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Bio-efficacy of herbicide mixtures against complex weed flora in wheat (*Triticum aestivum*)

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ABSTRACT

A field experiment was conducted at Baraut in Uttar Pradesh during 2001-02 and 2002-03 to study the effect of different herbicides as sole and their tank mixtures on wheat (*Triticum aestivum* L. emend. Fiori & Paol.). The highest grain yield of 4.49 t/ha was recorded with fenoxaprop-*p*-ethyl + carfentrazone (100 + 10 g/ha) applied 30 days after sowing, which was at par with weed-free treatment. The lowest dry weight of weeds (22.0 g/m^2) and highest weed-control efficiency (84.7%) were observed with fenoxaprop-*p*-ethyl + carfentrazone due to control of grassy and broad-leaf weeds. Although the tank mixture of isoproturon + carfentrazone showed greater control of broad-leaf weeds, it gave significantly lower control of grassy weed (*Phalaris minor*) compared with fenoxaprop-*p*-ethyl + carfentrazone. Metsulfuron alone at 4 and 8 g/ha was found superior to 2,4-D and carfentrazone 10 g/ha for dry weight of weeds and weed-control efficiency. There was reduction of 25.7% in seed yield under weedy check conditions. None of herbicide alone or in mixture showed residual effect on succeeding crops of fodder maize and mungbean.

Key words: Bio-efficacy, Economics, Herbicide, Residual effect, Tank mixture, Weed density, Yield

Weeds are the major deterrent factor to the development of a more sustainable agricultural system. With the adoption of high-yielding dwarf varieties of wheat, *Phalaris minor* (little canary grass) has become a serious problem in north-western parts of India. After the development of resistance by *Phalaris minor* to isoproturon (Malik and Singh, 1994), new herbicide molecules like fenoxaprop-p-ethyl were recommended to combat the resistant biotypes. Fenoxaprop-*p*-ethyl was found effective against grassy weeds, but it remained ineffective against broad-leaved weeds (Singh and Singh, 2005). Isoproturon is still being used in areas where resistant biotypes are absent, and also due to its lower cost and non-availability of alternative herbicides. Continuous use of isoproturon in wheat for the control of *Phalaris minor* and also use of alternative herbicide has increased the density of broad-leaf weeds. To manage the dynamic and complex weed flora in wheat, it is essential to evaluate tank mixtures of herbicides to have a broad-spectrum weed control. Punia *et al.* (2002) reported 96-100% control of broad-leaf weeds and 92-100% control of *Phalaris minor* with application of tank mixture of fenoxaprop-*p*-ethyl + chlorosulfuron, resulting in significant increase in grain yield than application of these herbicides alone. Carfentrazone ethyl is a new post-emergent herbicide, belonging to the aryl triazoline family. It controls a wide spectrum of broad-leaf weeds in wheat (Singh *et al.*, 2004) but is ineffective against grassy weeds. It is a fast-acting contact herbicide that controls the weeds through membrane disruption. Its foliar uptake is rapid and weed desiccation can occur within 1 to 4 days of application (FMC, 2003). On its application white speclings are observed on wheat leaves, which disappear within 12-15 days. As the information on residual activity of metsulfuron methyl, carfentrazone ethyl, herbicide mixture of fenoxaprop-*p*-ethyl with metsulfuron methyl and carfentrazone ethyl is meagre, the present investigation was carried out to find out the suitable herbicide (carfentrazone ethyl and metsulfuron methyl) to be used as tank mixture with fenoxaprop-*p*-ethyl and isoproturon to widen the weed-control spectrum, including grasses and broad-leaf weeds and their phytotoxicity, if any, to the crop and their residual effect on the succeeding crops of fodder maize and mungbean.

MATERIALS AND METHODS

A field experiment was conducted during winter (*rabi*) season of 2001-02 and 2002-03 at research farm of J V

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College, Baraut to study the effect of herbicides and their mixtures on weed control, wheat productivity and their residual effect on the succeeding crops. The geographical location of Baraut is 29.6° N and 79.6° E, 230 m above mean sea level. The soil was sandy loam, with pH 7.6. The organic carbon, electrical conductivity and the available N, P and K were 0.44%, 0.31 dS/m, and 180, 18.1 and 245 kg/ha, respectively. The experiment comprised 11 treatments, viz. 2,4-D ethyl ester (400 g/ha), metsulfuron methyl (4 and 8 g/ha), carfentrazone ethyl (10 and 20 g/ha), isoproturon (500 g) + metsulfuron methyl (4 g/ha), isoproturon (500 g) + carfentrazone ethyl (10 g/ha); fenoxaprop-*p*-ethyl (100 g) + metsulfuron methyl (4 g/ha), fenoxaprop-*p*-ethyl (100 g) + carfentrazone ethyl (10 g/ha), weed-free season long; and weed check season long. These were tried in randomized block design with four replications. Wheat cv 'HD 2687' was sown in plots measuring 4.0 x 6.0 m on 16 and 28 November in 2001 and 2002 respectively after rice. Recommended doses of fertilizers as 120 kg N + 26.2 kg P + 33.3 kg K/ha were applied. Full dose of P and K along with one-third N were applied at the time of sowing, and the remaining dose of N was applied in two equal splits after first and second irrigation. All the herbicides alone or in mixture were applied 30 days after sowing (DAS) with knapsack sprayer fitted with flat-fan nozzle using 600 liters water/ha. Data on weed density and dry weight of weeds were recorded at 90 DAS using quadrates of 1 x 1 m and the data on weed density were analyzed after subjecting the original data to square-root transformation. Yield attributes and seed yield of wheat were recorded at the time of harvest. The residual study of herbicides in maize fodder and mungbean was conducted during rainy (*kharif*) season of 2002 and 2003 on the same set of treatments of the experiment. Germination was recorded in fodder maize and mungbean after 10 DAS. The green-and dry-forage yields in maize and the seed yield in mungbean were recorded at harvest. The economic analysis of each treatment was done on the basis of prevailing market rates of the inputs used and outputs obtained under each treatment. The market prices of 2,4-D at 400 g/ha, carfentrazone at 10 and 20 g/ha, metsulfuron at 4 and 8 g/ha, isoproturon at 500 g/ha and fenoxaprop 100 g/ha were: Rs 408,162.5 and 325, 325 and 650, 525 and 1,525/ha, respectively. The expenditure incurred on keeping the wheat crop weed-free was Rs 4,500/ha through manual weeding. The cost of wheat grain was taken as Rs 7.20/kg.

RESULTS AND DISCUSSION

Weed growth

Seven different species belonging to grasses and broadleaf weeds were observed in the experimental field. The maximum weed density was recorded in weedy check and the dominant weeds were: *Phalaris minor* (29.3%), *Poa annua* (15.0%), *Melilotus indica* (7.8%), *Anagalis arvensis* (11.1%), *Coronopus dydimus* (20.2%), *Rumex maritimus* (11.9%) and *Chenopodium album* (4.1%). Their occurrence and intensity varied under different treatments. Application of 2,4-D, metsulfuron methyl at 4 and 8 g/ha and carfentrazone ethyl at 10 and 20 g/ha remained ineffective against the grassy weeds like *Phalaris minor* and *Poa annua*. Metsulfuron at both the doses and carfentrazone at 20 g/ha recoded significantly lower weed density than 2,4-D and carfentrazone 10 g/ha (Table 1). Punia *et al.* (2005) reported lower efficacy of 2,4-D

Table 1. Effect of weed-control treatments on density of different weed species, total weed density, dry weight and weed-control efficiency at 90 DAS in wheat (mean data of 2 seasons)

Herbicide (g/ha)	*Anagais arvensis*	*Phalaris minor*	*Melilotus indica*	*Coronopus dydimus*	Total weed density (no/m^2)	Total dry weight of weeds (g/m^2)	Weed control efficiency (%)
2,4-D (400)	(9.0) 3.1	(62.8) 7.9	(10.5) 3.4	(19.6) 4.5	(145.4) 12.1	73.0	46.7
Metsulfuron (4)	(3.7) 2.0	(60.2) 7.7	(6.1) 2.6	(11.7) 3.5	(110.8) 10.5	51.1	63.4
Metsulfuron (8)	(1.6) 1.6	(52.1) 7.2	(3.5) 2.1	(4.1) 2.2	(88.6) 9.4	45.7	67.5
Carfentrazone (10)	(11.4) 3.5	(69.8) 8.4	(9.5) 3.2	(16.5) 4.1	(152.7) 12.3	89.5	35.3
Carfentrazone (20)	(6.8) 2.7	(63.0) 7.9	(5.8) 2.6	(10.1) 3.3	(119.1) 10.9	60.8	36.2
Isoproturon (500) + metsulfuron (4)	(5.8) 2.6	(35.7) 6.0	(6.0) 2.6	(15.0) 4.0	(81.1) 9.0	42.8	69.8
Isoproturon (500) + carfentrazone (10)	(9.1) 3.1	(35.5) 6.0	(8.1) 3.0	(14.6) 3.9	(87.6) 9.4	44.7	68.1
Fenoxaprop (100) + metsulfuron (4)	(5.0) 2.4	(21.8) 4.7	(5.2) 2.5	(13.7) 3.8	(61.9) 7.9	23.7	83.5
Fenoxaprop (100) + carfentrazon (10)	(9.7) 3.2	(8.6) 3.1	(8.4) 3.0	(14.4) 3.9	(57.8) 7.6	22.0	84.7
Weed free	(0.0) 1.0	(0.0) 1.0	(0.0) 1.0	(0.0) 1.0	(0.0) 1.0	0.0	100.0
Weedy check	(28.5) 5.4	(77.0) 8.7	(20.0) 4.6	(50.8) 7.2	(255.8) 16.0	137.8	
SEm ±	(1.2) 0.2	(3.2) 0.2	(0.8) 0.1	(1.8) 0.2	(4.4) 0.2	2.5	1.7
CD (P=0.05)	(3.6) 0.6	(9.3) 0.7	(2.3) 0.5	(5.2) 0.6	(13.7) 0.6	8.0	5.2

Data subjected to square-root ($\sqrt{x+1}$) transformation; figures in parentheses are original values against broad-leaf weeds like *Medicago denticulata*, *Lathyrus aphaca, Rumex maritimus* and *Melilotus indica.* Significantly lower weed density was observed in the herbicide mixture of fenoxaprop + carfentrazone than in isoproturon + carfentrazone and isoproturon + metsulfuron due to better control of both grasses and broad-leaf weeds. Isoproturon was found less effective in controlling *Phalaris minor* compared with that in fenoxaprop, confirming the results of Chopra and Chopra (2005). Significantly higher density of *Phalaris minor* was observed when fenoxaprop was tank mixed with metsulfuron methyl compared with fenoxaprop + carfentrazone ethyl.

The highest dry matter of weeds was recorded under weedy check treatment at 90 DAS, which was significantly higher than of all the herbicidal treatments. At this stage the lowest dry mater of weeds was recorded in the herbicide mixture of fenoxaprop + carfentrazone. In general, the dry matter of weeds increased with increase in the weed density. Application of 2,4 D was unable to control the grassy weed *Phalaris minor* and showed lower efficacy towards broad-leaf weeds. Metsulfuron methyl at 4 and 8 g/ha recorded significantly lower dry weight of weeds and higher weed-control efficiency compared with weedy check and 2,4-D, carfentrazone ethyl alone at 10 and 20 g/ha. The herbicide mixture of fenoxaprop with both carfentrazone and metsulfuron recorded significantly lower dry matter of weeds and higher weed-control efficiency compared with the herbicide mixture of isoproturon with carfentrazone and metsulfuron, due to better control of *Phalaris minor* with fenoxaprop.

Yield

The maximum values of yield attributes and yield were recorded in weed-free plots during both the seasons. Weed-free condition increased the availability of nutrients, space, light and water to wheat crop due to absence of crop-weed competition, which resulted in maximum number of spikes/m², grains/spike and 1,000-seed weight. All the herbicides alone or as tank mixture recorded significantly higher number of spikes/m². Among the herbicides, tank mixture of fenoxaprop-*p*-ethyl + carfentrazone ethyl and fenoxaprop-*p*-ethyl + metsulfuron registered 52.4% and 50.4% higher spikes/m² than weedy check. Fenoxaprop-*p*-ethyl + carfentrazone ethyl, isoproturon + metsulfuron methyl, isoproturon + carfentrazone ethyl and fenoxaprop-p-ethyl + metsulfuron methyl recorded significantly higher seeds/spike than 2,4-D, metsulfuron methyl 4 and 8 g/ha and carfentrazone ethyl 10 and 20 g/ha (Table 2). Higher levels of these yield parameters could be attributed to low competition stress and clean cultivation. The mixed population of grass and broad-leaf weeds showed 25.7% reduction in seed yield in weedy-check conditions compared with season-long weed-free condition. Fenoxaprop-*p*–ethyl + carfentrazone ethyl recorded 32.0, 28.9 and 26.1% higher seed yield than weedy check, 2,4-D ethyl ester and carfentrazone ethyl 10 g/ha due to control of both grassy and broad-leaf weeds, and gave grain yield on a par with that of weed free and fenoxaprop + metsulfuron treatments. It may be due to higher weed-control efficiency, which provided a favourable environment for growth and development of the crop. The herbicide mixture of isoproturon + metsulfuron methyl and isoproturon + carfentrazone ethyl significantly affected the seed yield of wheat compared with weedy check and sole application of different herbicides.

Table 2. Effect of weed-control treatments on yield attributes, yield and economics in wheat

Herbicide (g/ha)	Spikes/m²		Grains/spike		1,000-seed weight (g)		Seed yield (t/ha)		Net returns* (x 10³ Rs/ha)	Benefit : cost ratio
	2001-02	2002-03	2001-02	2002-03	2001-02	2002-03	2001-02	2002-03		
2,4-D (400)	386.2	356.2	38.8	37.6	38.3	39.0	3.53	3.44	12.63	2.00
Metsulfuron (4)	463.5	444.0	43.9	42.3	40.3	39.3	4.05	3.87	16.01	2.26
Metsulfuron (8)	493.5	482.5	44.5	43.1	40.7	39.9	4.15	4.00	16.51	2.28
Carfentrazone (10)	375.0	351.0	38.0	35.0	38.7	39.0	3.58	3.54	13.28	2.07
Carfentrazone (20)	448.5	428.5	44.1	42.4	40.3	39.7	3.86	3.63	14.44	2.15
Isoproturon (500) + metsulfuron (4)	497.5	483.5	45.6	44.3	41.9	40.7	4.20	4.27	17.68	2.38
Isoproturon (500) + carfentrazone (10)	503.5	476.0	45.1	43.6	41.6	39.7	4.13	4.09	16.82	2.31
Fenoxaprop (100) + metsulfuron (4)	547.5	521.0	46.5	44.9	41.9	40.8	4.57	4.25	17.73	2.26
Fenoxaprop (100) + carfentrazon (10)	543.5	512.5	46.2	45.0	41.9	40.2	4.62	4.36	18.48	2.33
Weed free	571.0	542.5	47.6	47.4	42.1	41.2	4.73	4.42	16.44	2.05
Weedy check	367.5	333.5	34.8	32.0	37.8	37.8	3.49	3.31	12.50	2.04
SEm±	12.4	15.7	0.83	1.17	0.50	0.50	0.07	0.08		
CD (P=0.05)	35.5	45.3	2.40	3.37	1.43	1.43	0.20	0.23		

*Mean of two seasons

Economics

All the herbicides alone or as tank mixtures recorded higher monetary returns over weedy check. Among the weed-control treatments, fenoxaprop tank mixed with carfentrazone ethyl and metsulfuron methyl gave the maximum monetary returns, due to excellent control of grassy and broad-leaf weeds without any adverse effect on crop growth. Tank mixture of isoproturon with metsulfuron and carfentrazone proved to be the next best treatment. Lower monetary returns were recorded with 2,4-D and sole application of carfentrazone at 10 and 20 g/ha and metsulfuron at 4 and 8 g/ha (Table 2) due to inability of these herbicides to control *Phalaris minor.* The herbicide mixtures of fenoxaprop and isoproturon with metsulfuron and carfentrazone recorded higher monetary advantage compared with the sole application of metsulfuron and carfentrazone at different doses. Weed free treatment recorded lower monetary returns and benefit: cost ratio than fenoxaprop + carfentrazone, mainly due to the high cost involved in repeated manual weeding to keep the crop weed free in spite of higher grain yield. Among the weed-control treatments, highest benefit : cost ratio (2.38) was recorded with isoproturon + carfentrazone, followed by fenoxaprop + carfentrazone, and least with 2,4-D .

None of the herbicide as sole or in tank mixture showed adverse effect on the succeeding crops of maize fodder and mungbean.

It was concluded that tank mix of fenoxaprop-*p*–ethyl (100 g) + carfentrazone ethyl (10 g/ha) followed by fenoxaprop-*p*-ethyl (100 g) + metsulfuron (4 g/ha) applied 30 days after sowing were the most remunerative and effective herbicide mixtures for controlling the complex weed flora in wheat under western Uttar Pradesh conditions.

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