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Optimizing the surfactant dose for sulfosulfuron and ready mix combination of sulfosulfuron and carfentrazone against weeds in wheat

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ABSTRACT

Field and pot studies were conducted to determine the efficacy of sulfosulfuron and ready mixture, sulfosulfuron + carfentrazone- 45 (25+20) WDG at different surfactant doses against complex weed flora of wheat. The weed control, particularly the grass was significantly poor, when sulfosulfuron or its ready mix combination with carfentrazone was applied without surfactant compared with surfactant. The grass (*Avena ludoviciana, Echinochoa crusgalli, Phalaris minor* and *Polypogon monspeliensis*) weed control with sulfosulfuron or ready mixture (RM) of sulfosulfuron + carfentrazone- 45 WDG was similar at surfactant doses of 625, 750 and 1250 ml/ha indicating the possibility of reducing the surfactant doses by 40-50% from the present recommendation of 1250 ml/ha in India. The optimum dose of RM, sulfosulfuron + carfentrazone was 45 (25+20) g/ha with 625-750 ml/ha surfactant. This combination was superior over sulfosulfuron, due to the control of *Rumex dentatus,* thereby increased the wheat yield by 7.6% on an overall mean basis. The RM, sulfosulfuron + carfentrazone with surfactant was similar to ready mixtures, Total (sulfosulfuron 75 + metsulfuron 5)-80 WDG at 32 (30+2) g/ha and Atlantis (mesosulfuron + iodosulfuron) at 14.4 (12+ 2.4) g/ha in controlling weeds and producing wheat yield. The carry over effect of sulfosulfuron involving treatments (sulfosulfuron, sulfosulfuron + metsulfuron, sulfosulfuron + carfentrazone) was observed on succeeding maize (*Zea mays* L.) crop. At 2X dose of sulfosulfuron + carfentrazone (50+40 g/ha), the reduction in maize biomass was 62.6-73.0% in comparison to weed free check.

Key words: Ready mixture, herbicide carryover effect, Herbicide efficacy, *Polypogon monspeliensis*

Chemical weed control is a preferred practice in wheat due to scarce and costly labour as well as lesser feasibility of manual weeding in broadcast sown wheat. Wheat is generally infested by both grassy as well as broad-leaved weeds (Singh *et al*. 1995). For the management of grass weeds like Wild oat (*Avena ludoviciana* Dur.), rabbitfoot grass/beard grass {*Polypogon monspeliensis* (L.) Desf.}and isoproturon resistant littleseed canarygrass (*Phalaris minor* Retz.) in northern Indian plains, three herbicides namely clodinafop, fenoxaprop and sulfosulfuron are being used (Chhokar and Malik 2002, Chhokar *et al*. 2008). Among these, clodinafop and fenoxaprop only control the grass weeds but sulfosulfuron controls many broad-leaved weeds also (Chhokar and Malik 2002). However, sulfosulfuron is not effective against some of the broad-leaved weeds like toothed dock (*Rumex dentatus* L.*),* little mallow (*Malva parviflora* L.*),* field bind weed (*Convolvulus arvensis* L.)*,* and black night shade *(Solanum nigrum* L.). Carfentrazone ethyl effectively controls these weeds but is not effective against grassy weeds (Chhokar *et al.* 2007a). Therefore, to control broad-spectrum weed flora, combinations of herbicides are required (Chhokar *et al*. 2007b, Singh *et al.* 2008, Singh *et al*. 2011). To save application cost and time, tank mix combinations are preferred by growers compared to sequential application but pre-requisite for pre-mix combination is their compatibility. Tank mix combinations of grass herbicides (clodinafop or fenoxaprop) with broad-leaved herbicides (2, 4-D or metsulfuron) are not compatible (Mathiassen and Kudsk 1998). However, carfentrazone shows good compatibility (Howatt 2005) with grass herbicides (fenoxaprop, tralkoxydim and clodinafop) compared to 2, 4-D and metsulfuron and other BLW herbicides (Singh 2009, Singh *et al.* 2008b, Singh *et al.* 2011) besides providing the control of some problematic weeds like *Malva parviflora* (Chhokar *et al*., 2007a). Carfentrazone causes some leaf injury in wheat and sulfonylurea herbicides provide safening of carfentrazone injury (Howatt 2005). So, combination of carfentrazone and sulfosulfuron can be effective for broad-spectrum weed control with good crop safety.

Surfactants have been found to reduce the dose of herbicides and increase the spectrum of weed control with

increased efficiency (Malik *et al.* 1988). Many workers (Chhokar *et al*. 2010, Green and Green 1993, Singh *et al*. 2002, Singh *et al.* 2008, Walia *et al*. 2010) have reported improvement in the efficacy of sulfonylurea herbicides with surfactant. Cationic surfactant is being used with sulfosulfuron 1250 ml/ha for more than a decade in India (Balyan *et al*. 2000, Chhokar and Malik 2002, and Chhokar *et al*. 2010). The lower dose of surfactant has not been tried with sulfosulfuron. The possibility of reducing the surfactant dose for sulfosulfuron or its combination with other herbicides needs to be explored. Besides, improving the efficacy of herbicides, surfactant may also alter the crop tolerance (Chhokar *et al*. 2010).

In today's scenario, increasing population and declining land holding have compelled the farmers to adopt intensive cropping system. Therefore, it is essential to evaluate the effect of herbicide on the succeeding crops. Summer green gram (*Vigna radiata* L. Wilczek.) and maize (*Zea mays* L.) are two important short duration crops that immediately follow the wheat harvest.

Keeping in view these facts, field and pot studies were conducted with the aims (1) to determine the bio-efficacy of sulfosulfuron and ready-mix combination of sulfosulfuron 25% WDG + carfentrazone-ethyl 20% -45 WDG against grassy and broad-leaved weeds in wheat ; (2) to optimize the surfactant dose for sulfosulfuron and ready mixture of sulfosulfuron + carfentrazone and (3) to determine the residual effect of herbicides applied in wheat on the succeeding crops of maize and green gram.

MATERIALS AND METHODS

Two sets of field and four sets of pot experiments were conducted at Resource Management Block, Directorate of Wheat Research, Karnal, Haryana, India to determine the possibility of reducing the surfactant dose for sulfosulfuron alone and its RM with carfentrazone. The details of the studies done are given under following heads.

Field study 1: Effect of surfactant on the efficacy of sulfosulfuron and ready mixture of sulfosulfuron + carfentrazone in wheat

In this study (Table 1 and 2) sulfosulfuron (Leader 75 WDG) at 25 g/ha and ready mixture of sulfosulfuron + carfentrazone 45 (25+20) WDG at 45 g/ha were evaluated without and with surfactant (625 and 1250 ml/ha). The surfactant used was cationic surfactant (Leader Mix) and spraying was done using a spray solution of 350 l/ha with knapsack sprayer fitted with flat fan nozzles. The experiment was conducted for two consecutive *rabi* seasons of 2007-08 and 2008-09 in a randomized block design with each treatment replicated thrice. Wheat variety DBW 17 was sown at a row spacing of 20 cm using a seed rate of 100 kg/ha. The dry weight of dominant weeds was recorded at 120 DAS.

Field study 2: Comparative performance of ready mixtures of sulfosulfuron + carfentrazone, mesosulfuron + iodosulfuron (Atlantis) and sulfosulfuron + metsulfuron (Total)

The RM of sulfosulfuron + carfentrazone 45 (25+20) WDG was evaluated at 36, 45, 54 and 90 g/ha along with recommended doses of carfentrazone 20 g, sulfosulfuron 25 g, isoproturon 1000 g, Total (sulfosulfuron + metsulfuron) 32(30+2) g/ha and Atlantis (mesosulfuron + iodosulfuron) 14.4 (12+2.4) g/ha against weeds in wheat (Table 3). The RM sulfosulfuron + carfentrazone at doses of 45 and 90 g/ha were evaluated with and without surfactant. Cationic surfactant (Leader mix) was used with sulfosulfuron, sulfosulfuron + carfentrazone and Total. Anionic surfactant, Atlantis activator (Alkyl ether sulfate) at 625 ml/ha was used with Atlantis. Surfactant rates for ready mixture of sulfosulfuron + carfentrazone were 625, 750 and 1250 ml/ha. The experiment was conducted for two consecutive *rabi* seasons of 2008-09 and 2009-10. Wheat varieties, PBW 343 and DBW 17 were sown on 8th Nov. 2008 and 19th Nov 2009, during first and second year, respectively, using a seed rate of 100 kg/ha.

The major weeds infesting the experimental plots were *P. minor, A. ludoviciana*, lesser swine cress {*Coronopus didymus* (L.) Sm.}, *C. arvensis*, blue pimpernel (*Anagallis arvensis* L.), *R. dentatus,* yellow sweet clover (*Melilotus indica* All.) and toothed bur clover (*Medicago denticulata* Willd.). The experiment was laid out in randomized block design with each treatment replicated thrice.

The herbicides were sprayed at 34-37 DAS with knapsack sprayer fitted with flat fan nozzles using 350 l/ha water. Fertilizer and irrigation were applied according to recommended package of practice for wheat. Weed dry weight was taken at 120 DAS (Days after sowing) by placing a quadrat (0.25 m^2) randomly at two places in each plot. For recording weed dry weight, samples were first sun dried followed by oven drying at 65^{o}C till constant weight was achieved. The crop was harvested on 4th April in 2009 and 9th April in 2010.

To determine the herbicide residual effect, plots were irrigated after wheat harvest and green gram (cv SML 668) and maize (cv Sawarana during first year, African Tall during second year) were grown in the fixed plots under no- till conditions. The sowing of these crops was done on 12th April 2009 and 15th April 2010. The row to row spacing was 40 cm for green gram and 20 cm for

maize. Maize seeds were soaked overnight in water before seeding. Need based irrigation and fertilizer applications were done for these crops. Since, no visual phyto-toxicity was observed on green gram, so its biomass was not recorded. Maize biomass was recorded 40 and 43 DAS, during first and second year, respectively.

Pot Study 3: Response of four grassy weeds to sulfosulfuron and sulfosulfuron + carfentrazone at different surfactant doses

Pot experiments were also conducted to optimize the surfactant dose for sulfosulfuron (Leader 75 WDG) and ready mix combination of sulfosulfuron + carfentrazone (45% WDG). Four test weed species (*Echinochoa crus-galli* (L.) Beauv.*, P. minor, A. ludoviciana and Polypogon monspeliensis*) were evaluated against two sets of herbicide treatments, one with graded doses of sulfosulfuron and other with graded doses of ready mix combination of sulfosulfuron + carfentrazone 45 WDG (Table 6 and 7). The rates for sulfosulfuron were 6.25, 12.5, 25 g/ha and for RM of sulfosulfuron + carfentrazone 45 (25+20) WDG were 11.25, 22.5 and 45 g/ha. The ready mixture had same doses of sulfosulfuron as in sulfosulfuron alone *i.e*. 6.25, 12.5, 25 g/ha. The surfactant used was cationic (Leader mix) at doses of 0, 625 and 1250 ml/ha.

Each weed species with one herbicide treatments set was considered as separate experiment. Seeds of these species were grown in pots (4.5 kg soil capacity) filled with soil:FYM in ratio of 6:1 (v/v). Seeding depth for *E. crus-galli, P. minor* and *A. ludoviciana* was 2-2.5 cm, whereas *P. monspeliensis* was sown just near the surface. Finally 10-12 plants/pot were maintained except *P. monspeliensis* where 35 plants/pot were retained. At 3-4 leaf stage of *E. crus-galli, P. minor* and *A. ludoviciana* and tillering stage of *P. monspeliensis,* herbicides were sprayed using spray volume of 350 lit/ha with knapsack sprayer fitted with flat fan nozzles. Four week after herbicide spray, fresh weight of weed species was recorded and based on fresh weight of control pots, the % relative fresh weight under various treatments was calculated.

Each experiment was conducted 3 to 4 times with at least three replications in CRD and for statistical analysis experiment repetitions were considered as replicates. Data were subjected to analysis of variance and means separated by Fisher's protected LSD test at P = 0.05 level (Panse and Sukhatme, 1995).

RESULTS AND DISCUSSION

Study 1: Bio-efficacy of sulfosulfuron and sulfosulfuron + carfentrazone without and with surfactant

The control of grassy weeds (*P. minor* and *A. ludoviciana*) was significantly poor when sulfosulfuron and RM of sulfosulfuron + carfentrazone 45 WDG were applied without surfactant (Table 1 and 2). The addition of surfactant to sulfosulfuron and RM sulfosulfuron + carfentrazone reduced the weed dry weight by 33.4-86.8 and 75.8-88.0%, respectively, over without surfactant. The respective reductions for wild oat were 84.3-89.4 and 79.3-91.4%; and for *P. minor* ranged 80-97.9 and 74.0-92.8%. The improvement in herbicide efficacy with surfactant has been reported by many research workers (Chhokar *et al.* 2010, Malik *et al*. 1988, Singh *et al.* 2008 and Walia *et al*. 2010). However, the control of broad-leaved weeds (*R. dentatus* and *M. denticulata*) with RM of sulfosulfuron + carfentrazone was not affected by surfactant. The performance of sulfosulfuron alone or in combination with carfentrazone was not different at 625 compared to 1250 ml/ha rate of surfactant. The weed control and wheat productivity was better with ready mixture compared to sulfosulfuron alone. The magnitude of yield differences was more during the first year compared to second year due to higher *R. dentatus* infestation in the first year. The improvement in wheat grain yield and weed control has already been reported with herbicide combination (Chhokar *et al*. 2007b; Singh *et al*. 2008; Walia *et al*. 2010).

Study 2: Comparative performance of ready mixtures against complex weed flora in wheat

Sulfosulfuron and carfentrazone when applied alone failed to control the *Rumex dentatus* and grass weeds, respectively (Table 3 and 4). When both the herbicides were applied as ready-mix combination then broad-spectrum weed kill was achieved. The efficacy of ready-mix combination of sulfosulfuron + carfentrazone 45 WDG (Premix) @ 25 + 20 g/ha without external surfactant was significantly poor on grassy weeds (*P. minor* and *A. ludoviciana*) to application with cationic surfactant at 625 or 1250 ml/ha. No significant difference in the performance of sulfosulfuron or RM sulfosulfuron + carfentrazone was observed between surfactant doses of 625 and 1250 ml/ha. The dry weight of *P. minor* under application of ready mixture at 45 g/ha without surfactant was 67.6 and 170.3 g/m^2 and that of wild oat was 119.6 and 32.8 g/m^2 during first and second year, respectively. The dry matter accumulated by *P. minor* and *A. ludoviciana* in sulfosulfuron + carfentrazone mixture treatment at 45 g/ha

Table 1. Efficacy of sulfosulfuron and ready mixture of sulfosulfuron+carfentrazone-45 (25+20) WDG with and without surfactant against weeds in wheat (2007-08)

Treatments	Dose		Weed dry weight g/m^2						Wheat grain yield q/ha
	Herbicide g./ha	Surfactant ml/ha	*P. minor*	*A. ludoviciana*	*R. dentatus*	*M. denticulata*	Others	Total	
Sulfosulfuron	25	-	4.42(19.0)*	7.94(62.4)	9.45(88.6)	1.18(0.4)	2.49(6.9)	13.33(176.8)	49.2
Sulfosulfuron +S**	25	625	2.19(3.8)	2.83(7.2)	9.72(94.2)	1.00(0.0)	1.36(1.0)	10.33(106.2)	53.6
Sulfosulfuron + S	25	1250	1.18(0.4)	2.46(6.6)	10.41(109.8)	1.00(0.0)	1.35(0.9)	10.75(117.7)	54.7
Sulfosulfuron +carfentrazone	45 (25+20)	-	5.00(24.2)	7.35(53.7)	1.56(1.7)	1.00(0.0)	1.11(0.2)	8.95(79.9)	55.4
Sulfosulfuron +carfentrazone +S	45 (25+20)	625	2.55(6.3)	3.14(11.1)	1.64(1.8)	1.00(0.0)	1.05(0.1)	4.25(19.3)	59.1
Sulfosulfuron +carfentrazone +S	45 (25+20)	1250	2.02(3.2)	2.6(6.9)	1.54(1.5)	1.00(0.0)	1.00(0.0)	3.52(11.6)	59.2
Weedy Check	-	-	12.08(149.7)	11.08(123.1)	8.72(76.9)	9.88(107.7)	2.72(7.9)	18.9(357.6)	41.8
LSD (P= 0.05)			2.09	2.42	1.89	2.74	NS	2.57	3.25

* Original values given in parenthesis are square root transformed for statistical analysis **S= Cationic surfactant

Table 2. Efficacy of sulfosulfuron and ready mixture of sulfosulfuron+ carfentrazone-45 (25+20) WDG with and without surfactant against weeds in wheat (2008-09)

Treatments	Dose		Weed dry weight g/m^2				Wheat grain yield q/ha
	Herbicide g/ha	Surfactant ml/ha	*P. minor*	*A. ludoviciana*	*R. dentatus*	Total	
Sulfosulfuron	25	-	14.30(206.7)*	12.60(161.1)	3.60(12.5)	19.46(380.3)	34.4
Sulfosulfuron +S**	25	625	4.70(21.9)	4.20(18.2)	3.40(10.4)	7.07(50.4)	50.1
Sulfosulfuron +S	25	1250	4.50(19.3)	5.0(25.3)	3.10(8.8)	7.32(53.3)	49.3
Sulfosulfuron +carfentrazone	45 (25+20)	-	13.80(188.2)	12.0(144.0)	1.00(0.0)	18.24(332.1)	37.1
Sulfosulfuron +carfentrazone +S	45 (25+20)	625	5.30(28.7)	3.80(20.1)	1.00(0.0)	6.81(48.8)	51.1
Sulfosulfuron +carfentrazone +S	45 (25+20)	1250	4.90(23.8)	3.80(16.1)	1.00(0.0)	6.32(40.0)	50.1
Weedy Check	-	-	25.50(652.7)	25.50(670.4)	1.70(2.6)	36.15(1325.7)	2.7
LSD (P= 0.05)			2.49	4.55	0.82	4.08	3.55

* Original values given in parenthesis are square root transformed for statistical analysis **S= Cationic surfactant

with surfactant (625, 750 and 1250 ml/ha) was 8.1-16.5 and 4.3-33.7 g/m^2, respectively. The total weed dry matter accumulation was reduced by 71.8-95.4%, when sulfosulfuron + carfentrazone mixture was applied with surfactant compared to without surfactant. The respective reductions for wild oat and *P. minor* were 71.8-86.9 and 83.1-97.6%.

The total weed dry matter accumulation reduced with increased dose of RM sulfosulfuron + carfentrazone-ethyl with surfactant but the differences were not significant among doses = 45 g/ha. Among the various weed control treatments, sulfosulfuron had the significantly higher dry weight of *R. dentatus* followed by untreated weedy check. The lesser dry weight of *R. dentatus* in weedy control was due to presence of grass weed competition. Sulfosulfuron + carfentrazone, Total (Sulfosulfuron + metsulfuron), Atlantis (Mesosulfuron + iodosulfuron), isoproturon and carfentrazone-ethyl were effective in controlling the broad-leaf weeds, *R. dentatus* and *M. denticulata* (Table 3 and 4). Carfentrazone @ 20 g/ha was significantly better than sulfosulfuron with regard to *R. dentatus* control but at par with rest of the herbicide treatments.

The total weed dry weight in Total (Sulfosulfuron + metsulfuron) 30 +2 g/ha., Atlantis (Mesosulfuron + iodosulfuron) 12+2.4 g/ha. and premix combination of sulfosulfuron + carfentrazone with surfactant at 45 (20+25), 54 (24+30), 90 (50+40) g./ha was not significantly different and all these treatments were significantly superior to the rest of the treatments. The RM sulfosulfuron + carfentrazone can be advantageous over other mixtures in situation having the infestation of *M. parviflora* and *S. nigrum*. Isoproturon failed to control *P. minor* (439.2 and 284.3 g/m^2) effectively due to presence of isoproturon resistant population. Some escapes of wild oat were also observed with isoproturon application.

Among various treatments, the lowest wheat grain yield was recorded in weedy control (16.80 and 12.5 q/ha) followed by carfentrazone 20 g/ha (20.90 and 13.56 q/ha). The lower wheat yield in carfentrazone was mainly due to its effectiveness against broad-leaved weeds only and uncontrolled grass weeds reduced the yield. Compared to weedy control, all the weed control treatments resulted in significant yield improvement except carfentrazone during the second year of study. The yield reduction due to presence of weeds through out the crop season was 70.3 and 74.8%, during first and second year, respectively. Wheat grain yield in premix combination of sulfosulfuron + carfentrazone-ethyl at 45 g/ha without surfactant was on an average basis 12.1 and 17.9 % less to its application with surfactant during first and second year, respectively. The RM sulfosulfuron + carfentrazone at 45 g/ha without surfactant as well as lower dose of 36 g/ha with surfactant were inferior to doses = 45 g./ha with surfactant, Atlantis (Mesosulfuron + Iodosulfuron), Total (sulfosulfuron + metsulfuron) and season long weed free maintenance in reducing the dry weight of weeds as well as producing the wheat grain yield. Considering the sulfosulfuron and sulfosulfuron + carfentrazone treatments in various experiments in this study, there was an average wheat grain yield gain of 7.6 % with addition of carfentrazone to sulfosulfuron. Similarly, the yield improvement with usage of sulfosulfuron + carfentrazone over sulfosulfuron alone application has been reported by Walia *et al*. 2010.

The results of field studies showed that the efficacy of ready-mix combination of sulfosulfuron+ carfentrazone 45 WDG did not differ among surfactant rates of 625, 750 and 1250 ml/ha.

Herbicide carryover effect

Herbicide carryover effect on maize and green gram was evaluated. As, no visual adverse effect of any herbicide treatment on green gram was observed, so, the data were not recorded. The visual phyto-toxicity was observed in maize crop. The phyto-toxicity was more in treatments, where 2X dose (90 g/ha) of the ready-mix combination sulfosulfuron + carfentrazone was applied leading to significant reduction in maize fresh biomass (Table 5). The reduction in maize fodder yield was 20.7-73.0 %, where the herbicide treatments comprised the involvement of sulfosulfuron. At 2X dose of sulfosulfuron + carfentrazone (50+40 g/ha), the reduction in maize biomass was 62.6-73.0% compared to weed free check. No phyto-toxicity was observed with carfentrazone, Atlantis, and isoproturon.

Pot studies

Sulfosulfuron applied without surfactant had less effect compared to its application with surfactant on all the four test weed species *viz. E. crus-galli, P. monspeliensis, P. minor* and *A. ludoviciana* (Table 6). The fresh weight of *P. monspeliensis* with application of sulfosulfuron at 6.25 g/ha without surfactant and untreated control was not statistically different. Sulfosulfuron dose of 6.25 g/ha with surfactant 625 ml/ha reduced the fresh weight of four test weed species similar to 25 g/ha without surfactant. However, no significant differences were observed between surfactant doses of 625 and 1250 ml/ha indicating that 625 ml may be sufficient for sulfosulfuron. *P. monspeliensis* is increasing in many wheat fields due to its poor control by sulfosulfuron, Total (sulfosulfuron+ metsulfuron) and Atlantis (mesosulfuron + iodosulfuron) herbicides (Singh 2009b).

Table 3. Efficacy of ready mixture sulfosulfuron + carfentrazone 45 (25+20) WDG on weeds in wheat (2008-09)

Treatments	Dose		Weed dry weight, g/m^2					Wheat grain yield q/ha	1000 grain wt (g)
	Herbicide g/ha	Surfactant ml/ha	*Phalaris minor*	*Avena ludoviciana*	*Rumex dentatus*	Other weeds	Total weeds		
Sulfosulfuron + carfentrazone	45(25+20)	-	8.27 (67.6)**	10.91 (119.6)	1.82 (3.0)	1.08 (0.2)	13.81 (190.3)	48.90	42.89
Sulfosulfuron + carfentrazone +S*	36(20+16)	625	4.47 (20.7)	8.09 (64.8)	4.92 (24.1)	2.02 (4.4)	10.67 (114.0)	51.87	43.61
Sulfosulfuron + carfentrazone +S	36(20+16)	750	4.18 (18.5)	7.81 (60.4)	4.52 (20.6)	1.17 (0.4)	10.01 (99.9)	51.66	43.42
Sulfosulfuron + carfentrazone +S	45(25+20)	625	3.32 (10.2)	5.87 (33.7)	2.29 (4.5)	1.02 (0.0)	7.02 (48.4)	55.57	43.57
Sulfosulfuron + carfentra zone +S	45(25+20)	750	3.48 (11.4)	5.55 (30.1)	2.76 (7.2)	1.59 (2.2)	7.18 (50.9)	56.17	43.33
Sulfosulfuron + carfentrazone +S	54(30+24)	625	2.43 (6.0)	4.80 (22.1)	2.05 (3.3)	1.00 (0.0)	5.69 (31.5)	55.97	43.23
Sulfosulfuron + carfentrazone +S	54(30+24)	750	2.26 (5.0)	4.48 (19.5)	2.20 (4.8)	1.08 (0.2)	5.45 (29.4)	55.60	43.61
Sulfosulfuron + carfentrazone +S	45(25+20)	1250	2.98 (8.1)	5.12 (25.4)	2.14 (4.7)	1 (0.0)	6.21 (38.1)	55.14	43.09
Sulfosulfuron + carfentrazone	90 (50+40)	-	4.06 (16.1)	6.16 (38.6)	1.71 (2.4)	1.00 (0.0)	7.57 (57.1)	53.31	43.15
Sulfosulfuron + carfentrazone +S	90(50+40)	750	1.57 (1.5)	3.39 (10.7)	1.91 (3.1)	1.26 (0.7)	4.04 (16.0)	53.27	42.67
Carfentrazone ethyl	20	-	21.23 (450.4)	17.03 (289.3)	1.64 (1.9)	1.14 (0.3)	27.25 (741.9)	20.90	40.38
Sulfosulfuron +S	25	1250	2.65 (6.1)	4.63 (21.2)	14.20 (201.8)	1.08 (0.2)	15.12 (229.2)	49.62	43.65
Sulfosulfuron +S	25	625	3.04 (9.1)	4.79 (22.0)	13.83 (191.3)	1.29 (0.9)	14.94 (223.2)	49.94	43.00
Total (sulfosulfuron + metsulfuron)+S	32(30+2)	1250	1.99 (3.3)	3.98 (15.0)	1.62 (2.4)	1.00 (0.0)	4.57 (20.6)	55.88	43.31
Atlantis (Mesosulfuron +Iodosulfuron) +S	14.4(12+2.4)	500	1.73 (2.3)	1.00 (0.0)	2.59 (5.8)	1.15 (0.4)	3.03 (8.4)	55.33	43.49
Isoproturon	1000	-	20.97 (439.2)	9.34 (86.5)	1.00 (0.0)	3.72 (13.2)	23.22 (538.9)	26.37	42.25
Weedy check		-	20.17 (406.8)	14.07 (199.2)	11.94 (142.9)	8.71 (75.0)	28.70 (823.9)	16.80	41.05
Weed free		-	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	56.47	43.77
LSD (P= 0.05)			1.57	1.33	1.51	0.82	1.64	3.36	1.88

*S- Surfactant

** Original values given in parenthesis are square root transformed for statistical analysis

Table 4. Efficacy of ready mixture of sulfosulfuron + carfentrazone 45 (25+20) WDG against weeds in wheat (2009-10)

Treatments	Dose		Weed dry weight, g/m^2						Wheat grain Yield q/ha	1000 grain wt (g)
	Herbicide g/ha	Surfactant ml/ha	*Phalaris minor*	*Avena ludoviciana*	*Rumex dentatus*	*Medicago denticulata*	Other weeds	Total weeds		
Sulfosulfuron + Carfentrazone	45(25+20)	-	12.84 (170.3)**	5.40 (32.9)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	13.94 (203.2)	39.87	32.93
Sulfosulfuron + Carfentrazone +S*	36(20+16)	625*	7.75 (59.9)	3.28 (10.5)	1.09 (0.2)	1.00 (0.0)	1.07 (0.2)	8.39 (70.8)	44.75	33.08
Sulfosulfuron + Carfentrazone +S	36(20+16)	750	7.69 (64.4)	3.44 (13.5)	1.04 (0.1)	1.00 (0.0)	1.14 (0.3)	8.42 (78.3)	45.71	33.29
Sulfosulfuron + Carfentrazone +S	45(25+20)	625	4.15 (16.5)	2.15 (5.0)	1.00 (0.0)	1.00 (0.0)	1.17 (0.4)	4.72 (22.0)	48.48	33.03
Sulfosulfuron + Carfentrazone +S	45(25+20)	750	3.31 (10.5)	2.15 (4.3)	1.27 (0.7)	1.00 (0.0)	1.12 (0.3)	4.00 (15.7)	49.09	32.72
Sulfosulfuron + Carfentrazone +S	54(30+24)	625	3.12 (9.9)	1.36 (0.9)	1.04 (0.1)	1.00 (0.0)	1.06 (0.1)	3.27 (11.0)	49.77	33.29
Sulfosulfuron + Carfentrazone +S	54(30+24)	750	2.43 (5.5)	2.00 (3.0)	1.00 (0.0)	1.00 (0.0)	1.26 (0.7)	3.13 (9.2)	48.80	33.21
Sulfosulfuron + Carfentrazone +S	45(25+20)	1250	3.47 (12.1)	2.94 (8.6)	1.04 (0.1)	1.00 (0.0)	1.00 (0.0)	4.43 (20.9)	48.04	32.71
Sulfosulfuron + Carfentrazone	90 (50+40)	-	8.94 (79.2)	3.40 (18.8)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	9.83 (98.0)	45.85	32.31
Sulfosulfuron + Carfentrazone +S	90(50+40)	750	1.66 (1.9)	1.69 (2.6)	1.04 (0.1)	1.00 (0.0)	1.00 (0.0)	2.21 (4.5)	48.59	33.05
Carfentrazone ethyl	20	-	25.00 (624.2)	13.74 (204.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	28.72 (828.1)	13.56	30.31
Sulfosulfuron +S	25	1250	3.55 (12.8)	2.51 (9.4)	8.10 (65.4)	1.10 (0.2)	1.80 (2.3)	9.50 (90.1)	44.49	32.39
Sulfosulfuron +S	25	625	4.21 (17.6)	4.38 (18.4)	8.65 (75.2)	1.05 (0.1)	1.95 (3.3)	10.72 (114.6)	45.73	32.48
Total (Sulfosulfuron + Metsulfuron)+S	32(30+2)	1250	3.23 (9.6)	2.74 (7.3)	1.09 (0.2)	1.00 (0.0)	1.06 (0.1)	4.24 (17.2)	47.94	32.37
Atlantis (Mesosulfuron + Iodosulfuron)+S	14.4(12+2.4)	500	1.62 (1.7)	1.22 (0.6)	1.59 (2.2)	1.00 (0.0)	1.47 (1.3)	2.57 (5.8)	48.27	32.49
Isoproturon	1000	-	16.74 (284.3)	6.69 (54.8)	1.00 (0.0)	1.50 (1.8)	1.30 (0.7)	18.49 (341.5)	36.33	30.53
Weedy check	-	-	24.38 (595.7)	15.57 (246.3)	4.51 (23.9)	4.86 (28.0)	1.12 (0.3)	29.83 (894.1)	12.51	29.66
Weed free	-	-	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	49.55	33.27
LSD (P= 0.05)			2.56	3.56	1.27	1.16	0.41	3.08	4.04	2.16

*S- Surfactant

** Original values given in parenthesis are square root transformed for statistical analysis

Table 5. Carry over effect of wheat herbicide on succeeding maize

Treatments	Dose		Maize fresh biomass (fodder) (q/ha)	
	Herbicide g/ha	Surfactant ml/ha	2009	2010
Sulfosulfuron + carfentrazone- 45 WDG	45(25+20)	-	64.24	115.86
Sulfosulfuron + carfentrazone- 45 WDG +S*	36(20+16)	625*	77.05	129.54
Sulfosulfuron + carfentrazone- 45 WDG +S	36(20+16)	750	80.59	139.38
Sulfosulfuron + carfentrazone- 45 WDG +S	45(25+20)	625	67.36	120.69
Sulfosulfuron + carfentrazone- 45 WDG +S	45(25+20)	750	68.23	114.19
Sulfosulfuron + carfentrazone- 45 WDG +S	54(30+24)	625	62.77	107.17
Sulfosulfuron + carfentrazone- 45 WDG +S	54(30+24)	750	59.78	100.10
Sulfosulfuron + carfentrazone- 45 WDG +S	45(25+20)	1250	69.81	108.20
Sulfosulfuron + carfentrazone- 45 WDG	90 (50+40)	-	28.80	55.23
Sulfosulfuron + carfentrazone- 45 WDG +S	90(50+40)	750	33.28	65.74
Carfentrazone	20	-	99.83	168.98
Sulfosulfuron +S	25	1250	60.19	125.27
Sulfosulfuron +S	25	625	65.00	118.23
Total (sulfosulfuron 75%+metsulfuron 5%)+S	32(30+2)	1250	62.78	96.21
Atlantis (mesosulfuron3%+iodosulfuron 0.6%)+S	14.4(12+2.4)	500	104.83	169.97
Isoproturon	1000	-	107.71	166.34
Weedy check	-	-	100.48	179.07
Weed free	-	-	106.78	175.80
LSD (P= 0.05)			13.10	24.56

*S- Surfactant, ml/ha

Like sulfosulfuron, the effect of ready-mix combination of sulfosulfuron + carfentrazone was significantly improved with the addition of surfactant against all the three test species (*E. crus-galli*, *P. minor* and *A. ludoviciana*). No significant differences were observed between the two surfactant rates *i.e.* 625 and 1250 ml/ha on the three test grass species (Table 7).

Further, the role of certain fertilizer salts {urea ammonium nitrate (28% UAN), urea, and ammonium sulfate (AMS)}in combination with different surfactants in improving the efficacy of sulfosulfuron and sulfosulfuron + carfentrazone need to be evaluated. As, these additives increase the herbicide absorption into plants (Wills *et al.* 1998, Young and Hart 1998, Miller *et al.* 1999). Urea fertilizer at 0.25% w/v (Woznica *et al.* 2001*)* and calcium nitrate (Woznica *et al.* 2003*)* enhances the efficacy of sulfosulfuron. It has also been observed that AMS overcomes the decreased herbicide activity due to antagonism caused by the presence of metal cations (Ca, Na, K and Mg) in water used as spray solution (Nalewaja and Matysiak 1993, McMullen 1994, Nalewaja *et al.* 1995).

Conclusions

The field and pot studies indicate that for better efficacy of sulfosulfuron and sulfosulfuron + carfentrazone against grass weeds (*E. crus-galli, P. monspeliensis, P. minor* and *A. ludoviciana*), surfactant is a must. The optimum surfactant dose required for sulfosulfuron alone and its combination with carfentrazone was 625 ml/ha indicating that surfactant dose can be reduced from the present level of 1250 ml/ha by 40-50% i.e. 625-750 ml/ha**.** If this saving is extended on an area of about 1.56 m ha (Crop Life India, 2011) covered by sulfosulfuron or its combination with metsulfuron (Total/Bracket etc.) a saving of about 0.78 to 0.97 million l/annum of surfactant can be made. The ready mixtures provided better wheat production due to broad spectrum weed kill compared to alone application of carfentrazone and sulfosulfuron. The optimum dose of ready mix combination of sulfosulfuron + carfentrazone was 45 (25+20) g/ha with 625-750 ml/ha of surfactant. The performance of this combination with regard to wheat productivity and weed control was similar to already recommended herbicide mixtures *i.e.* Atlantis (Mesosulfuron + Iodosulfuron) 14.4(12+2.4) g/ha and Total (sulfosulfuron + metsulfuron) 32 (30+2) g/ha.

Table 6. Influence of surfactant on sulfosulfuron efficacy against grass weeds

Treatments	Dose		Fresh weight % of control			
	Herbicide g/ha	Surfactant ml/ha	*E. crus-galli	*P. minor	*A. ludoviciana	*P. monspeliensis
Control	-	-	100.0	100.0	100.0	100.0
Sulfosulfuron	6.25	-	54.6	50.3	78.7	98.1
Sulfosulfuron	12.5	-	28.0	23.8	50.3	66.3
Sulfosulfuron	25.0	-	12.8	9.4	29.8	60.2
Sulfosulfuron + surfactant	6.25	625	7.4	14.4	20.4	66.3
Sulfosulfuron + surfactant	12.5	625	4.4	5.9	8.9	26.5
Sulfosulfuron + surfactant	25.0	625	0.5	1.4	4.3	3.7
Sulfosulfuron + sur factant	6.25	1250	7.1	11.6	23.8	65.6
Sulfosulfuron + surfactant	12.5	1250	3.0	3.1	7.7	22.9
Sulfosulfuron+ surfactant	25.0	1250	0.7	0.5	3.2	4.4
LSD (P= 0.05)			14.45	14.43	15.25	13.12

*At the time of spraying weeds were 3-4 leaf stage except *Polypogon monspeliensis, which was at tillering stage*

Table 7. Influence of surfactant on efficacy of ready mix combination of sulfosulfuron + carfentrazone- 45 WDG against grass weeds

Treatments	Dose		Fresh wt % of control		
	Herbicide g/ha	Surfactant ml/ha	*E. crus-galli*	*P. minor*	*A. ludoviciana*
Control	-	-	100.0	100.0	100.0
Sulfosulfuron + carfentrazone	11.25(6.25 + 5)	-	59.6	71.5	79.5
Sulfosulfuron + carfentrazone	22.5(12.5 + 10)	-	39.2	37.0	44.9
Sulfosulfuron + carfentrazone	45 (25.0 + 20)	-	12.3	17.2	11.0
Sulfosulfuron + carfentrazone + Surfactant	11.25(6.25 + 5)	625	8.9	22.9	8.0
Sulfosulfuron + carfentrazone + Surfactant	22.5(12.5 + 10)	625	2.6	8.9	3.7
Sulfosulfuron + carfentrazone + Surfactant	45(25.0 + 20)	625	0.2	1.2	1.0
Sulfosulfuron + carfentrazone + Surfactant	11.25(6.25 + 5)	1250	7.0	19.7	7.0
Sulfosulfuron + carfentrazone + Surfactant	22.5(12.5 + 10)	1250	1.7	3.3	2.4
Sulfosulfuron + carfentrazone + Surfactant	45(25.0 + 20)	1250	0.4	1.7	0.4
LSD (P= 0.05)			10.13	15.27	11.20

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