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Assessing bio-efficacy potential of herbicide combinations for broad-spectrum weed control in late-sown wheat

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ABSTRACT

A field experiment was conducted during 2015-16 and 2016-17 at Rajasthan College of Agriculture, Udaipur, India with the objective to assess bio-efficacy potential of the ready-mix herbicides against complex weed flora in wheat. The experiment consisting of fifteen treatments, was laid out in a randomized block design with four replications. The results indicated significant reduction in population and growth of weeds by ready-mix application of sulfosulfuron + metsulfuron (32.0 g/ha) and mesosulfuron + iodosulfuron (14.4 g/ha) followed by clodinafop + metsulfuron (64.0 g/ha), pinoxaden + metsulfuron (64.0 g/ha) over other weed control treatments. However, two hand weeding (30 and 45 DAS) registered maximum decline in density and dry biomass of all the weeds. Moreover, herbicides combination sulfosulfuron + metsulfuron and mesosulfuron + iodosulfuron attributed to greater value of weed control index (WCI) with maximum reduction of weed density and dry biomass. At 60 DAS, the array of WCI ranged from 9.19 to 95.01 and 57.48 to 97.01% for monocots and dicots, respectively and resulted into higher grain yield (34.3 and 20.5% more), net returns (49.1 and 47.7% more) and B-C ratio (2.34 and 2.32) over the unweeded control. The study concluded that the use of sulfosulfuron + metsulfuron (32.0 g/ha) and mesosulfuron + iodosulfuron (14.4 g/ha) as post-emergence at 5 WAS provided efficacious control of all sorts of weeds in wheat with higher yield and net returns.

INTRODUCTION

Weeds are one of the major biotic constraints not only in the wheat production but in other crops also as they compete with crops for nutrients, moisture, light and space (Chhokar *et al.* 2012). Weeds possess many growth characteristics and adaptations which enable them to successfully exploit the numerous ecological niches (Zimdahl 2013). Weeds suppress the crop growth in the early stages which results in reduction of yield (Verma *et al.* 2015). Fahad *et al.* (2015) opined that allowing weeds to grow with wheat at the beginning of the season has a greater negative impact on crop yield than allowing the weeds to grow in the crop later in the season. In late-sown wheat, the reduction in grain yield due to mixed weed flora was reported up to 34.3% which leads to the loss of 2.57, 0.43 and 1.27% of NPK (Meena *et al.* 2017a, b, 2019). Wheat is infested with grassy as well as broad-leaved weeds. To control mixed population of weeds and to avoid herbicide resistance and weed flora shift by continuous use of single herbicide, compatible mixtures can be employed (Das and Yaduraju 2012). Under such circumstances, mix or sequential application of herbicides with different selectivity can widen the range of weed control, save time, application cost and reduce impact of herbicides on environment, resulting in biological activity higher than their individual applications (Sharma *et al.* 2015). Application of tank-mix herbicides may result in better control of weeds due to possible synergistic actions (Das and Yaduraju 2012, Susha *et al.* 2014). Tank-mix or pre-mix application of pre- and post-emergence herbicide at different time showed effective weed control. Besides controlling mixed weed flora, the integrated use of herbicides may help in managing herbicide resistance problems. Keeping above facts in view, an investigation was carried out with the objective to assess the efficacy of herbicide combinations for broad spectrum weed control in wheat.

MATERIALS AND METHODS

The study was consisting of two experiments that conducted during *Rabi* season of 2015-16 and 2016-17 at the Rajasthan College of Agriculture, Udaipur (India) which is situated at 24°5' N latitude and 74°42' E longitude with an altitude of 582.17 m above mean sea level. The region falls under NARP agro climatic zone IVa (Sub-Humid Southern Plains and Arawali Hills) of Rajasthan (India).The soil of the experimental site was clay loam in texture, non-saline and slightly alkaline in reaction. The soil was low in available nitrogen, medium in organic carbon and phosphorus and high in available potassium. The experiment consists of fifteen treatments that were tested on the wheat crop variety '*Raj- 3765*'. All the treatments were replicated four times in a randomize block design. The crop was sown on 10th December, 2015 during first year and 12th December, 2016 during the second year at a row spacing of 22.5 cm with a recommended seed rate of 125 kg/ha. The crop was supplied with 90 kg N and 35 kg P/ha through urea and di-ammonium phosphate (DAP). Half dose of nitrogen and full dose of phosphorus were applied as basal at the time of sowing while remaining half dose of nitrogen was top dressed in two equal splits at the time of first and second irrigation.

The herbicides were sprayed with battery operated knapsack sprayer fitted with flat-fan nozzle using spray volume of 500 L/ha. The observations were taken on different weed parameters during crop growth period. Data on density and dry matter of weeds were recorded at 60 DAS under each treatment with the help of 0.25 m^2 quadrate selected randomly in each plot. After identification, the weed species were categorized into monocots and dicots. Weed density was calculated on the basis of the total number of an individual weed species/m^2 and weed control index were computed using the standard procedure as following details:

To compare the different treatments of weed control on the basis of dry weight, weed control index (WCI) was calculated as follows. It indicates the per cent reduction in the dry weight in treated plots compared to weedy plots.

$$WCI\ (\%) = \frac{WDc - WDt}{WDc} X\ 100$$

Where, WD_C is the weed dry matter in unweeded control (g/m^2) and WDt is the weed dry matter in treated plot (g/m^2).

Data were subjected to the statistical analysis by using SAS 9.3. Analysis of variance was performed using PROCGLM after square root transformation ($\sqrt{x+0.5}$) of the original data as appropriate for weed density and dry weight to hold the normality assumption, where, x is the observed value and 0.5 is a constant. The treatment means were separated at p=0.05.

RESULTS AND DISCUSSION

Weed species

The field was severely infested with both grassy as well as broad-leaf weeds. The population of broad-leaf weeds was more (91%) as compared to monocots (9%). Among the dicots, *Melilotus indica* was more prominent with highest density (45%) followed by *Fumaria parviflora* (15%), *Chenopodium album* (9%), *Chenopodium murale* (6%), *Convolvulus arvensis* (5%) and others dicots (11%) (*Anagallis arvensis*, *Spergulla arvensis* and *Coronopus didymus*) with *Phalaris minor* (9%) only species under monocots.

Effect on weed density and weed dry matter

Different weed management options significantly reduced the density and dry weight of monocot and dicot weeds over unweeded control. The highest density of different weeds was observed in unweeded control whereas two hand weeding recorded lowest pooled density (**Table 1**). The per cent reduction in pooled density of dicots (*Melilotus indica*, *Fumaria parviflora*, *Chenopodium murale*, *Chenopodium album* and *Convolvulus arvensis*) was varied from 59.25 to 95.30, 44.30 to 88.36, 11.36 to 93.13, 45.08 to 90.89 and 23.12 to 91.64%, respectively as lowest in pendimethalin to highest in two hand weeding. Similarly, the reduction in weed density of monocot (*Phalaris minor*) ranged between 16.65-87.70% among the treatments. Further, the highest reduction in the dry weight of monocot and dicots was noticed under two hand weeding (2.06 and 4.38 g/m^2) over the control (28.68 and 146.42 g/m^2), which recorded highest value (**Table 2**). Among the herbicidal treatments, mixed application of sulfosulfuron + metsulfuron curtailed the dry weight of monocot and dicot weeds to 92.12 and 95.97%, respectively followed by mesosulfuron + iodosulfuron (90.37 and 95.57%) and proved significantly superior over rest of the herbicidal treatments. The combined application of these herbicides furnished superior results as compare to application of single herbicide. Application of pendimethalin followed by different post-emergence herbicides also provided satisfactory result in curbing density and dry weight of weeds.

Weed control index (WCI)

Data confirm that the herbicide mixtures and sequential application attributed to higher weed control index than singly applied herbicides due to stunted weed growth and their dry biomass. The array of weed control index at 60 DAS was between 7.2 to 97.8% for monocot and dicot weeds (**Table 2**). Among the treatments, two hand weeding brought about greatest reduction in pooled dry matter accumulation of monocot, dicot and total weeds (92.8, 97.0 and 96.3%). However, variations were at par with sulfosulfuron + metsulfuron (92.2, 95.9 and 95.4%), mesosulfuron + iodosulfuron (90.4, 95.6 and 94.7%), clodinafop + metsulfuron (90.2, 95.3 and 94.4%) and pinoxaden + metsulfuron (89.7, 95.0 and 94.2%), respectively for dry biomass of monocot, dicot and total weeds. The performances of sole applied herbicides were not up to the satisfactory level. The solitary application of pendimethalin lagged behind herbicide mixtures and sequential application and hence leads to lesser WCI among all the treatments. However, the results were significant over the unweeded control, which accounted for the minimum weed control index among all weed control measures.

Effect on yield attributes and economics

All the treatment significantly improved the yield attributes that ascribed to augmented grain yield and

Table 1. Effect of weed control treatments on density of weeds at 60 DAS of wheat (pooled data of two year)

Treatment	Weed density (no/m^2)						
	Melilotus indica	*Fumaria parviflora*	*Cheno-podium murale*	*Cheno-podium album*	*Convol-vulus arvensis*	Others dicotyledons weeds	*Phalaris minor*
Pendimethalin (750 g/ha) PE	6.24(38.4)	4.25(17.6)	3.42(11.2)	3.35(10.7)	2.77(7.2)	3.84(14.3)	5.97(35.1)
Sulfosulfuron (25 g/ha) PoE	4.67(21.3)	3.03(8.7)	1.98(3.4)	2.48(5.7)	1.65(2.2)	2.60(6.2)	4.38(18.7)
Metribuzin (210 g/ha) PoE	4.42(19.0)	2.95(8.2)	1.85(2.9)	2.46(5.6)	1.61(2.1)	2.49(5.7)	4.10(16.3)
Clodinafop (60 g/ha) PoE	4.36(18.5)	2.89(7.9)	1.81(2.8)	2.39(5.2)	1.59(2.0)	2.44(5.5)	4.16(16.8)
Metsulfuron (4 g/ha) PoE	4.17(16.9)	2.82(7.4)	1.62(2.1)	2.07(3.8)	1.57(2.0)	2.19(4.3)	3.82(14.1)
Pendimethalin + metribuzin (750 + 175 g/ha) PE	3.91(14.8)	2.75(7.1)	1.62(2.1)	2.02(3.6)	1.52(1.8)	2.17(4.2)	3.72(13.3)
Pendimethalin *fb* sulfosulfuron (750 + 20 g/ha) PE *fb* PoE	3.89(14.6)	2.67(6.6)	1.61(2.1)	1.98(3.4)	1.48(1.7)	1.91(3.1)	3.45(11.4)
Pendimethalin *fb* clodinafop (750 + 50 g/ha) PE *fb* PoE	3.41(11.1)	2.58(6.1)	1.51(1.8)	1.98(3.4)	1.40(1.5)	1.89(3.1)	3.14(9.4)
Pendimethalin *fb* metsulfuron (750 + 4 g/ha) PE *fb* PoE	3.10(9.1)	2.53(5.9)	1.46(1.6)	1.93(3.2)	1.32(1.2)	1.84(2.9)	3.10(9.1)
Sulfosulfuron + metsulfuron (30 + 2 g/ha) PoE	2.56(6.0)	2.17(4.2)	1.23(1.0)	1.67(2.3)	1.16(0.8)	1.74(2.5)	2.62(6.3)
Pinoxaden + metsulfuron (60 + 4 g/ha) PoE	2.78(7.2)	2.37(5.1)	1.36(1.4)	1.87(3.0)	1.26(1.1)	1.83(2.8)	3.05(8.8)
Mesosulfuron + iodosulfuron (12 + 2.4 g/ha) PoE	2.68(6.7)	2.25(4.6)	1.26(1.1)	1.82(2.8)	1.21(1.0)	1.78(2.7)	2.83(7.5)
Clodinafop + metsulfuron (60 +4 g/ha) PoE	2.76(7.1)	2.36(5.1)	1.32(1.2)	1.85(2.9)	1.23(1.0)	1.79(2.7)	2.89(7.8)
Two hand weeding at 30 and 45 DAS	2.22(4.4)	2.04(3.7)	1.17(0.9)	1.51(1.8)	1.13(0.8)	1.68(2.3)	2.38(5.2)
Unweeded control	9.74(94.3)	5.66(31.5)	3.63(12.7)	4.48(19.5)	3.14(9.3)	5.01(24.6)	6.53(42.1)
LSD (p=0.05)	2.28	1.11	0.90	0.88	0.69	1.14	1.43

*Data subjected to $\sqrt{X + 0.5}$ transformation and figures in parentheses are original weed count/m^2

Table 2. Effect of weed control treatments on weed dry weight and weed control index at 60 DAS of wheat (pooled data of two year)

Treatment	Weed dry matter accumulation (g/m^2)			Weed control index (%)		
	Monocot weeds	Dicot weeds	Total weeds	Monocot weeds	Dicot weeds	Total weeds
Pendimethalin (750 g/ha) PE	5.18 (26.34)	7.95 (62.76)	9.47 (89.10)	9.2	57.5	49.4
Sulfosulfuron (25 g/ha) PoE	3.14 (9.38)	4.48 (19.58)	5.43 (28.96)	68.4	86.6	83.4
Metribuzin (210 g/ha) PoE	3.01 (8.58)	4.25 (17.54)	5.16 (26.12)	71.4	88.0	85.1
Clodinafop (60 g/ha) PoE	3.02 (8.63)	4.15 (16.76)	5.09 (25.39)	71.2	88.5	85.5
Metsulfuron (4 g/ha) PoE	2.95 (8.18)	4.14 (16.68)	5.04 (24.86)	72.9	88.6	85.8
Pendimethalin + metribuzin (750 + 175 g/ha) PE	4.09 (16.23)	6.61 (43.24)	7.74 (59.47)	43.8	70.5	66.0
Pendimethalin *fb* sulfosulfuron (750 + 20 g/ha) PE *fb* PoE	2.08 (3.84)	3.80 (13.96)	4.28 (17.80)	88.6	90.5	89.8
Pendimethalin *fb* clodinafop (750 + 50 g/ha) PE *fb* PoE	2.00 (3.52)	3.64 (12.78)	4.10 (16.30)	89.7	91.3	90.7
Pendimethalin *fb* metsulfuron (750 + 4 g/ha) PE *fb* PoE	1.98 (3.48)	3.48 (11.62)	3.95 (15.10)	89.9	92.1	91.4
Sulfosulfuron + metsulfuron (30 + 2 g/ha) PoE	1.64 (2.24)	2.52 (5.89)	2.94 (8.13)	94.4	96.0	95.4
Pinoxaden + metsulfuron (60 + 4 g/ha) PoE	1.85 (2.96)	2.78 (7.24)	3.27 (10.20)	91.7	95.1	94.2
Mesosulfuron + iodosulfuron (12 + 2.4 g/ha) PoE	1.79 (2.76)	2.64 (6.48)	3.12 (9.24)	92.5	95.6	94.7
Clodinafop + metsulfuron (60 +4 g/ha) PoE	1.82 (2.82)	2.73 (6.94)	3.20 (9.76)	92.3	95.3	94.4
Two hand weeding at 30 and 45 DAS	1.58 (2.06)	2.21 (4.38)	2.63 (6.44)	95.0	97.0	96.3
Unweeded control	5.40 (28.68)	12.12 (146.42)	13.25 (175.10)	0.0	0.0	0.0
LSD (p=0.05)	4.46	6.78	5.79	-	-	-

*Data subjected to $\sqrt{X + 0.5}$ transformation and figures in parentheses are original weed count/m^2

Table 3. Effect of weed control treatments on yield attributes and economics of wheat (pooled data of two year)

Treatment	Tillers/m row length)	Grains /spike (no.)	1000-grains weight	Grain yield (t/ha)			Net returns (x10^3₹/ha)	B:C
				2015-16	2016-17	Pooled		
Pendimethalin (750 g/ha) PE	78.0	35.4	36.9	3.52	3.80	3.66	49.17	1.84
Sulfosulfuron (25 g/ha) PoE	83.1	37.4	37.6	3.71	3.99	3.85	52.35	1.92
Metribuzin (210 g/ha) PoE	82.1	37.6	37.8	3.69	3.97	3.83	52.65	1.97
Clodinafop (60 g/ha) PoE	85.1	38.2	38.5	3.72	4.00	3.86	53.19	1.97
Metsulfuron (4 g/ha) PoE	85.8	39.5	38.5	3.76	4.04	3.90	54.19	2.03
Pendimethalin + metribuzin (750 + 175 g/ha) PE	82.2	36.7	37.3	3.67	3.95	3.81	52.26	1.95
Pendimethalin *fb* sulfosulfuron (750 + 20 g/ha) PE *fb* PoE	88.0	40.7	39.2	3.83	4.05	4.04	56.57	2.10
Pendimethalin *fb* clodinafop (750 + 50 g/ha) PE *fb* PoE	88.5	41.4	40.0	3.84	4.11	3.98	55.46	2.05
Pendimethalin *fb* metsulfuron (750 + 4 g/ha) PE *fb* PoE	89.5	41.7	42.1	3.85	4.15	4.02	56.25	2.07
Sulfosulfuron + metsulfuron (30 + 2 g/ha) PoE	94.0	44.8	44.1	4.27	4.55	4.41	63.83	2.34
Pinoxaden + metsulfuron (60 + 4 g/ha) PoE	91.4	42.3	43.3	4.14	4.42	4.28	61.45	2.27
Mesosulfuron + iodosulfuron (12 + 2.4 g/ha) PoE	93.3	44.3	44.0	4.24	4.52	4.38	63.23	2.32
Clodinafop + metsulfuron (60 + 4 g/ha) PoE	92.1	43.2	43.8	4.18	4.46	4.32	61.53	2.21
Two hand weeding at 30 and 45 DAS	95.6	45.4	44.4	4.36	4.64	4.50	59.58	1.79
Unweeded control	73.5	32.7	36.5	3.14	3.42	3.28	42.81	1.62
LSD (p=0.05)	6.6	4.0	3.1	0.40	0.38	0.39	3.97	0.22

economics over the unweeded control (**Table 3**). The highest number of tillers per meter row length, grains per spike and 1000-grains weight were through the ready-mix application of metsulfuron + sulfosulfuron (94.0, 44.8 and 44.1) followed by mesosulfuron + iodosulfuron (93.3, 44.3 and 44.0) which is at par with two hand weeding (95.6, 45.4 and 44.4) that attributed to enhanced grain yield. The maximum yield increase was recorded under two hand weeding (37.0% higher) with respect to control. Further, the grain yield data elucidated that combined application of herbicides either as pre-mix, tank-mix or sequentially performed better in obtaining higher yield of wheat over their sole application or applied singly. Among the herbicidal treatments, the mixed application of metsulfuron + sulfosulfuron and mesosulfuron + iodosulfuron provided 34.3 and 20.5% yield augmentation compared to unweeded control. The solitary application of any of the herbicide resulted lesser yield. The similar trend of results was also recorded for net returns and B-C ratio. The highest net returns was realized by applying metsulfuron + sulfosulfuron and mesosulfuron + iodosulfuron (49.1 and 47.7% more) with B-C ratio of 2.34 and 2.32 over unweeded control (1.62).

Hand weeding (30 and 45 DAS) obtained the highest density for all the weeds due to their complete and effective removal whereas, sulfosulfuron + metsulfuron found more superior among the herbicidal treatments in curtailing the weed growth and their population over the unweeded control. The tank mixtures of broad-leaf (e.g. metsulfuron, carfentrazone) and grassy weed (e.g. clodinafop, pinoxaden) killing herbicides provided higher order of performance in terms of weed density and intensity of total weeds (Meena *et al.* 2017a). The application of tank-mixtures (sulfosulfuron + metsulfuron) provided better broad spectrum (both monocot and dicot) weed control. This combination exhibit properties of both foliar and soil activity that inhibits cell division in shoots and roots and growth by inhibiting plant enzyme acetolactase synthase, thereby, blocking branches chain of amino acid biosynthesis and hence the plant suffers. Due to this, phloem transport of the plant is hampered. A secondary effect is stunted growth on account of cessation of cell division and slow plant death. Contrary to the alone application of either of the herbicide was not found effective to control all sort of the weeds in the entire crop season (Lekh Chand and Puniya 2017, Chaudhari *et al.* 2017, Meena *et al.* 2017a, b). Tank-mix application of broad-leaf weeds and grass suppressing herbicides over their individual applications in reducing total weed density and dry matter gave better results (Singh *et al.* 2017, Barla *et al.* 2017, Meena *et al.* 2019). Application of mesosulfuron + iodosulfuron inhibits the acetohydroxy acid synthesis enzyme in the plants, which is responsible for the synthesis of the branched chain amino acids valine, leucine, and isoleucine and cell division in the growing tips of roots and shoots. Further, its secondary effect on photosynthesis, respiration and ethylene production produce the symptoms of yellowing and reddening of monocot and leaf dropping in dicot weeds. Sole application of a single herbicide was less effective in controlling weeds as compared to their ready-mix application, but metsulfuron had significant effects on population of broad-leaf weeds as compared to other single herbicide (Meena *et al.* 2019). The superiority of tank mix application of broad-leaf weed and grass suppressing herbicides over their individual applications in curtailing total weed density and dry matter has also been reported by other authors (Singh *et al*. 2017, Barla *et al*. 2017).

From the results, it was concluded that the tank-mixtures application of sulfosulfuron + metsulfuron (32 g/ha), mesosulfuron + iodosulfuron (14.4 g/ha) as post-emergence at 5 WAS provided better broad-spectrum weed control. Both the herbicide combinations have higher compatibility in mixtures and hence their higher compatibility and synergistic effects led to better broad-spectrum weed control that attributed to higher grain yield, net returns and B-C ratio.

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