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Research Article

Optimizing of sulfosulfuron and sulfosulfuron plus metsulfuron-methyl herbicides efficiency against Japanese downy brome *Bromus japonicus* L. by adjuvants application

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Abstract: Efficiency of many herbicides can be increased by adding adjuvants to the spray solution. So, the addition of an appropriate adjuvant to foliar herbicides is important in weed control researches. To identify an appropriate adjuvant for sulfosulfuron and sulfosulfuron + metsulfuron-methyl herbicides against Japanese downy brome *Bromus japonicus*, two experiments were conducted in randomized complete block design with two factors under field condition separately in Zabol and Zahedan, Iran. Factor A was different doses of herbicide namely 0, 50, 75 and 100% of their recommended dose and factor B was adjuvants including: sweet almond oil, olive oil, sesame seed oil and D-Octil. Results showed that efficiency of sulfosulfuron and sulfosulfuron + metsulfuron-methyl herbicides increased by increasing their doses and adjuvant addition. The addition of sesame seed oil (followed by D-octil) had the highest effect on sulfosulfuron efficacy against Japanese downy brome control. In general, sulfosulfuron at 100% of its recommended dose (26.5 g ha^{-1}) plus sesame seed oil was the best formulation to control of Japanese downy brome. In addition, this formulation significantly improved wheat grain and biological yield. Adding of D-Octil had the highest influence on sulfosulfuron plus metsulfuron-methyl performance in Japanese downy brome control. The highest wheat grain and biological yield were mainly obtained at 100% recommended dose (40 g ha^{-1}) of sulfosulfuron + metsulfuron-methyl plus D-Octil followed by sesame oil.

Keywords: adjuvants, herbicide, vegetable oils, wheat

Introduction

Wheat *Triticum aestivum* L. is one of the most important cereal crops and is significantly affected by weed competition. Weeds compete with wheat for resources such as water, light, space and nutrients (Baghestani *et al*., 2007). Their interference can cause significant yield reduction in winter wheat. Winter annual grasses such as Japanese downy brome *Bromus japonicus* L., found in winter wheat are more difficult to control than other weeds and cause greater yield losses. Japanese downy brome interference with winter wheat occurs within 2–3 weeks after wheat emergence and is more competitive than later emerging plants (Reddy *et al*., 2013). Stahlman and Miller (1990) showed that Japanese downy brome plants at densities of 24, 40, and 65/m^2 reduced wheat yields by 10%, 15%, and 20%, respectively, when emerging within 14 days after wheat emergence. Basiri *et al*. (2016) also reported that grain and biological

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yield of wheat varieties were negatively affected by competition with Japanese brome.

Sulfonylurea herbicides which inhibit acetolactate synthase (ALS) are the most effective herbicides for selective control of winter annual grasses (Baghestani *et al*., 2008a). Currently, sulfosulfuron and sulfosulfuron plus metsulfuron-methyl are considered to be the most effective herbicides for controlling weeds in wheat fields (Zand *et al*., 2007; Baghestani *et al*., 2008 a,b). Sulfosulfuron can be applied pre-emergence (PRE) and some experiments have shown a higher efficacy level of PRE, compared to post emergence (POST) application in wheat (Blackshaw and Hamman, 1998). Recently, many researches have proven that application of sulfosulfuron or sulfosulfuron plus metsulfuron-methyl significantly inhibited Japanese downy brome growth. For instance, Galavi and Sarani (2010) reported that sulfosulfuron and sulfosulfuron plus metsulfuron-methyl significantly decreased Japanese downy brome growth, but had no negative effects on wheat growth and grain yield. Furthermore, application of 33 g ha^{-1}metsulfuronmethyl + sulfosulfuron herbicide in five-leaf growth stage of wheat decreased Japanese downy brome dry weight, while increased wheat grain yield (Sarani and Baghestani, 2016). However, the widespread use of these herbicides could have major side-effects on the environment and human health by leaching and runoff from agricultural land to drinking water (Gawad *et al*., 2005). Moreover, it might result in resistance in grasses due to high selective pressure and persistence of sulfonylurea herbicides in soil can cause great problems for subsequent susceptible crops (Devine and Shimabukuro 1994). It must be noted that herbicide persistence would be longer under low precipitation (< 300 mm), highly alkaline (pH > 8.5) soils; problems which most farmers face in Iran especially in spring and summer (Baghestani *et al*., 2008b).

Recently, Herbicide reducing programs have been enforced in many countries (Kudsk, 2008). A solution to the negative impacts of continuous application of post-emergence herbicides such as sulfonylureas is to use adjuvants. These compounds can increases the efficiency of herbicides through reducing surface tension and by increasing diffusion of droplets on leaf surface (Kudsk, 2008). Therefore, they decrease the application dose of herbicides and reduce the risk of their side effects and also user cost (Penner, 2000; Aliverdi *et al*., 2009; Rashed-Mohassel *et al*., 2011; Izadi-Darbandi *et al*., 2013). There are several types of adjuvants which positively affect herbicides efficiency. Vegetable oils are one of the most important groups of adjuvants that not only are very pleasant for herbicide applicators, but also they are not phytotoxic and are likely degraded quickly in the environment (Cabanne *et al*., 1999). Several researchers indicated that application of vegetable oils improve and enhance herbicides efficiency to control weed growth. For instance, Hammami *et al*. (2013) found that the addition of emulsifiable vegetable oils significantly improved sethoxydim effectiveness. In addition, Giysopoulos *et al*. (2014) showed that the use of vegetable oil mixtures with diquat herbicide indicating significantly enhanced diquat efficacy on grasses.

Efficiency of vegetable oils as adjuvants depends on concentration, type of herbicide, plant species and environmental conditions (Zolinger, 2000; Bunting *et al*., 2004). In this regard there is a fundamental question; application of what vegetable oil can increase downy brome control with no impact on wheat performance. Therefore, in this study we followed the hypothesis that by providing vegetable oils, the efficiency of sulfosulfuron and sulfosulfuron plus metsulfuron-methyl would be increased. To date, there is no published and comprehensive research related to application of sulfosulfuron and sulfosulfuron plus metsulfuron-methyl together with vegetable oils against downy brome. Therefore, the objective of this study was to seek for an adjuvant that could significantly enhance the efficacy of two sulfonylurea herbicides against downy brome without causing unacceptable injury to wheat.

Materials and Methods

In order to investigate the effects of two sulfonylurea herbicides, sulfosulfuron (Apyrus®, 75% WG, Monsanto, USA) and Sulfosulfuron plus metsulfuron-methyl (Total®, 75 + 5% WG, UPL, India) and vegetable oils as adjuvants on Japanese downy brome control in winter wheat field, two field experiments were conducted at research center of Agricultural Farm of Sistan and Baluchestan provenience of Iran at two separate stations (Zabol (30°54′N, 61°41′E, 483 m altitude) and Zahedan (29°30′N, 60°51′E, 1385 m altitude)) during 2015-2016 growing season. Each experiment was arranged as factorial based on randomized complete block design (RCBD) with three replications. First factor was different each herbicide doses including 0, 50, 75 and 100% of recommended dose [sulfosulfuron (0, 13.25, 19.87 and 26.5 g ha^{-1}) and sulfosulfuron plus metsulfuron-methyl (0, 20, 30 and 40 g ha^{-1})] and second factor was adjuvants including: (i) without adjuvants, (ii) sweet almond *Prunus nana* L., oil (iii) olive *Olea europaea* L., oil (iv) Sesame *Sesamum indicum* L. oil and (v) D-Octil. All adjuvants were applied at 0.5 % (v/v) (Izadi-Darbandi and Aliverdi, 2015). D-Octil contains 70% sodium sulfosuccinate, 0.05% molybdenum and 0.1% copper with a P^H of 7 (AMC Company, Spain). The emulsifiable vegetable oils were prepared by dissolving the emulsifier alkylarylpolyglycol ether (Zarnegaran Pars Company, Karaj, Iran) in each vegetable oil (95% crude vegetable oil plus 5% alkylarylpolyglycol ether).

After land preparation, winter wheat *Triticum aestivum*, cv. Sistan seeds were cultivated in plots consisting of six 4 m rows spaced 0.3 m apart and at a density of 400 plants m^{-2}. In order to achieve the uniform density of Japanese downy brome, at the same time as the wheat cultivation, Japanese downy brome seeds were cultivated in the distance between the wheat rows with a density of 300 plants m^{-2}. All operations such as planting, irrigation, fertilizer application, etc. were carried out according to the customary practices. In addition, during the growing season, all weeds except Japanese downy brome were removed by hand.

Herbicides were sprayed at three- to four-leaf stage of wheat by using a sprayer equipped with a Flat-fan nozzle, delivering 300 L spray solution ha^{-1} at 250 KPa. Thirty days after spraying, the number of survived Japanese downy brome plants per m^{-2} was recorded and the fresh and dry weight of above-ground biomass in each plot were measured after drying at 70 °C for 48 hours. At the end of the season, wheat plants harvested from 1 m^{-2} of each plot and grain yield and biological yield were determined. The data was subjected to analysis of variance using the GLM procedure in SAS (Version, 9.1). Mean comparisons were performed using Duncan Multiple Range Test (DMRT) set at 0.05.

Results

Sulfosulfuron

As shown in Table 1, survival percentage and dry weight of Japanese downy brome plants were significantly differed between two experimental sites after sulfosulfuron application. Results showed that sulfosulfuron and adjuvant application significantly affected the weed survival and dry weight in the two locations, but their interaction was not significant (Table 1). By increasing sulfosulfuron dosage survival of Japanese downy brome decreased significantly in both locations (Table 2). Application of adjuvants increased its foliar activity (Table 2). Among the adjuvants, incorporation of sesame seed oil to sulfosulfuron formulation increased its efficiency in decreasing the survival of Japanese downy brome in both Zabol and Zahedan locations (Table 2). Dry weight of Japanese downy brome was significantly affected by sulfosulfuron dosage and adjuvant in both locations, but it was not significantly influenced by herbicide dosage × adjuvant interaction (Table 1). According to Table 2, weed dry weight decreased with increasing the herbicide dosage and the lowest values were achieved by 100% recommended dose. Adjuvants application increased effectiveness of sulfosulfuron on downy brome dry weight and the highest efficiency of sulfosulfuron in was obtained by sesame oil followed by D-octil (Table 2).

Wheat grain and biological yield were not significantly different between the two locations (Table 1). Results showed that sulfosulfuron dosage and adjuvant application significantly affected wheat grain and biological yield. Interaction of herbicide dosage × adjuvant application had not significant effected on wheat grain and biological yield (Table 1). As shown in Table 3, wheat grain and biological yield increased with increasing the herbicide dosage. Addition of adjuvant could increase sulfosulfuron efficiency. Among the adjuvants, sesame oil remarkably increased wheat grain and biological yield (Table 2).

Table 1 Mean squares of Japanese downy brome *Bromus japonicus* and wheat traits in response to adjuvant and different doses of sulfosulfuron at Zabol and Zahedan stations.

Source of variation		Japanese downy brome				Wheat	
		Survival		Dry weight		Grain yield (Kg.ha^{-1})	Biological yield (kg.ha^{-1})
	df	Zabol	Zahedan	Zabol	Zahedan	Pooled	Pooled
Replication	2	28.70^{ns}	3.97^{ns}	0.11^{ns}	1.14^{ns}	2931^{ns}	60364^{ns}
Herbicide Dose (HD)	3	4672**	5031**	67.50**	56.90**	223043**	7708697**
Adjuvant (A)	4	1326**	776.00**	53.80**	44.80**	170547**	5137997**
HD × A	12	11.80^{ns}	14.20^{ns}	1.94^{ns}	0.20^{ns}	5043^{ns}	63657^{ns}
Error	36	11.07	11.06	1.10	0.83	4809	62922
CV		8.81	9.25	12.10	13.90	6.68	3.22
Combined analysis Place	1	76.02**		105.90**		14040^{ns}	75965^{ns}

$^{*, **}$ Significant at P ≤ 0.05 and P ≤ 0.01, respectively. ns: Non-significant.

Table 2 The response of Japanese downy brome *Bromus japonicus* and wheat traits in response to different doses of sulfosulfuron and adjuvants.

Treatments	Conc. (%)	Japanese downy brome				Wheat	
		Survival (%)		Dry weight (g m^{-2})		Grain yield (Kg.ha^{-1})	Biological yield (kg.ha^{-1})
		Zabol	Zahedan	Zabol	Zahedan		
Sulfosulfuron	0	99.6^{a}	100^{a}	15.80^{a}	13.40^{a}	653^{d}	5916^{d}
	50	41.3^{b}	39.5^{b}	9.31^{b}	6.85^{b}	982^{c}	7244^{c}
	75	33.3^{c}	32.1^{c}	8.16^{c}	6.07^{bc}	1066^{b}	7992^{b}
	100	26.0^{d}	23.3^{d}	7.03^{d}	5.32^{c}	1143^{a}	8497^{a}
Control	0	62.1^{a}	55.5^{a}	11.70^{a}	9.66^{a}	792^{c}	6664^{d}
Sweet almond	0.5	40.2^{b}	38.0^{b}	9.59^{b}	7.97^{b}	1078^{b}	7603^{c}
Olive	0.5	33.5^{c}	34.8^{c}	9.24^{b}	6.42^{c}	1091^{b}	7994^{b}
Sesame	0.5	18.2^{e}	17.8^{e}	4.32^{d}	3.29^{e}	1216^{a}	8991^{a}
D-Octil	0.5	26.3^{d}	26.8^{d}	7.24^{c}	4.32^{d}	1093^{b}	8053^{b}

Means with similar letters in each column are not significantly different at 5% level (Duncan multiple range test).

Table 3 Mean squares of Japanese downy brome *Bromus japonicus* and wheat traits in response to adjuvant and different doses of sulfosulfuron plus metsulfuron-methyl.

Source of variation		Japanese downy brome		Wheat		Biological yield
				Grain yield		
	df	Survival	Dry Weight	Zabol	Zahedan	
Replication	2	8.70^{ns}	0.24^{ns}	3281^{ns}	6887^{ns}	89747^{ns}
Herbicide Dose (HD)	3	4183.00**	75.30**	219545**	213205**	10118245**
Adjuvant (A)	4	1056.30**	20.50**	50944**	64399**	3052760**
HD × A	12	41.60*	0.15^{ns}	1144^{ns}	2640^{ns}	96006^{ns}
Error	36	14.70	0.30	4818	5526	127253
CV		9.14	12.40	5.20	5.89	4.08
Combined analysis place	1	57.60^{ns}	0.03^{ns}	49504**		20937^{ns}

$^{*, **}$ Significant at P ≤ 0.05 and P ≤ 0.01, respectively. ^{ns}: Non-significant.

Sulfosulfuron plus metsulfuron-methyl

Survival percentage and dry weight of Japanese downy brome plants were not significantly different in the two studied places after sulfosulfuron plus metsulfuron-methyl application (Table 3). Although Japanese downy brome survival and dry weight were significantly affected by sulfosulfuron plus metsulfuron-methyl doses and adjuvant, their interaction had significant effect only on survival percentage (Table 3). According to Table 4, Japanese downy brome survival decreased with increasing sulfosulfuron plus metsulfuron-methyl dose and its lowest values were achieved by 100% recommended dose. Among the adjuvants, D-octil addition followed by sesame oil effectively increased sulfosulfuron plus metsulfuron-methyl efficiency in decreasing the weed survival compared with the others. However, at recommend dose of sulfosulfuron plus metsulfuron-methyl, there was no significant difference between sesame seed oil and D-octil efficiency (Fig. 1). Japanese downy brome plants dry weight also significantly decreased by incremental dose increases of sulfosulfuron plus metsulfuron-methyl. Among the adjuvants, D-octil decreased plants dry weight more than the others. However, was not significantly different from sesame oil (Table 4).

Analysis of variance showed that wheat grain yield differed significantly in the two studied places after sulfosulfuron plus metsulfuron-methyl application (Table 3). In both Zabol and Zahedan stations, wheat grain yield was significantly affected by different doses of sulfosulfuron plus metsulfuron-methyl and adjuvants application, while it was not influenced by their interaction (Table 3). In both Zabol and Zahedan stations, wheat grain yield increased by increasing the sulfosulfuron plus metsulfuron-methyl herbicide doses. Among the adjuvants, D-octil to sulfosulfuron plus metsulfuron-methyl formulation remarkably increased wheat grain yield compared with other adjuvants. However, it was not significantly different from sesame seed oil (Table 4). Wheat biological yield was significantly affected by sulfosulfuron plus metsulfuron-methyl doses and adjuvant application, while their interaction was significant only in Zabol station (Table 3). As shown in Table 4, wheat biological yield increased with increasing the herbicide doses. Incorporation of adjuvant into sulfosulfuron plus metsulfuron-methyl formulation increased its efficiency and the highest efficiency was achieved by D-octil followed by sesame seed oil (Table 4).

Table 4 The response of Japanese downy brome *Bromus japonicus* and some wheat traits to application of different doses of sulfosulfuron plus metsulfuron-methyl and adjuvants.

Treatments	Conc. (%)	Japanese downy brome		Wheat		
				Grain yield ($Kg.ha^{-1}$)		Biological yield ($kg.ha^{-1}$)
		Survival (%)	Dry weight ($g\ m^{-2}$)	Zabol	Zahedan	
Sulfosulfuron	0	99.6^{a}	12.50^{a}	931^{d}	930^{d}	6793^{d}
	50	45.8^{b}	4.50^{b}	1258^{c}	1183^{c}	8129^{c}
	75	38.8^{c}	3.90^{c}	1339^{b}	1285^{b}	8808^{b}
	100	29.8^{d}	3.00^{d}	1418^{a}	1379^{a}	9682^{a}
Control	0	64.7^{a}	7.49^{a}	1158^{d}	1110^{c}	7697^{d}
Sweet almond	0.5	424.0^{b}	4.54^{b}	1299^{c}	1221^{b}	8626^{c}
Olive	0.5	38.7^{c}	4.21^{b}	1352^{bc}	1306^{a}	8986^{b}
Sesame	0.5	32.8^{d}	2.57^{c}	1375^{ab}	1351^{a}	9303^{ab}
D-Octil	0.5	24.4^{e}	2.11^{c}	1431^{a}	1365^{a}	9451^{a}

Means with similar letters in each column are not significantly different at 5% level (Duncan multiple range test).

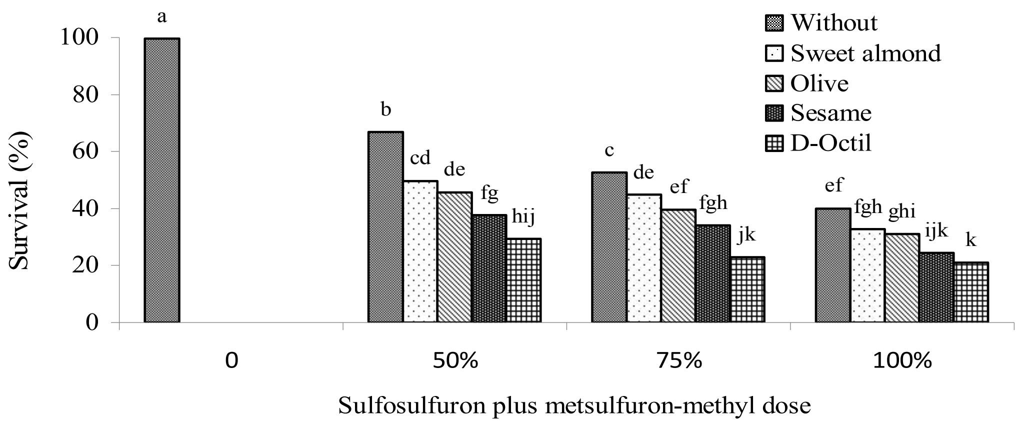

Figure 1 Survival response of Japanese downy brome *Bromus japonicus* to interaction of vegetable oils and sulfosulfuron plus metsulfuron-methyl doses. The means with similar letters are not significantly different at 5% level (Duncan multiple range test).

Discussion

Results showed that Japanese downy brome plants survival and dry weight significantly decreased by sulfosulfuron and sulfosulfuron plus metsulfuron-methyl at both Zabol and Zahedan stations. Sulfosulfuron at 100% of its recommended dose plus sesame seed oil as adjuvant was the best formulation to control Japanese downy brome growth and to decrease its dry weight. In addition, the best sulfosulfuron formulation by which wheat produced high grain and biological yield were the application of sulfosulfuron in at recommended dose plus sesame oil as adjuvant. In the case of sulfosulfuron plus metsulfuron-methyl, the best formulation to decrease the Japanese downy brome survival and dry weight was in 100% of recommended dose of sulfosulfuron plus metsulfuron-methyl plus D-octil. The highest wheat grain and biological yield were achieved by application of recommended dose of sulfosulfuron plus metsulfuron-methyl plus D-octil followed by sesame seed oil as adjuvant.

Several authors have reported that vegetable and methylated seed oil probably disrupt and solubilize cuticular waxes and consequently, facilitate the penetration of the active ingredient (McMullan and Chow, 1993; Rashed-Mohassel *et al.*, 2010; Izadi-Darbandi *et al.*, 2013). In addition, it is believed that adjuvants improve the transfer of effective substance from the target surface to the interior tissues due to the softness, elasticity, or dissolution of the cuticle (Izadi-Darbandi *et al.*, 2013). This allows the release of herbicide down to the lower layer with more hydrophilic properties. The increase in herbicides efficiency by addition of vegetable oils has been documented in several researches (Mousavinik *et al.*, 2009; Rashed-Mohassel *et al.*, 2011; Hammami *et al.*, 2014). Izadi-Darbandi and Aliverdi (2015) reported that cotton seed and coconut oil enhanced the efficacy of sulfosulfuron or sulfosulfuron plus metsulfuron-methyl to control wild barley *Hordeum spontaneum* Koch. They also found that there is a negative correlation between the efficiency of vegetable oils and its unsaturated/saturated fatty acids ratio (Izadi-Darbandi and Aliverdi, 2015). Therefore, high effectiveness of sesame seed oil in our study may be related to its low unsaturated/saturated fatty acids ratio (Izadi-Darbandi and Aliverdi, 2015). The results of other studies revealed that oils with low unsaturated and short carbon chain have lower surface tension (Freitas *et al*., 2011). A decrease in surface tension of spray solution compatibility affects atomization and produces smaller droplets (Ejim *et al.*, 2007) and lower level of energy exists in smaller droplets that improves the retention of droplets by the leaf surface (Rashed-Mohassel *et al*., 2009). With greater interception and retention of droplets, the efficacy of an herbicide would be improved accordingly.

It is generally believed that D-Octil, as an adjuvant, reduces the surface tension of the herbicide solution (Aliverdi *et al*., 2009) thereby producing smaller droplets with lower energy, so they could easily spread on the leaf surface. In addition, it reduces the contact angle of the droplets with the target surface which results in improving herbicide efficiency (Penner 2000). Aliverdi *et al*. (2009) and Rashed-Mohassel *et al*. (2011) reported that addition of D-Octil increased tested herbicides efficiency.

It seems that application of the herbicides and adjuvants increased the accessibility of growth resources and reduced competition against wheat and ultimately increased its yield due to decreasing weed growth. In line with our results, Jamali *et al*. (2016) reported that sulfosulfuron and sulfosulfuron plus metsulfuron-methyl treatments in wheat contaminated with wild barley increased wheat grain yield. Baghestani *et al*. (2008a) showed that the use of sulfosulfuron herbicide in wheat field caused a reduction in the competitive pressure of wild barley on the crop and caused the positive effect of this herbicide on different measured wheat traits. In other words, weed growth prevention by sulfosulfuron reduced competition for nutritional and water sources.

Conclusions

Results showed that efficiency of sulfosulfuron and sulfosulfuron plus metsulfuron-methyl herbicides increased by increasing their doses and by adjuvant addition. The addition of sesame seed oil (followed by D-octil) had the highest effect on sulfosulfuron efficacy against Japanese downy brome survival and growth. In general, sulfosulfuron at 100% of its recommended dose plus sesame seed oil was the best formulation to control Japanese downy brome growth and to decrease its dry weight. In addition, this formulation significantly improved wheat grain and biological yield. Adding of D-Octil had the highest influence on sulfosulfuron plus metsulfuron-methyl performance against Japanese downy brome survival and growth. The highest wheat grain and biological yield were mainly obtained by 100% recommended dose of sulfosulfuron plus metsulfuron-methyl plus D-Octil as adjuvants. However incorporation of sesame oil (followed by D-octil) and D-Octil (followed by sesame oil) to sulfosulfuron and sulfosulfuron plus metsulfuron-methyl respectively not only increased their efficiency in the control of Japanese downy brome plants growth, but also could significantly increase wheat grain and biological yields.

Statement of Conflicting Interests

The Author state that there is no conflict of interest.

References

Aliverdi, A., Rashed Mohassel, M. H., Zand, E. and Nassiri Mahallati, M. 2009. Increased foliar activity of clodinafop-propargyl and/or tribenuron-methyl by surfactants and their synergistic action on wild oat (*Avena ludoviciana*) and wild mustard (*Sinapis arvensis*). Weed Biology and Management, 9: 292-299.

Baghestani, M. A., Zand, E., Mesgaran, M. B., Veysi, M., Pour Azar, R. and Mohammadipour, M. 2008a. Control of weed barley species in winter wheat with sulfosulfuron at different rates and times of application. Weed Biology and Management, 8: 181-190.

Baghestani, M. A., Zand, E., Soufizadeh, S., Jamali, M. and Maighani, M. 2007.

Evaluation of sulfosulfuron for broadleaved and grass weed control in wheat (*Triticum aestivum* L.) in Iran. Crop Protection, 26: 1385-1389.

Baghestani, M. A., Zand, E. and Sufizadeh, S. 2008b. Study on the efficacy of weed control in wheat (*Triticum aestivum*L.) whit tank mixtures of grass herbicide with broadleaf herbicide. Crop Protection, 27: 104-111.

Basiri, M., Mousavi-Nik, S. M., Siahmarguee, A., Sabbagh, S. K. and Sarani, M. 2016. The reaction of grain yield and yield components of wheat (*Triticum aestivum* L.) varieties in competition with Japanese brome (*Bromus japonicus* L.) in Sistan region. Cereal Research, 5: 371-385.

Blackshaw, R. E. and Hamman, W. M. 1998. Control of Downy Brome (*Bromus tectorum*) in Winter Wheat (*Triticum aestivum*) with MON 37500. Weed Technology, 12: 421-425.

Bunting, J. A., Spragueand, C. L. and Riechers, D. E. 2004. Proper adjuvant selection for foramsulfuron activity. Crop Protection, 23: 361-366.

Cabanne, F., Gaudry, J. and Streibig, J. C. 1999. Influence of alkyl oleates on efficacy of phenmedipham applied as an acetone: water solution on *Galium aparine*. Weed Research, 39: 57-67.

Devine, M. D. and Shimabukuro, R. H. 1994. Resistance to acetyl coenzyme A carboxylase inhibiting herbicides. In: Powles S.B. and Holtum J.A.M., eds. Herbicide Resistance in Plants Biology and Biochemistry. Boca Raton, FL: Lewis. 141-169.

Ejim, C. E., Fleck, B. A. and Amirfazli, A. 2007. Analytical study for atomization of biodiesels and their blends in a typical injector: surface tension and viscosity effects. Fuel, 86: 1534-1544.

Freitas, S. V. D., Oliveira, M. B. and Queimada, A. J. 2011. Measurement and prediction of biodiesel surface tensions. Energy Fuels, 25: 4811-4817.

Galavi, M. and Sarani, M. 2010. Evaluating the efficacy of three new herbicide on japanes brome (*Bromua japonicus*) in wheat (*Triticum aestivum*) fields on sistan region. The 3rd Iranian Weed Science Congress, Feb.

Gawad, A. S., Vanjara, A. K. and Sawant, M. R. 2005. Removal of herbicide from water with sodium chloride using surfactant treated alumina for wastewater treatment. Separation and Purification Technology, 41: 65-71.

Giysopoulos, T. K., Damalas, C. A. and Georgoulas, I. 2014. Improving diquat efficacy on grasses by adding adjuvants to the spray solution before use. Planta Daninha, 32: 355-360.

Hammami, H., Aliverdi, A. and Parsa, M. 2014. The effectiveness of clodinafop-propargyl, haloxyfop-p-methyl and difenzoquatmethyl-sulfate plus Adigor and Propel adjuvants to control of *Avena ludoviciana* Durieu. Journal of Agricultural Science and Technology, 16: 291-299.

Hammami, H., Rashed-Mohassel, M. H., Parsa, M. and Bannayan-Aval, M., Zand, E. 2013. Optimizing dosage of sethoxydim with vegetable oils to control wild oat (*Avena ludoviciana* Durieu.). Advanced Crop Science, 3: 687-694.

Izadi-Darbandi, E. and Aliverdi, A. 2015. Optimizing Sulfosulfuron and Sulfosulfuron Plus Metsulfuron-methyl Activity when Tank-Mixed with Vegetable Oil to Control Wild Barley (*Hordeum spontaneum* Koch.). Journal of Agricultural Science and Technology, 17: 1769-1780.

Izadi-Darbandi, E., Aliverdi, A. and Hammami, H. 2013. Behavior of vegetable oils in relation to their influence on herbicides' effectiveness. Industrial Crops and Products, 44: 712-717.

Jamali, M. R., Baghestani, M. A. and Jokar, L. 2016. Control of wild barley by sulfosulfuron+metsulfuron (Total) and sulfosulfuron (Apyrus) herbicides using time of application and wheat density. Iran Agro Science, 47: 393-400.

Kudsk, P. 2008. Optimising herbicide dose: a straightforward approach to reduce the risk of side effects of herbicides. Environmentalist, 28: 49-55.

McMullan, P. M. and Chow P. N. 1993. Efficacious adjuvants for fluazifop or sethoxydim in flax and canola. Crop Protection, 12: 544-548.

Mousavinik, A., Zand, E., Baghestani, M. A., Deihimfard, R., Soufizadeh, S., Ghezeli, F. and Aliverdi, A. 2009. Ability of adjuvants in enhancing the performance of pinoxaden and clodinafoppropargyl herbicides against grass weeds. Iranian Journal of Weed Science, 5: 65-77.

Penner, D. 2000. Activator adjuvants. Weed Technology, 14: 785-791.

Rashed-Mohassel, M. H., Aliverdi, A. and Ghorbani, R. 2009. Effects of a magnetic field and adjuvant in the efficacy of cycloxydim and clodinafop-propargyl on the control of wild oat (*Avena fatua*). Weed Biology and Management, 9: 300-306

Rashed-Mohassel, M. H., Aliverdi, A., Hamami, H. and Zand, E. 2010. Optimizing the performance of diclofop-methyl, cycloxydim, and clodinafop-propargyl on little seed canary grass (*Phalaris minor*) and wild oat (*Avena ludoviciana*) control with adjuvants. Weed Biology and Management, 10: 57-63.

Rashed-Mohassel, M. H., Aliverdi, A. and Rahimi, S. 2011. Optimizing dosage of sethoxydim and fenoxaprop-p-ethyl with adjuvants to control wild oat. Industrial Crops and Products, 34: 1583-1587.

Reddy, S. S., Stahlman, P. W. and Geier, P. W. 2013. Downy Brome (*Bromus tectorum* L.) and Broadleaf Weed Control in Winter Wheat with Acetolactate Synthase-Inhibiting Herbicides. Agronomy, 3: 340-348.

Sarani, M. and Baghestani, M. A. 2016. Evaluation of the efficacy of herbicide Total (metsulfuron methyl + sulfosulfuron) at different growth stages of wheat and Bromus in reduced rates. The 6rd Iranian Weed Science Congress, Birjand.

Stahlman, P. W. and Miller, S. D. 1990. Downy brome (*Bromus tectorum*) interference and economic thresholds in winter wheat (*Triticum aestivum*). Weed Science, 38: 224-228.

Zand, E., Baghestani, M. A., Soufizadeh, S., Eskandari, A., Pour Azar, R. and Veysi, M. 2007. Evaluation of some newly registered herbicides for weed control in wheat (*Triticum aestivum* L.) in Iran. Crop Protection, 26: 1349-1358.

Zolinger, R. K. 2000. Extension perspective on grower confusion in adjuvant selection. Weed Technology, 14: 814-818.

بهینه‌سازی کارایی علف‌کش‌های سولفوسولفورون و سولفوسولفورون + مت‌سولفورون-متیل در کنترل علف پشمکی ژاپنی *Bromus japonicus* L. با استفاده از مواد افزودنی

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چکیده: کارایی بسیاری از علف‌کش‌ها را با افزودن مواد افزودنی به محلول پاشش می‌توان افزایش داد. از این‌رو، اضافه کردن مواد افزودنی مناسب به علف‌کش‌ها، از اولویت‌های اصلی در تحقیقات کنترل علف‌های هرز است. به‌منظور شناسایی یک ماده افزودنی مناسب برای بهینه‌سازی کارایی علف‌کش‌های سولفوسولفورون و سولفوسولفورون + مت سولفورون-متیل در کنترل علف پشمکی ژاپنی، دو آزمایش در قالب طرح بلوک‌های کامل تصادفی با دو عامل تحت شرایط مزرعه به‌طور جداگانه در زابل و زاهدان انجام شدند. فاکتور A مقادیر مختلف کاربرد هر یک از علف‌کش‌ها شامل، ۵۰، ۷۵ و ۱۰۰ درصد مقدار کاربرد توصیه شده و فاکتور B کاربرد مواد افزودنی شامل: روغن بادام شیرین، روغن‌زیتون، روغن کنجد و D-Octil بودند. نتایج نشان دادند که با افزایش مقدار کاربرد علف‌کش‌ها و مواد افزودنی، کارایی علف‌کش‌های سولفوسولفورون و سولفوسولفورون + مت سولفورون-متیل در کنترل علف پشمکی ژاپنی افزایش یافت. افزودن روغن کنجد (پس از D-octil) بیش‌ترین تأثیر را در کارایی سولفوسولفورون در برابر بقاء و رشد بروموس ژاپنی داشت. به‌طورکلی، کاربرد سولفوسولفورون به میزان توصیه شده آن به‌همراه روغن کنجد به‌عنوان بهترین ترکیب برای کنترل علف پشمکی ژاپنی بود. علاوه بر این، این ترکیب به‌طور قابل‌توجهی عملکرد دانه و عملکرد بیولوژیکی گندم را افزایش داد. افزودن D-Octil بیش‌ترین تأثیر را بر کارایی سولفوسولفورون + مت سولفورون-متیل در کنترل علف پشمکی ژاپنی داشت. بیش‌ترین عملکرد دانه و عملکرد بیولوژیکی گندم در ۱۰۰ درصد مقدار کاربرد توصیه شده سولفوسولفورون + مت سولفورون-متیل به‌همراه D-Octil و پس از آن روغن کنجد حاصل شد.

واژگان کلیدی: مواد افزودنی، علف‌کش، روغن‌های گیاهی، گندم