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Research Paper

Alleviation of weed stress in wheat (*Triticum aestivum*) through herbicides and their combinations

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ABSTRACT

A field experiment was conducted during the winter (*rabi*) seasons of 2012–13 and 2013–14 at Udaipur (Rajasthan), to study the effect of 12 different herbicide combinations to control complex weed flora in wheat (*Triticum aestivum* L.) crop. Pooled data of 2 years experimentation indicated that the application of various herbicide combinations significantly reduced density and biomass of complex weed flora. The yield attributes, viz. plant height, effective tillers, days to heading; days to maturity and 1,000-seed weight were significantly influenced by application of various herbicide combinations. The application of herbicides increased the yield, harvest index and monetary income of wheat crop compared to weedy check, although maximum grain yield was recorded under weed free plots. Amongst the herbicides, application of sulfosulfuron + metsulfuron @ 30 + 2 g a.i./ha rsulted in higher number of effective tillers (485.8/m^2), the maximum grain yield (5.29 t/ha), harvest index (37.9%), net returns (₹79,480/ha) and benefit: cost ratio (3.06), which was superior to rest of the treatments, as the same treatment caused significant reduction in weed density (6.65/m^2) and weed biomass (6.24 g/m^2). Two-year study indicates that application of a ready-mixed herbicide (sulfosulfuron + metsulfuron) @ 32 g a.i/ha was best for weed-control, higher yield and net returns from wheat in southern plain zone of Rajasthan.

Key words **:** Herbicides, Net returns, Weed-control efficiency, Weed densities, Wheat, Yield

Wheat is one of the most important cereal crops of India not only in terms of meeting calorie requirement of sizable segment of the society, but also in terms of its versatility for adoption under wide range of agro-climatic conditions and crop-growing situations. The statistics of 2013–14 regarding acreage (31.09 million ha), production (95.91 million tonnes) and yield (3,075 kg/ha) of India symbolizes the importance of this crop in national food security. The total factor productivity and production growth have however, slowed down with production hovering around 94–95 million tonnes in the last 5 years (Government of India, 2015). On the other hand, the increasing demand of escalating human population forced to increase the production at the same or even higher rate as that of human population. This goal can be achieved only by increasing the yield as the scope of area expansion has ceased. Singh *et al*. (2013), while analyzing yield gaps, found 26.4% less wheat yield on farmers' field compared to demonstration yield. Their technical constraint analysis revealed that weed infestation was the second most important hindrance in wheat-harvest. Numerous trials in India have shown the average yield loss cause by weeds in different wheat growing zones ranging from 20 to 32% (Chhokar *et al*., 2012). Therefore, appropriate weed-management technology can help in increasing the productivity and production of this crop.

Wheat crop is prone to a variety of weeds which are classified as annual grassy and broad leaf. Wide ranges of herbicides are under recommendation for weed control in wheat, but most of them suffer from narrow spectrum control, viz. either grassy or broad leaf ones. This has opened a new vista of applying herbicides of diverse selectivity together. One way is to apply 2 herbicides one after the other in sequence. However, mixtures have shown encouraging results (Kumari *et al*., 2013, Chopra *et al*., 2015) to save time and cost, instead of sequential application of herbicides. It is advantageous to tank mix broad leaf weed herbicide with grass-controlling herbicide to combat broad-spectrum weed flora. However, the major requirement is that they should be compatible and the chance of

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herbicide compatibility in poaceae (grasses) is ˆ 20% (Zhang *et al*., 1995). Isoproturon was a nationwide recommended herbicide in wheat. However, continuous reliance on isoproturon resulted in a heavy buildup of resistant *Phalaris minor* (Malik and Singh, 1995). Clodinafop and sulfosulfuron were recommended as alternate herbicides against isoproturon- resistant *Phalaris minor*. But reports of resistance against these herbicides were also documented (Chhokar and Malik, 2002; Dhawan *et al*., 2009,), necessitating the search for new herbicide molecules. Sulfosulfuron and metsulfuron belong to sulfonylurea group of herbicides which inhibit acetolactate synthase (ALS) enzyme in susceptible plants. Some of the herbicides in vogue control either broad leaf or grassy weeds hence an attempt was made to evaluate the bio-efficacy of different tank-mix and ready-mix herbicide combinations for managing complex weed flora in wheat.

MATERIALS AND METHODS

An experiment was conducted with wheat at Instructional Farm of Agronomy, Department of Agronomy, Rajasthan College of Agriculture, Udaipur (24° 35' N, 74° 42' E, 579.5 m above mean sea-level). The soil was clay loam, with *p*H 8.2, medium in available nitrogen (295.3 kg/ha), phosphorus (18.4 kg/ ha) and high in potassium (292.7 kg/ha). Fourteen treatments comprised 4 single herbicides, viz. metribuzin 210 g/ha, clodinafop 60 g/ha, pinoxaden 40 g/ha and sulfosulfuron 25 g/ha; 4 tank mixtures, viz. clodinafop + metribuzin (60 + 210 g/ ha), pinoxaden + metribuzin (40 + 210 g/ha), sulfosulfuron + metribuzin (25 + 210 g/ha) and isoproturon + 2, 4-D (1,000 + 500 g/ha) and 4 premixes, viz. accord plus (fenoxaprop + metriburin) 310 g/ha, total (sulfosulfuron + metsulfuron) 32 g/ha, atlantis (mesosulfuron + iodosulfuron) 12 + 2.4 g/ha and vesta (clodinafop + metsulfuron) 60 + 4 g/ha, along with weed-free and weedy check. The experiment was laid out in a randomized block design with 3 replications. All the herbicides were applied 32 days after sowing (DAS) by knapsack sprayer, fitted with flat-fan nozzle using 600 litres water/ha. Wheat cultivar 'Raj 4037' was sown on 24 November 2012 and 22 November 2013, using seed rate of 100 kg/ha with a row spacing of 22.5 cm. The crop was supplied with 120 kg N, 60 kg P_2O_5 and 40 kg K_2O/ ha. One-third nitrogen and full dose of phosphorus and potash were applied basal and the remaining nitrogen was applied in 2 splits–at first and second irrigation stage of the crop according to zonal package of IVa of Rajasthan (Government of Rajasthan, 2012–13). Density and dry weight of weeds were recorded 60 and 120 DAS, using quadrate of 0.5 m × 0.5 m, placed at 2 random spots in each plot. Weed density and biomass data showed variation and were subjected to square-root transformation $\sqrt{(x + 1)}$ to normalize their distribution. The samples were first dried in sun and then oven dried at 65°C until constant weight was obtained. The dried samples were weighed and expressed in g/0.5 m².

Yield attributes and yield were recorded at maturity of the crop as per the standard procedures. Crop was harvested on 10 April, 2012 and 11 April 2013. Economics of wheat production was worked out on prevailing market price of different inputs and final produce. Since the data of 2 years was homogenous, were subjected to pooled analysis (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Density and dry weight of weeds

The field was infested with both grassy (*Phalaris minor* Retz., *Avena fatua* L., *Lolium temulentum* L.) and broadleaf weeds [*Chenopodium album* L., *Chenopodium murale* L., *Melilotus indica indicus* (L.) All., *Convolvulus arvensis* L., *Spergula arvensis* L., *Malva parviflora* L., *Fumaria parviflora* Lamk.). However, the flora was dominated by grassy weeds in this experiment. The lowest density of total weeds (0.5 m row length) was observed in weed-free plots and it was statistically significant over rest of the treatments at 60 DAS (Table 1). Amongst application of ready-mix herbicides, sulfosulfuron + metsulfuron @ 32 g a.i./ha showed the minimum total weed density (6.65/m²) which was at par with ready-mix mesosulfuron + iodosulfuron @ 14.4 g a.i./ha tank mix, sulfosulfuron + metribuzin (25 + 210 g a.i./ha), clodinafop + metribuzin (60 + 210 g a.i./ha), sulfosulfuron 25 g a.i./ha, pinoxaden 40 g a.i./ha, clodinafop 60 g a.i./ha and metribuzin 210 g a.i./ha while gave significantly superior weed control to rest of the herbicidal treatments and weedy check at 60 DAS. Kulshrestha *et al*. (2003) also reported similar effectiveness of sulfosulfuron + metribuzin. But in case of grassy weed, the minimum count (3.54/m²) was observed under metribuzin 210 g a.i./ha, being at par with clodinafop, pinoxaden, sulphosulhuron, sulfosulfuron + metsulfuron and mesosulfuron + iodosulfuron, while significant lower than the other treatments and weedy check at 60 DAS. In case of broad-leaf weeds sulfosulfuron + metsulfuron @ 32 g a.i /ha recorded the minimum weed density (2.31/m²) which was at par with sulfosulfuron + metribuzin, mesosulfuron + iodosulfuron, clodinafop + metribuzin and clodinafop + metsulfuron but significantly lower weed density than the remaining treatments and weedy check at 60 DAS. At 120 DAS, clodinafop + metribuzin (60 + 210 g a.i./ha) recorded the lowest total weed count (5.15/m²) which was at par with clodinafop @ 60 g *a.i*./ha, sulfosulfuron + metribuzin, pinoxaden and mesosulfuron + iodosulfuron while significantly lower weed count than rest of the treatments.

The lowest dry-matter of weeds (grassy + broad leaf) was recorded (6.24 g/m^2) with the application of ready-mix sulfosulfuron + metsulfuron @ 32 g a.i./ha, being at par with clodinafop + metribuzin, metribuzin, clodinafop, mesosulfuron + iodosulfuron, pinoxaden, sulfosulfuron + metribuzin and clodinafop + metsulfuron showed significantly lower weed dry matter than the remaining treatments at 60 DAS. However, at 120 DAS clodinafop + metribuzin resulted in the minimum weed dry matter (4.82 g/m^2), closely followed by clodinafop, sulfosulfuron + metsulfuron and sulfosulfuron + metribuzin while significantly lower than rest of the chemical weed control treatments (Table 2). Better performance of herbicide mixtures in reducing the density and dry-matter of weeds could be attributed to their synergetic interactions and compatibility that was responsible for broad-spectrum suppression of

Table 1. Effect of weed-management practices in wheat on pooled weed density of different type of weeds at various crop growth stages (pooled data of 2 years)

Treatment		Weed density (weeds/0.5 m row length)					
Herbicides	Dose	60 days after sowing			120 days after sowing		
	(g/ha)	Grassy	Broad leaf	Total	Grassy	Broad leaf	Total
Metribuzin	210	1.98 (3.54)	2.38 (5.15)	3.03 (8.69)	1.59 (2.03)	2.12 (3.99)	2.55 (6.02)
Clodinafop	60	2.00 (3.57)	2.29 (4.74)	2.96 (8.31)	1.58 (2.00)	2.06 (3.75)	2.50 (5.75)
Pinoxaden	40	2.04 (3.72)	2.33 (4.95)	3.03 (8.67)	1.61 (2.08)	2.07 (3.78)	2.52 (5.86)
Sulfosulfuron	25	2.06 (3.81)	2.34 (4.99)	3.05 (8.80)	1.62 (2.12)	2.12 (4.02)	2.58 (6.14)
Clodinafop + metribuzin	60 + 210	2.24 (4.50)	1.74 (2.52)	2.74 (7.02)	1.99 (3.47)	1.48 (1.68)	2.38 (5.15)
Pinoxaden + metribuzin	40 + 210	2.40 (5.24)	1.94 (3.28)	3.00 (8.52)	2.16 (4.18)	1.62 (2.13)	2.61 (6.31)
Sulfosulfuron + metribuzin	25 + 210	2.20 (4.35)	1.69 (2.34)	2.68 (6.69)	2.12 (3.98)	1.51 (1.79)	2.50 (5.77)
Fenoxaprop + metribuzin	120 + 210	2.43 (5.39)	1.95 (3.31)	3.03 (8.70)	2.18 (4.25)	1.66 (2.25)	2.65 (6.50)
Sulfosulfuron + metsulfuron	30+2	2.20 (4.34)	1.68 (2.31)	2.67 (6.65)	2.15 (4.13)	1.59 (2.04)	2.58 (5.90)
Mesosulfuron + iodosulfuron	12+ 2.4	2.20 (4.36)	1.72 (2.45)	2.70 (6.81)	2.11 (3.97)	1.55 (1.90)	2.52 (5.87)
Clodinafop + metsulfuron	60+4	2.26 (4.62)	1.79 (2.72)	2.80 (7.34)	2.20 (4.35)	1.63 (2.17)	2.65 (6.52)
Isoproturon +2,4-D	1000 + 500	2.34 (4.98)	1.93 (3.24)	2.95 (8.22)	2.13 (4.02)	1.56 (1.92)	2.54 (5.93)
Weedy check	-	5.74 (32.46)	5.03 (24.83)	7.60 (57.29)	4.73 (21.87)	3.60 (12.47)	5.90 (34.34)
Weed-free	-	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
SEm±	0.30	0.19	0.48	0.17	0.10	0.26	
CD (P=0.05)	0.85	0.53	1.36	0.47	0.27	0.74	

*Data subjected to $\sqrt{x + 0.5}$ transformation; figures in parentheses are original weed counts/m^2

Table 2. Effect of weed-management practices in wheat on pooled dry-matter accumulation of different type of weeds at various crop growth stages (pooled data of 2 years)

Treatment		Weed dry matter (g/0.5 m row length)					
Herbicides	Dose	60 days after sowing			120 days after sowing		
	(g/ha)	Grassy	Broad leaf	Total	Grassy	Broad leaf	Total
Metribuzin	210	2.85	3.51	6.36	3.22	2.70	5.92
Clodinafop	60	2.62	3.81	6.43	3.17	2.03	5.20
Pinoxaden	40	2.65	4.27	6.92	3.42	2.25	5.67
Sulfosulfuron	25	3.07	4.75	7.82	3.68	2.40	6.08
Clodinafop + metribuzin	60 + 210	3.64	2.65	6.29	1.96	2.86	4.82
Pinoxaden + metribuzin	40 + 210	5.58	3.12	8.71	2.40	4.39	6.79
Sulfosulfuron + metribuzin	25 + 210	4.48	2.55	7.03	2.21	3.16	5.37
Fenoxaprop + metribuzin	120 + 210	5.38	3.11	8.50	2.46	4.43	6.89
Sulfosulfuron + metsulfuron	30+2	3.82	2.42	6.24	1.88	3.38	5.26
Mesosulfuron + iodosulfuron	12+ 2.4	4.27	2.62	6.89	2.22	3.49	5.71
Clodinafop + metsulfuron	60+4	4.41	2.72	7.13	2.25	4.00	6.25
Isoproturon + 2,4-D	1000 + 500	5.13	2.96	8.09	2.34	3.39	5.73
Weedy check	-	31.07	27.20	58.26	8.79	7.19	15.98
Weed-free	-	0.00	0.00	0.00	0.00	0.00	0.00
SEm±		0.24	0.22	0.46	0.08	0.07	0.15
CD (P=0.05)		0.69	0.61	1.30	0.22	0.21	0.43

different categories of weeds (Jat *et al.,* 2014). Bharat and Kachroo (2007) also reported significant reduction in density and dry matter of broad leaf and grassy weeds by applying herbicide mixtures compared to their single application.

Yield attributes, and yield

On an average, weeds in weedy check reduced the grain yield of wheat by 32.67% compared to weed-free check. All herbicidal treatments were found significantly superior to weedy check in increasing plant height, effective tillers, 1,000-seed weight and thereby grain yield of wheat (Table 3). The higher number of effective tillers (485.5/m^2) were produced when weeds were controlled by the application of sulfosulfuron + metsulfuron, which was superior to all the other herbicidal treatments. Taller plant were (86.5 cm) recorded with the application of sulfosulfuron, result of which was statistically equivalent to sulfosulfuron + metribuzin, pinoxaden + metribuzin, sulfosulfuron + metsulfuron and mesosulfuron + iodosulfuron and significantly superior to rest of the chemical treatments. The reduced days to heading (74.2) and days to maturity (132.3) were observed under mesosulfuron + iodosulfuron treatments which were at par with all other herbicidal mixture. The higher 1,000-seed weight (44.6 g) observed with the application of isoproturon + 2, 4-D was at par with clodinafop, sulfosulfuron, pinoxaden + metribuzin and metribuzin while superior to rest of the chemical weed control treatments. The higher yield and yield attributes were owing to better weed control both in terms of reduction in density and biomass of weeds. Application of ready-mix sulfosulfuron + metsulfuron @ 32 g a.i./ha resulted in the highest grain yield (5.29 t/ha), which was at par with clodinafop + metsulfuron and mesosulfuron + iodosulfuron while statistically superior to the other herbicidal treatments. Higher yield was recorded in wheat might be owing to low weed density and dry matter which helped in better crop growth and production of more effective tillers.

The better expression of yield attributes of wheat plants under the influence of herbicide mixtures was owing to poor resurgence and growth of weeds, as is evident from the weed density and dry matter studies. Significant increase in yield attributes finally manifested into higher yield. Bharat and Kachroo (2007) also reported higher wheat yield with herbicide mixtures. The highest straw yield was recovered from plots under the effect of pinoxaden (8.83 t/ha) which was at par with most of the chemical weed-control treatments except metribuzin, clodinafop, mesosulphuron + iodosulhuron and pinoxaprop + metribuzin. The low straw yield in

Table 3. Effect of weed management practices on pooled yield attributes, yields and economics of wheat

Treatment		Yield attributes					Yield (t/ha)		Harvest	Economics	
Herbicides	Dose (g/ha)	Plant height (cm)	Tillers /m^2	Days to heading	Days to maturity	1,000-grain weight (g)	Grain	Straw	index (%)	Net returns (× 10^3 ₹/ha)	Benefit: cost ratio
Metribuzin	210	83.3	406.7	76.3	134.5	43.5	4.02	7.46	35.0	57.0	2.22
Clodinafop	60	83.3	436.6	77.3	135.0	44.5	4.93	8.82	35.9	74.8	2.92
Pinoxaden	40	85.3	444.7	76.5	134.5	43.0	5.04	8.83	36.3	76.4	2.98
Sulfosulfuron	25	86.5	459.1	75.7	133.8	43.9	4.88	8.70	36.0	73.7	2.87
Clodinafop + metribuzin	60 + 210	83.5	415.4	75.0	133.0	42.7	4.85	8.68	35.9	72.8	2.80
Pinoxaden + metribuzin	40 + 210	85.7	415.0	74.7	132.5	43.8	4.55	8.62	34.5	68.1	2.62
Sulfosulfuron + metribuzin	25 + 210	86.0	460.5	74.5	132.5	41.7	5.16	8.80	37.0	77.8	3.00
Fenoxaprop + metribuzin	120 + 210	82.7	423.6	75.7	133.7	43.2	4.53	7.85	36.8	65.5	2.52
Sulfosulfuron + metsulfuron	30+2	85.3	485.8	76.3	134.5	44.2	5.29	8.70	37.9	79.5	3.06
Mesosulfuron + iodosulfuron	12+ 2.4	85.2	458.7	74.2	132.3	40.9	5.10	8.82	36.7	77.0	2.96
Clodinafop + metsulfuron	60+4	84.5	454.2	75.7	133.7	43.4	5.09	8.81	36.7	76.8	2.96
Isoproturon + 2,4-D	1000 + 500	82.7	455.3	75.7	133.7	44.6	4.73	8.70	35.3	71.1	2.74
Weedy check	-	81.5	387.6	75.0	132.5	38.6	3.77	7.84	32.6	57.1	2.48
Weed-free	-	86.0	505.6	76.5	134.8	43.5	5.6.0	8.5.4	39.6	79.9	2.78
SEm±	0.59	4.69	0.70	0.71	0.41	0.08	0.14	0.70	1.6	0.0618	
CD (P=0.05)	1.68	13.29	1.99	2.02	1.15	0.23	0.41	1.98	4.5	0.18	

metribuzin-applied plots is due to burning effect of metribuzin on crop.

The highest harvest index (39.6%) was recorded in weed-free plots which was superior to all the herbicide treatments and weedy check except sulfosulfuron + metsulfuron (37.9%); in case of herbicidal treatments, an application of ready-mix sulfosulfuron + metsulfuron @ 32 g a.i./ha resulted in the highest harvest index (37.9%), being at par with pinoxaprop + metribuzin, mesosulfuron + iodosulfuron, clodinafop + metribuzin, sulfosulfuron + metribuzin, pinoxaden and sulfosulfuron. The more harvest index is owing to more grain: straw ratio in the sulfosulfuron + metsulfuron herbicide treatment.

Economics

The highest net return (₹79,480/ha) and benefit: cost ratio (3.54) were observed in herbicide treatment sulfosulfuron + metsulfuron which was statistically similar to mesosulfuron + iodosulfuron, clodinafop + metsulfuron and pinoxaprop + metribuzin while superior to rest of the herbicide treatments.

Based on the above results, it may be concluded that application of total, a ready-mixed herbicide (sulfosulfuron + metsulfuron) @ 32 g a.i./ha reduces population of weeds and weed biomass and thereby recommended for higher yield, net returns and benefit: cost ratio of wheat in Southern Plain zone of Rajasthan.

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