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Article

Use of Adjuvants to Optimize the Activity of Two Broad-Spectrum Herbicides for Weed Control in Wheat

Uso de Adjuvantes para Otimizar a Atividade de Dois Herbicidas de Amplo Espectro no Controle de Ervas Daninhas no Trigo

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ABSTRACT - Herbicide resistance development among weeds, environmental contamination and health concerns due to the overuse of herbicides have led researchers to focus on ways to reduce herbicides to be sprayed for weed management. Adjuvants are best suited for that purpose, as they accomplish a crucial role in achieving satisfactory control of weeds by maximizing herbicidal activity. A two-year field investigation was carried out at the Agronomic Research Area, in the University of Agriculture, in Faisalabad, Pakistan during the winter of 2014 and 2015, with the objective to optimize the activity of two broad-spectrum herbicides at reduced dose (75% of the label mentioned rate) for weed control in wheat. Minimum weed density, weed dry weight and NPK uptake were recorded with reduced dosed mesosulfuron methyl + iodosulfuron methyl sodium at 10.60 g a.i. ha^{-1} combined with fatty alcohol ethoxylate at 200 mL ha^{-1}. This was followed by reduced dosed sulfosulfuron at 18.75 g a.i. ha^{-1} combined with the same adjuvant. Among various herbicidal treatments, application of reduced dosed mesosulfuron methyl + iodosulfuron methyl sodium at 10.60 g a.i. ha^{-1} combined with fatty alcohol ethoxylate at 200 mL ha^{-1} was proved to be most cost effective and resulted in maximum wheat yield during both years of study.

Keywords: *Triticum aestivum* L., adjuvants, grain yield, benefit-cost ratio.

RESUMO - O aumento da resistência das plantas daninhas aos herbicidas, a contaminação ambiental e as preocupações com a saúde devido ao uso excessivo de herbicidas são fatores que têm instigado os pesquisadores a se concentrarem em soluções para reduzir as doses de herbicidas aplicados no controle de plantas daninhas. Os adjuvantes são mais adequados para esse propósito, pois desempenham papel crucial na obtenção de um controle satisfatório das plantas daninhas, maximizando a atividade dos herbicidas. Uma pesquisa de campo de dois anos foi realizada no Departamento de Pesquisa Agronômica da Universidade de Agricultura de Faisalabad, no Paquistão, durante o inverno de 2014 e 2015, com o objetivo de otimizar a atividade de dois herbicidas de amplo espectro em dose reduzida (75% da dose recomendada pelo fabricante) para o controle de plantas daninhas no trigo. Foi registrada a densidade mínima da planta daninha, assim como seu peso seco e a captação de NPK, com dose reduzida de mesosulfuron-methyl + iodosulfuron-methyl-sodium a 10,60 g i.a. ha^{-1} combinada com etoxilato de álcool gordo a 200 mL ha^{-1}. Em seguida, foram aplicadas doses reduzidas de sulfosulfuron a 18,75 g i.a. ha^{-1}, combinadas com o mesmo adjuvante. Entre vários tratamentos com herbicidas, a aplicação da dose reduzida de mesosulfuron-methyl + iodosulfuron-methyl-sodium a 10,60 g i.a. ha^{-1} combinada com o etoxilato de

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álcool gordo a 200 mL ha^{-1} provou ser mais rentável e proporcionou o mais alto rendimento de trigo durante os dois anos de estudo.

Palavras-chave: *Triticum aestivum* L., rendimento do grãos, relação custo-benefício.

INTRODUCTION

Wheat is the most important cereal, as it is the staple diet of a huge population of the world, and of two-third of the population of Pakistan. In addition, (Phillips and Norton, 2012). Pakistan's national average grain yield of wheat (2,787 kg ha^{-1}) is very low compared to the genetic yield potential (6,000 to 8,000 kg ha^{-1}) of its local wheat varieties. It reflects a huge gap between actual and potential yield (PARC, 2011; Govt. Pakistan, 2014). Among the various factors that contribute to such yield gap, weeds alone cause up to 50% reduction in wheat yield (Kumar et al., 2011). Wheat fields are infested with both grassy and broadleaf weeds and these reduce wheat yield depending on their type and intensity (Singh et al., 2014). Due to their easy adapting to wheat crop and heavy seed-bearing capacity, some weeds such as canary grass (*Phalaris minor* Ritz.), field bind weed (*Convolvulus aevensis* L.), and swine cress (*Cornopus didymus* L.), are known to be great damaging weeds (Shamsi and Ahmed, 1984; Khan and Marwat, 2006). Although various scientific communities criticize herbicide use, it is still the most productive, fast, and practical method for securing crop yields against weeds (Khaliq et al., 2014; Mustari et al., 2016). Controlling weeds through herbicides help to develop a substantial crop stand, especially boosting the growth of crop at its early stages by helping the crop to gather resources efficiently (Santos et al., 2009). However, problems such as herbicide resistance development in weeds, herbicide residual effects and environmental pollution are associated with excessive use of herbicides. Development of resistance among weeds against certain herbicides and other health and environmental issues due to an excessive, continuous and non-judicious application of herbicides, are factors that have demanded scientists to find out new and substitute weed control strategies (Zand et al., 2007). One of them is to reduce the quantity of herbicides sprayed without compromising their efficiency. Adjuvants are best suited for that purpose, as they accomplish a crucial role in achieving satisfactory control of weeds by maximizing herbicidal activity (Woznica et al., 2007; Zimbdahl, 2000). This choice may lead to environmental preservation along with crop improvement (Pannacci, 2010). Sulfosulfuron methyl and mesosulfuron methyl + iodosulfuron methyl sodium belongs to the sulfonylurea family of herbicides and are classified as ALS (acetolactate synthase) inhibitors (Baghestani et al., 2007). These herbicides act by inhibiting the synthesis of amino acids, specifically valine and isoleucine, preventing cell division and cell growth. Selectivity occurs due to the differences in the metabolism of sulfonylureas between crops and weeds. The use of adjuvants may enhance the activity of sulfosulfuron (Izadi-Darbandi and Aliverdi, 2015) and mesosulfuron methyl + iodosulfuron by increasing spray coverage on leaf surfaces, reducing surface tension, solubilizing leaf cuticle, acting as an emulsifier, modifying rainfastness or movement of spray to the target site. This experiment was conducted with the objective to find the best-suited adjuvant for sulfosulfuron and mesosulfuron methyl + iodosulfuron methyl sodium and to assess the response of weeds and wheat yield against these post-emergence herbicides combined with adjuvants.

MATERIALS AND METHODS

A field study to optimize the activity of two broad-spectrum herbicides for weed control in wheat (*Triticum aestivum* L.) was conducted at the Agronomic Research Area, Department of Agronomy, University of Agriculture, Faisalabad, Pakistan during winter 2014 and winter 2015. The experimental site is situated at 31^{o} N latitude, 73^{o} E longitudes and at 184.4 m altitude. This experiment consisted of 13 treatments, including unweeded control, sulfosulfuron at 25.00 g a.i. ha^{-1}, sulfosulfuron at 18.75 g a.i. ha^{-1} + 2% AMS, sulfosulfuron at 18.75 g a.i. ha^{-1} + 3% AMS, sulfosulfuron at 18.75 g a.i. ha^{-1} + fatty alcohol ethoxylate at 200 mL ha^{-1}, sulfosulfuron at 18.75 g a.i. ha^{-1} + alkyl ether sulphate sodium salt at 400 mL ha^{-1}, sulfosulfuron at 18.75 g a.i. ha^{-1} + rapsoel methyl eser at 400 mL ha^{-1}, mesosulfuron methyl + iodosulfuron methyl at 14.2 g a.i. ha^{-1}, mesosulfuron methyl + iodosulfuron methyl at 10.6 g a.i. ha^{-1} + 2% AMS, mesosulfuron methyl +

iodosulfuron methyl at 10.6 g a.i. ha^{-1} + 3% AMS, mesosulfuron methyl + iodosulfuron methyl at 10.6 g a.i. ha^{-1} + fatty alcohol ethoxylate at 200 mL ha^{-1}, mesosulfuron methyl + iodosulfuron methyl at 10.6 g a.i. ha^{-1} + alkyl ether sulphate sodium salt at 400 mL ha^{-1} and mesosulfuron methyl + iodosulfuron methyl at 10.6 g a.i. ha^{-1} + rapsoel methyl eser at 400 mL ha^{-1}. The experiment was laid out in randomized complete block design with three replications. Seedbed was prepared by cultivating the soil 2-3 times with a tractor mounted cultivator each followed by planking. The experimental area was finally levelled for the uniform application of irrigation water. Spring wheat variety 'Galaxy-2013' was seeded on November 25, 2014 and November 25, 2015 in lines 22.5 cm apart at a depth of 5 cm with recommended seed rate of 125 kg ha^{-1}. The crop was planted in the field having a heavy infestation of broadleaf and narrow leaf weeds from previous years. Recommended doses of N, P and K (N at 120 kg ha^{-1}, P_2O_5 at 85 and K_2O at 60 kg ha^{-1}) were applied in the form of urea, di-ammonium phosphate (DAP) and sulphate of potash (SOP), respectively. Whole P and K were applied at sowing while half of the nitrogen was applied at sowing and half at first irrigation. Other recommended cultural practices were followed as per requirement of the treatment and crop.

Spray solutions were prepared by adding herbicides alone or herbicide and adjuvant in a plastic bottle containing tap water. Herbicides were applied (post-emergence application) in optimum soil moisture conditions at almost 2-3 leaf growth stage of weeds. A hand operated Knapsack sprayer fitted with flat fan nozzle was used for the application of herbicide during both years of study. Weed count was made at 3 and 4 weeks after treatment. Observations related to weed density, weeds dry weight, weed control efficiency, and NPK uptake by weeds, number of spike bearing tillers, number of grains per spike and grain yield were recorded by adopting the standard procedures, and the results were statistically analyzed by Tukey's HSD procedure at 5% level of probability (Montogomery, 2013). Weed control efficiency (WCE) was calculated as formula is given below:

$$WCE(\%) = \frac{WPc - WPt}{WPc} x\,100$$

where *WPc* is the weed population (No. m^{-2}) in un-weeded control (T_1) plot, *WPt* is the weed population (No. m^{-2}) in treated plot.

Percent increase in grain yield was calculated by using the following formula:

$$\textbf{Increase in Grain Yield (\%)} = \frac{grain\ yield\ in\ treated\ plots - grain\ yield\ in\ weed\ plot}{grain\ yield\ in\ treated\ plots} x\,100$$

RESULTS AND DISCUSSION

Major weed flora observed in the experimental plots during the two seasons included *P. minor, C. arvensis,* and *C. didymus*. Different herbicidal treatments exerted a significant effect on weed density, weed dry matter, yield and yield contributing parameters of wheat.

Effect on total weed density at 3 WAT (Weeks after treatment) and 4 WAT: Fatty alcohol ethoxylate at 200 mL ha^{-1}, as an adjuvant significantly increased the activity of mesosulfuron methyl + iodosulfuron methyl at 10.6 g a.i. ha^{-1} and resulted in lowest weed density (9.33, 13.33 and 14.33, 9.33) and maximum weed control efficiency (95.46, 93.13% and 94.98, 94.83%) as compared to all other treatments during both years. It was followed by reduced dose of sulfosulfuron at 18.75 g a.i. ha^{-1} combined with fatty alcohol ethoxylate at 200 mL ha^{-1} (Table 1). Label recommended doses of both herbicides rendered statistically similar results to each other regarding weed control during both years and showed less weed control as compared to their reduced doses with fatty alcohol ethoxylate at 200 mL ha^{-1} and alkyl ether sulphate sodium salt at 400 mL ha^{-1}. However, significantly lower weed density was found compared to the remaining treatments. Application of herbicides at reduced rates in combination with both (2% and 3%) concentrations of AMS showed poor performance and minimum weed control efficiency (< 70%) compared to herbicides at recommended dose or reduced dose with other adjuvants during both years (Table 1).

Table 1 - Total weed density (m^{-2}) and weed control efficiency (%) at 3 WAT and 4 WAT with different herbicide treatments in wheat

Treatment	Dose (g a.i. ha^{-1})	Adjuvant	3 WAT		4 WAT	
			2014	2015	2014	2015
Untreated control	-	-	168.67	148.00	173.33	156.00
Sulfosulfuron	25.00	-	36.33 (78.46)	37.67 (73.66)	43.67 (74.21)	40.00 (72.60)
Sulfosulfuron	18.75	AMS 2%	70.00 (58.49)	67.67 (52.68)	73.67 (56.49)	70.00 (52.05)
Sulfosulfuron	18.75	AMS 3%	57.00 (66.20)	58.00 (59.44)	62.67 (62.99)	61.00 (58.22)
Sulfosulfuron	18.75	Fatty alcohol ethoxylate at 200 mL ha^{-1}	16.00 (94.51)	20.67 (91.54)	16.33 (91.35)	15.67 (92.27)
Sulfosulfuron	18.75	Alkyl ether sulphate Na salt at 400 mL ha^{-1}	24.00 (85.77)	28.33 (80.19)	33.67 (80.12)	31.33 (78.54)
Sulfosulfuron	18.75	Rapsoel methyl eser at 400 mL ha^{-1}	45.67 (72.92)	47.00 (67.13)	52.33 (69.09)	49.67 (65.98)
Mesosulfuron methyl + iodosulfuron methyl	14.2	-	33.67 (80.03)	35.00 (75.52)	41.33 (75.59)	37.67 (74.19)
Mesosulfuron methyl + iodosulfuron methyl	11.6	AMS 2%	61.33 (63.63)	62.33 (56.41)	67.67 (60.03)	65.33 (55.25)
Mesosulfuron methyl + iodosulfuron methyl	11.6	AMS 3%	51.00 (69.67)	54.33 (64.33)	58.00 (65.75)	56.33 (64.33)
Mesosulfuron methyl + iodosulfuron methyl	11.6	Fatty alcohol ethoxylate at 200 mL ha^{-1}	9.33 (95.46)	14.33 (94.98)	13.33 (93.13)	9.33 (94.83)
Mesosulfuron methyl + iodosulfuron methyl	11.6	Alkyl ether sulphate Na salt at 400 mL ha^{-1}	22.00 (86.95)	27.00 (81.12)	31.33 (81.50)	30.00 (79.45)
Mesosulfuron methyl + iodosulfuron methyl	11.6	Rapsoel methyl eser at 400 mL ha^{-1}	42.33 (74.90)	44.00 (69.23)	49.33 (70.87)	47.00 (67.81)
HSD ≤ 0.05			7.62	3.55	7.73	5.98

Contrast	3 WAT		4 WAT	
	2014	2015	2014	2015
Weedy check versus all treatments	168.67 vs 39.05**	143.00 vs 41.36**	169.33 vs 45.69**	146.00 vs 44.10**
Herbicides with adjuvants vs herbicides without adjuvants	39.86 vs 35**	42.36 vs 36.34**	46.33 vs 42.50**	45.17 vs 38.84**
Herbicides with chemical adjuvants vs herbicides with AMS	26.55 vs 59.83**	30.22 vs 60.58**	35.55 vs 65.50**	33.16 vs 63.16**

Figures in parenthesis are WCE in percentage.

Contrast comparisons (Table 1) showed that during both years, herbicides with adjuvants resulted in less weed control at 3 WAT and 4 WAT than herbicides without adjuvants. Similarly, herbicides with chemical adjuvants including fatty alcohol ethoxylate, alkyl ether sulphate Na salt and rapsoel methyl eser showed better weed control over AMS (2% and 3%) combined herbicide treatments during both years. Lower number of weeds in herbicide treated plots as compared to unweeded control might be due to a phytotoxic effect of herbicides or herbicide + adjuvant combinations towards weeds. This finding agrees with the results of Zand et al. (2007) who depicted that sulfosulfurons' effectiveness can be augmented against weeds of wheat by the addition of an appropriate adjuvant. These results are further supported by Tagour et al. (2011), who investigated that application of clodinafop-propargyl or pinoxadin + clodinafop + safener either alone at recommended dose or at lower dose in combination with 4% and 8% adjuvant nonyl phenol polyglycol ether resulted in significant decrease in weed density (m^{-2}) over weedy check.

Effect on individual weed density at 3 WAT and 4 WAT: The perusal of data in Table 2 indicated the dominance of *P. minor* among three major weed species observed during the two seasons of experimentation. Weed density (m^2) of individual weeds recorded under weedy check at 3 WAT and 4 WAT was *P. minor* (65.33, 63.00 and 56.67, 60.67), *C. arvensis* (38.66, 48.33 and 39.00, 47.00) and *C. dydimus* (60.33, 61.66 and 51.66, 49.66). Mesosulfuron methyl + iodosulfuron methyl applied at reduced rate at 10.6 g a.i. ha^{-1} with fatty alcohol ethoxylate at 200 mL ha^{-1} showed maximum weed control and weed control efficiency for all of the observed weeds; *P. minor* (96.43,

Table 2 **-** Individual weed density (m^{-2}) and weed control efficiency (%) at 3 and 4 WAT with different herbicide treatments in wheat

Treatment	Dose ($g\ a.i.\ ha^{-1}$)	Adjuvant	*P. minor* at 3 WAT		*P. minor* at 4 WAT		*C. arvensis* at 3 WAT		*C. arvensis* at 4 WAT		*C. dydimus* at 3 WAT		*C. dydimus* at 4 WAT	
			2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Untreated control	-	-	65.33	56.67	63.00	60.67	38.66	39.00	48.33	47.00	60.33	51.66	61.66	49.66
Sulfosulfuron	25.00	-	15.00 (77.03)	17.00 (74.50)	15.33 (76.77)	15.33 (78.30)	7.66 (80.18)	8.00 (79.48)	8.66 (82.08)	8.66 (81.57)	12.00 (80.10)	9.00 (82.58)	10.33 (83.25)	8.33 (84.48)
Sulfosulfuron	18.75	AMS 2%	35.00 (49.42)	35.00 (48.50)	29.33 (55.56)	27.67 (60.84)	11.00 (71.54)	10.33 (73.51)	15.00 (68.96)	14.00 (70.21)	30.66 (51.17)	24.33 (52.90)	26.66 (56.76)	22.33 (58.39)
Sulfosulfuron	18.75	AMS 3%	29.33 (55.10)	29.00 (56.50)	27.00 (59.09)	27.67 (60.84)	9.33 (75.86)	9.33 (76.07)	10.33 (78.62)	10.00 (78.72)	27.33 (54.70)	21.00 (59.33)	23.33 (62.17)	19.00 (64.59)
Sulfosulfuron	18.75	Fatty alcohol ethoxylate at 200 mL ha^{-1}	4.00 (93.87)	5.67 (92.51)	3.66 (94.44)	3.66 (94.81)	3.33 (92.38)	2.67 (93.15)	1.66 (96.56)	3.67 (92.19)	3.33 (94.48)	3.33 (93.55)	1.66 (97.31)	3.33 (93.97)
Sulfosulfuron	18.75	Alkyl ether sulphate Na salt at 400 mL ha^{-1}	13.00 (80.10)	11.00 (83.50)	9.33 (85.86)	9.00 (87.26)	6.66 (82.74)	6.67 (82.89)	7.33 (84.83)	7.66 (83.70)	9.00 (85.08)	5.66 (89.04)	7.00 (88.65)	6.00 (88.82)
Sulfosulfuron	18.75	Rapsoel methyl eser at 400 mL ha^{-1}	23.33 (64.28)	24.00 (64.00)	19.66 (70.21)	18.67 (73.58)	8.66 (77.59)	8.67 (77.76)	9.66 (80.01)	9.67 (79.42)	21.33 (64.64)	16.00 (69.03)	17.33 (71.89)	14.00 (73.91)
Mesosulfuron methyl + iodosulfuron methyl	14.2	-	16.33 (75.00)	15.66 (76.51)	14.00 (78.78)	13.00 (81.61)	7.33 (81.03)	7.67 (80.33)	8.66 (82.08)	8.33 (82.27)	12.00 (80.11)	7.00 (86.45)	10.00 (83.78)	6.33 (88.20)
Mesosulfuron methyl + iodosulfuron methyl	11.6	AMS 2%	32.33 (50.51)	31.99 (52.01)	30.66 (53.54)	29.33 (58.50)	9.33 (75.86)	9.67 (75.20)	13.33 (72.41)	11.67 (75.17)	28.33 (53.04)	22.00 (57.41)	24.33 (60.54)	20.00 (62.73)
Mesosulfuron methyl + iodosulfuron methyl	11.6	AMS 3%	26.67 (59.17)	27.00 (60.52)	26.00 (60.61)	25.67 (63.67)	9.33 (75.86)	9.33 (76.07)	10.00 (79.30)	10.33 (78.02)	24.66 (59.12)	19.00 (63.22)	20.66 (66.49)	17.00 (68.32)
Mesosulfuron methyl + iodosulfuron methyl	11.6	Fatty alcohol ethoxylate at 200 mL ha^{-1}	2.33 (96.43)	4.33 (94.50)	1.67 (97.46)	1.33 (98.11)	2.00 (94.82)	1.67 (95.17)	1.33 (97.24)	1.33 (97.17)	1.66 (97.25)	2.00 (96.13)	1.33 (97.84)	2.33 (95.66)
Mesosulfuron methyl + iodosulfuron methyl	11.6	Alkyl ether sulphate Na salt at 400 mL ha^{-1}	11.67 (82.12)	10.66 (84.01)	6.67 (89.89)	7.33 (89.62)	6.33 (83.62)	5.33 (86.33)	7.66 (84.15)	7.33 (84.49)	7.66 (87.30)	4.66 (90.98)	5.66 (90.82)	6.66 (87.59)
Mesosulfuron methyl + iodosulfuron methyl	11.6	Rapsoel methyl eser at 400 mL ha^{-1}	23.00 (64.79)	22.00 (67.00)	20.00 (69.68)	19.00 (73.11)	8.00 (79.30)	8.33 (78.64)	9.33 (80.69)	9.00 (80.85)	21.00 (65.19)	14.00 (72.90)	17.00 (72.43)	12.00 (77.64)
HSD ≤ 0.05			6.49	6.59	4.42	4.81	3.81	4.92	5.04	4.60	7.16	6.97	6.73	6.73

Contrast	*P. minor* at 3 WAT		*P. minor* at 4 WAT		*C. arvensis* at 3 WAT		*C. arvensis* at 4 WAT		*C. dydimus* at 3 WAT		*C. dydimus* at 4 WAT	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Weedy check versus all treatments	65.33 vs 19.33**	66.67 vs 10.43**	66.00 vs 15.94**	70.67 vs 16.94**	38.66 vs 7.52 **	39 vs 7.30**	48.33 vs 8.57**	47 vs 8.47**	60.33 vs 16.58**	51.66 vs 12.33**	61.66 vs 13.77**	53.66 vs 11.44**
Herbicides with adjuvants vs herbicides without adjuvants	20.06 vs 15.66**	20.07 vs 16.33**	17.40 vs 14.66**	16.93 vs 14.17**	7.53 vs 7.94**	7.20 vs 7.83**	8.56 vs 8.66NS	8.46 vs 8.49NS	17.50 vs 12.00**	13.20 vs 08.00**	14.50 vs 10.17**	12.27 vs 07.33**
Herbicides with chemical adjuvants vs herbicides with AMS	12.88 vs 30.83**	12.94 vs 30.74**	12.42 vs 28.25**	09.83 vs 27.59**	6.05 vs 9.75**	5.56 vs 9.66**	6.16 vs 12.16	6.44 vs 11.50	10.66 vs 27.74**	07.60 vs 21.58**	08.33 vs 23.75	07.38 vs 19.59**

Figures in parenthesis are WCE in percentage.

94.50% and 97.46, 98.11%), *C. arvensis* (94.82, 95.17% and 97.24, 97.17%) and *C. dydimus* (97.25, 96.13% and 97.84, 95.66%) at 3 WAT and 4 WAT, respectively during both years of study. Application of herbicides at their reduced doses with AMS (2% and 3%) showed minimum weed control compared to herbicide + adjuvant combinations during both years of study.

Contrast comparison between herbicides without adjuvants versus herbicides with adjuvants indicated that both herbicides applied alone at recommended dose rendered significantly better weed control as compared to herbicides at lower dose in combination with adjuvants. Herbicides at lower doses with chemical adjuvants showed significantly better weed control over herbicides with AMS as an adjuvant during both years of study. These results are similar to the findings of Stevan et al. (2010), who reported that the weed control efficacy of saflufenacil towards many weeds such as field bindweed (*C. arvensis*), common henbit (*Lamium amplexicaule*), prickly lettuce (*Lactuca serriola*) and dandelion (*Taraxacum officinale*) was improved over its single application when applied tank mixed with different adjuvants. These results are well supported by those of Knezevic et al. (2009) who indicated that adjuvants increased the phytotoxicity of herbicides and reduced the density of *C. arvensis* > 90% in wheat. These results are also conform those of

Wozinca et al. (2001) and Singh et al. (2016) who claimed that sulfosulfurons' effectiveness can be augmented against weeds of wheat by the addition of an appropriate adjuvant.

Effect on weed dry weight: Mesosulfuron methyl + iodosulfuron methyl at reduced rate at 10.6 g a.i. ha^{-1} in combination with fatty alcohol ethoxylate at 200 mL ha^{-1} during each year of study resulted in minimum weeds dry weight (1.41, 0.93 g m^{-2}) followed by that of sulfosulfuron at reduced rate at 18.75 g a.i. ha^{-1} with same adjuvant (1.61, 1.12 g m^{-2}) (Table 3). Mesosulfuron methyl + iodosulfuron at reduced rate at 10.6 g a.i. ha^{-1} with alkyl ether sulphate sodium salt at 400 mL ha^{-1} showed weeds dry weight statistically at par with that of reduced dose of sulfosulfuron at 18.75 g a.i. ha^{-1} applied with same adjuvant (Table 3). Sulfosulfuron at reduced rate at 18.75 g a.i. ha^{-1} with rapsoel methyl eser at 400 mL ha^{-1} showed significantly higher weeds dry weight (8.81, 7.66 g m^{-2}) over mesosulfuron methyl + iodosulfuron applied at reduced rate at 10.6 g a.i. ha^{-1} with same adjuvant (6.43, 5.54 g m^{-2}) during both years. Application of herbicides at reduced rates with AMS (2% and 3%) showed meagre performance during both years, as herbicides at reduced rate with 2% AMS caused < 66% reduction and herbicides at reduced rate with 3% AMS caused < 76% reduction in weeds dry weight (g m^{-2}) over unweeded control (Table 3).

Contrast comparisons showed that during both years herbicides applied at recommended rates without any adjuvant significantly lessened weeds dry weight (5.04, 4.13 g m^{-2}) as compared to herbicides at lessened rates with adjuvants (7.23, 6.39 g m^{-2}). Similarly, application of herbicides at lessened rates with chemical adjuvants caused a significant reduction in weeds dry weight (4.20, 3.47 g m^{-2}) as compared to herbicides at the lower rate with AMS (11.78, 10.76 g m^{-2}). These results are in agreement with the findings of Chopra et al., (2001) and Yadav et al. (2001). They reported the significant reduction in dry weight of weeds in herbicide treated plots over the weedy check.

Effect on NPK uptake (kg ha^{-1}) by weeds: Mesosulfuron methyl + iodosulfuron methyl at reduced dose at 10.6 g a.i. ha^{-1} in combination with fatty alcohol ethoxylate at 200 mL ha^{-1} resulted in minimum NPK uptake by weeds during both years (0.90, 0.60, 0.27 and 0.41, 0.20, 0.13 kg ha^{-1}). Statistically similar NPK uptake by weeds was recorded with the reduced dose of sulfosulfuron at 18.75 g a.i. ha^{-1} combined applied with fatty alcohol ethoxylate at 200 mL ha^{-1} during both years of study. Maximum NPK uptake (40.70, 39.70, 28.53 and 40.00, 39.07, 38.70 kg ha^{-1}) was observed in weedy check plots during both years (Table 3).

Contrast comparisons showed that herbicides applied alone at their recommended rate significantly decreased NPK uptake by weeds as compared to herbicides at th lower rate with adjuvants (Table 3). Similarly, herbicides applied at the lower rate with chemical adjuvants resulted in lower NPK uptake by weeds as compared to herbicides with AMS (2% and 3%). NPK uptake by weeds in wheat was increased in weedy check and reduced under weed control strategies (Kanojia and Nepalia, 2006). Verma et al. (2015) also publicized that herbicide application significantly increased nutrients (NPK) uptake by wheat rather than disbursed by weeds, as the case was with unweeded control plots.

Effect on yield components of wheat: During both years, application of mesosulfuron methyl + iodosulfuron methyl at lower rate at 10.6 a.i. ha^{-1} in combination with fatty alcohol ethoxylate at 200 mL ha^{-1} resulted in a maximum number of spike bearing tillers (370.33, 375.00 m^{-2}), the number of grains per spike (48.36, 50.46) and 1,000 grain weight (43.16, 44.89 g). This was followed by that of sulfosulfuron at the lower dose at 18.75 g a.i. ha^{-1} with same adjuvant (Table 4). Minimum number of spike bearing tillers (262.00, 265.33 m^{-2}), the number of grains per spike (34.60, 35.94) and 1,000 grain weight (32.06, 32.87 g) were recorded in unweeded control plots during both years (Table 4).

Contrast comparison showed that herbicides applied alone at recommended dose didn't result in any significant difference of different yield components of wheat over herbicides applied at lower dose with various adjuvants in both years of trialing. However, herbicides applied at a lower rate with chemical adjuvants resulted in a significantly higher number of spike bearing tillers, number of grains per spike, and 1,000 grain weight as compared to herbicides with AMS as an adjuvant (Table 4). The overall improvement in different yield components in plots where herbicides were applied may be due to no weed-crop competition for various agro-environmental

Table 3 - Effect of different herbicide treatments on weeds dry weight (g), percent reduction in dry weight of weeds and NPK uptake (kg ha^{-1}) by weeds

Treatment	Dose (g a.i. ha^{-1})	Adjuvant	Weeds dry weight		N		P		K	
			2014	2015	2014	2015	2014	2015	2014	2015
Untreated control	-	-	37.83	33.25	40.70	40.00	39.70	39.07	28.53	38.70
Sulfosulfuron	25.00	-	5.43 (85.64)	4.52 (86.40)	6.30	3.80	5.30	3.20	5.00	2.50
Sulfosulfuron	18.75	AMS 2%	14.36 (62.04)	13.52 (59.32)	18.80	14.70	17.80	14.20	3.20	6.80
Sulfosulfuron	18.75	AMS 3%	10.76 (71.55)	9.63 (71.04)	14.20	18.10	13.20	17.47	12.90	12.20
Sulfosulfuron	18.75	Fatty alcohol ethoxylate at 200 mL ha^{-1}	1.61 (95.74)	1.12 (96.64)	1.10	0.47	0.90	0.63	0.30	0.21
Sulfosulfuron	18.75	Alkyl ether sulphate Na salt at 400 mL ha^{-1}	4.16 (89.00)	3.21 (90.33)	3.70	8.40	2.70	7.80	2.40	1.70
Sulfosulfuron	18.75	Rapsoel methyl eser at 400 mL ha^{-1}	8.81 (76.71)	7.66 (76.95)	9.10	3.00	8.10	1.23	6.10	7.10
Mesosulfuron methyl + iodosulfuron methyl	14.2	-	4.65 (87.70)	3.74 (88.75)	4.50	5.60	3.50	5.03	7.50	4.30
Mesosulfuron methyl + iodosulfuron methyl	11.6	AMS 2%	13.10 (65.37)	11.96 (64.00)	15.40	10.20	14.40	12.90	14.10	13.40
Mesosulfuron methyl + iodosulfuron methyl	11.6	AMS 3%	8.90 (76.47)	7.95 (76.09)	10.90	18.10	9.90	9.60	9.60	8.90
Mesosulfuron methyl + iodosulfuron methyl	11.6	Fatty alcohol ethoxylate at 200 mL ha^{-1}	1.41 (96.28)	0.93 (97.20)	0.90	0.20	0.60	0.41	0.27	0.13
Mesosulfuron methyl + iodosulfuron methyl	11.6	Alkyl ether sulphate Na salt at 400 mL ha^{-1}	2.79 (92.62)	2.35 (92.92)	2.00	6.70	1.50	2.40	1.27	1.47
Mesosulfuron methyl + iodosulfuron methyl	11.6	Rapsoel methyl eser at 400 mL ha^{-1}	6.43 (83.00)	5.54 (83.33)	7.40	1.30	6.90	6.60	7.80	5.40
HSD ≤ 0.05			2.21	1.87	4.29	4.18	4.19	2.27	3.96	4.17

Contrast	Weeds dry weight		N		P		K	
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
Weedy check versus all tretments	37.83 vs 06.83**	33.25 vs 06.02**	39.7 vs 3.07**	39.1 vs 0.66**	35.70 vs 7.86**	34.00 vs 7.54**	28.53 v s 6.70**	32.70 vs 6.09**
Herbicides with adjuvants vs herbicides without adjuvants	07.23 vs 5.04**	06.39 vs 04.13**	0.76 vs 0.44**	0.73 vs 0.41**	8.35 vs 5.40**	8.11 vs 4.70**	5.79 vs 1.25**	6.63 vs 3.40**
Herbicides with chemical adjuvants vs herbicids with AMS	04.20 vs 11.78**	04.47 vs 10.76**	1.38 vs 3.45**	0.17 vs 1.35**	1.48 vs 4.03**	0.33 vs 1.52**	0.99 vs 3.02**	0.25 vs 1.28**

Figures in parenthesis are percentage reduction in weed dry weight over weedy check.

resources, which ultimately assured better plant growth. These findings agree with the results of Mitiku and Dalga (2014), who have investigated the performance of different herbicides and concluded that all the herbicide treatments caused an increase in plant height over the untreated weedy-check. These results are also in close agreement with the earlier findings of Tanveer et al. (2010) who reported that the number of grains per spike was increased due to less weed-crop competition and more availability of resources to crop plants in herbicide treated plots over weedy check plot.

Effect on grain yield: Maximum grain yield (5350.7, 5391.3 kg ha^{-1}) was recorded in plots being treated with mesosulfuron methyl + iodosulfuron methyl at reduced rate at 10.6 g a.i. ha^{-1} in combination with fatty alcohol ethoxylate at 200 mL ha^{-1} as an adjuvant and minimum grain yield (3050.3, 3059.7 kg ha^{-1}) was recorded in unweeded control plots during both years of study (Table 4). Sulfosulfuron at reduced rate at 18.75 g a.i. ha^{-1} with adjuvant fatty alcohol ethoxylate at 200 mL ha^{-1} resulted in grain yield (5164.7, 5311.0 kg ha^{-1}) statistically similar to that of

Table 4 - Effect of different herbicide treatments on number of spike bearing tillers (m^{-2}), number of grains per spike, 1000 grain weight (g), grain yield (kg ha^{-1}), percentage increase in grain yield over weedy check and benefit cost ratio (%)

Treatment	Dose (g a.i. ha^{-1})	Adjuvant	Spike bearing tillers		No. of grains $spike^{-1}$		1000 grain weight		Grain yield		BCR	
			2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Untreated control	-	-	262.00	265.33	34.60	35.94	32.06	32.87	3050.3	3059.7	1.30	1.31
Sulfosulfuron	25.00	-	335.67	336.33	42.31	43.65	38.61	39.71	4514.3 (32.43)	4634.3 (33.98)	1.75	1.78
Sulfosulfuron	18.75	AMS 2%	307.33	310.33	37.30	38.64	34.20	35.30	3448.0 (11.53)	3748.3 (18.37)	1.49	1.55
Sulfosulfuron	18.75	AMS 3%	300.33	304.33	38.00	39.45	35.59	35.36	3862.7 (21.03)	3902.7 (21.60)	1.59	1.61
Sulfosulfuron	18.75	Fatty alcohol ethoxylate at 200 mL ha^{-1}	367.00	368.67	47.37	49.07	41.59	42.69	5164.7 (40.94)	5311.0 (42.39)	1.90	1.94
Sulfosulfuron	18.75	Alkyl ether sulphate Na salt at 400 mL ha^{-1}	348.67	355.33	44.57	45.91	40.10	41.20	4825.0 (36.78)	4924.7 (37.87)	1.82	1.85
Sulfosulfuron	18.75	Rapsoel methyl eser at 400 mL ha^{-1}	318.33	321.33	39.47	40.81	37.12	38.70	4214.0 (27.62)	4349.3 (29.65)	1.67	1.71
Mesosulfuron methyl + iodosulfuron methyl	14.2	-	336.33	347.67	43.16	44.50	39.12	40.22	4610.0 (33.83)	4811.0 (36.40)	1.75	1.81
Mesosulfuron methyl + iodosulfuron methyl	11.6	AMS 2%	311.00	314.00	37.64	38.98	34.26	36.69	3647.0 (16.37)	3835.0 (20.21)	1.52	1.56
Mesosulfuron methyl + iodosulfuron methyl	11.6	AMS 3%	305.33	308.00	38.28	39.62	36.11	37.21	4056.3 (24.80)	4125.3 (25.83)	1.62	1.64
Mesosulfuron methyl + iodosulfuron methyl	11.6	Fatty alcohol ethoxylate at 200 mL ha^{-1}	370.33	375.00	48.36	50.50	43.16	44.89	5350.7 (42.99)	5391.3 (43.25)	1.94	1.97
Mesosulfuron methyl + iodosulfuron methyl	11.6	Alkyl ether sulphate Na salt at 400 mL ha^{-1}	351.33	360.67	45.50	47.64	40.61	41.71	4944.0 (38.30)	5035.3 (39.24)	1.84	1.87
Mesosulfuron methyl + iodosulfuron methyl	11.6	Rapsoel methyl eser at 400 mL ha^{-1}	326.33	326.00	40.68	42.00	37.60	38.22	4366.3 (30.13)	4404.3 (30.53)	1.70	1.72
HSD ≤ 0.05			47.83	37.40	3.65	4.30	3.73	3.56	385.12	325.70	-	-

Contrast	Spike bearing tillers		No. of grains $spike^{-1}$		1000 grain weight		Grain yield	
	2014	2015	2014	2015	2014	2015	2014	2015
Weedy check versus all tretments	262.00 vs 331.46^{**}	265.33 vs 335.65^{**}	34.60 vs 41.90^{**}	35.94 vs 43.40^{**}	30.06 vs 38.17^{**}	32.87 vs 39.32^{**}	3053.3 vs 4416.9^{**}	3059.3 vs 4539.4^{**}
Herbicides with adjuvants vs herbicides without adjuvants	330.60 vs 336.00^{NS}	334.45 vs 342.00^{NS}	41.74 vs 42.73^{NS}	43.26 vs 44.07^{NS}	38.03 vs 38.86^{NS}	39.19 vs 39.97^{NS}	4387.9 vs 4562^{NS}	4502.7 vs 4722.6^{*}
Herbicides with chemical adjuvants vs herbicids with AMS	346.99 vs 305.99^{**}	351.16 vs 309.17^{**}	44.34 vs 37.83^{**}	45.99 vs 39.17^{**}	40.03 vs 35.04^{**}	38.20 vs 36.14^{**}	4810.8 vs 3753.6^{**}	4902.6 vs 3902.8^{**}

Figures in parenthesis are percentage increase in wheat grain yield over weedy check.

mesosulfuron methyl + iodosulfuron methyl applied at reduced rate at 10.6 g a.i. ha^{-1} with fatty alcohol ethoxylate at 200 mL ha^{-1} in both years. During each year, both (2% and 3%) concentrations of AMS with reduced dose of herbicides showed less grain yield than either single application of both herbicides at recommended dose or at reduced dose with remaining adjuvants (fatty alcohol ethoxylate at 200 mL ha^{-1}, alkyl ether sulphate sodium salt at 400 mL ha^{-1} and rapsoel methyl eser at 400 mL ha^{-1}) but produced significantly higher grain yield (3448.0, 3862.7 and 3748.3, 3902.7) over unweeded control (3050.3, 3059.7).

Contrast comparisons showed that herbicides with adjuvants resulted in significantly less grain yield (4502.7 kg ha^{-1}) than that of herbicides without adjuvants (4722.6 kg ha^{-1}) during 2015-16. While during 2014-15 contrast between herbicides with adjuvants against herbicides without adjuvants was non-significant. However, herbicides applied at a lower rate with chemical adjuvants resulted in significantly higher grain yield as compared to herbicides with AMS as an adjuvant, during both years of study. The increase in grain yield in herbicides treated plots might be due to weeds growth suppression which leads to a reduction in resource share with wheat crop. Those plots treated with herbicides, and especially herbicides with adjuvant, have significantly reduced weed population and enhanced grain yield components, such as spike bearing tillers, number of grains per spike, and 1000 grain weight, which ultimately increased wheat grain yield. Similar to these, the findings of Tiwari et al. (2011) revealed that herbicide application increased the grain yield of wheat over unweeded control. Hashim et al. (2002) and Kleemann et al. (2016) also reported analogous findings to these results. They reported that herbicidal treatments significantly increased the grain yield of wheat.

Effect on benefit-cost ratio: During both years of experimentation, mesosulfuron methyl + iodosulfuron methyl applied at reduced rate at 10.6 g a.i. ha^{-1} in a blend with adjuvant fatty alcohol ethoxylate at 200 mL ha^{-1} was the most cost-effective treatment, which led to maximum benefit-cost ratio. It was followed by that of sulfosulfuron applied at reduced rate at 18.75 g a.i. ha^{-1} with fatty alcohol ethoxylate at 200 mL ha^{-1} (Table 4).

From this present study, we may come to the conclusion that, among the assessed adjuvants, fatty alcohol ethoxylate (200 mL ha^{-1}) showed strong adjuvant properties for both herbicides at their reduced rates, sulfosulfuron (18.75 g a.i. ha^{-1}) and mesosulfuron methyl + iodosulfuron methyl (10.6 g a.i. ha^{-1}) against narrow-leaved (*P. minor*) and broad-leaved (*C. arvensis, C. didymus*) weeds of wheat. Therefore, this sets a trend that, without compromising their efficacy, herbicide doses can be reduced by adding appropriate adjuvants.

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