyr	20 + 150	1.0	0.0	7.0	0.0
	Fluroxypyr + metsulfuron	150 + 13	1.0	2.0	1.0	0.0
	Tribenuron + 2,4-D	360 + 20	0.0	0.0	0.0	6.0
	Weed-free	–	0.0	0.0	0.0	0.0
				Kayakenstky region		
2	Weedy	–	0.0	0.0	0.0	0.0
	Tribenuron	20	0.0	0.0	0.0	2.0
	Pyroxsulam	15	1.0	8.0	0.0	0.0
	Sulfosulfuron	30	5.0	7.0	2.0	3.0
	Flucarbazone	35	0.0	0.0	1.0	2.0
	Tribenuron + pyroxsulam	20 + 15	4.0	7.0	0.0	10.0
	Pyroxsulam + sulfosulfuron	15 + 30	3.0	10.0	6.0	5.0
	Tribenuron + flucarbazone	20 + 35	0.0	0.0	1.0	0.0
	Weed-free	–	0.0	0.0	0.0	0.0

[a]Means followed by different letters are significantly different by Tukey's protected LSD ($P \leq 0.05$).
Abbreviation: WAA, weeks after application.

mesosulfuron-methyl in Turkey, and tribenuron-methyl in Iran (Heap 2019). Accordingly, using combination of herbicides with different active ingredients can reduce herbicide-resistant weeds in wheat. The critical period for weed control in wheat field is at the beginning of its growing cycle because weeds to enhance their biomass, requiring favorable environmental conditions (Evans et al. 2003). Hence, when weeds such as cleavers controlled at the early stages of wheat growth; then, at the later stages, weeds will hardly be able to compete, due to the plant density 'canopy' of wheat.

Regarding weed control, tribenuron and treatments containing tribenuron provided consistent and effective control of cleavers. Similar results have been obtained by Johnson et al. (2018), he also noted the efficacy and effectiveness of tribenuron and treatments containing tribenuron than other herbicides on weed control in winter wheat. Tribenuron and tank mixtures including tribenuron resulted in greater than a 78% reduction in cleavers population and higher wheat productivity at both sites in all experiments. The residual effect of similar mixtures has been recorded previously (EFSA 2016).

The necessity of POST herbicides with long-term activity against weeds was recommended; thus, it is therefore imperative for wheat to be free of weeds that can interfere with this crop. For sustainable cleavers management, the combinations of POST herbicides are recommended. For example, a broad-spectrum postemergence weed control can be achieved by combining tribenuron (sulfonylurea) and pyroxsulam (triazolopyrimidine) (Mohammadi and Ismail 2018). The application of mixed herbicides can prevent herbicide-resistant weeds due to the use of more than one active ingredient, thus multiple modes of action (Galon et al. 2018). Herbicides mixture program is mostly done for reducing cultivation costs, broaden application spectrum, obtain synergism and reduce herbicide residue.

Conclusions

POST application of tribenuron and treatments containing tribenuron provided effective control of cleavers in all experiments, and was also much safer to the wheat resulting in highest yield increase. The present study suggests that tank mixture of tribenuron plus each of fluroxypyr, pyroxsulam and metsulfuron could facilitate managing cleavers resistance to herbicides in winter wheat. Additional research is needed to illustrate the response of subsequent crops as affected by the residue of herbicides applied in winter wheat in the form of crop rotation.

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