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Bio-efficacy of readi-mix herbicides on weeds and productivity 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 to evaluate the bio-efficacy of readi-mix herbicides in late sown wheat. The experiment consisting of fifteen treatments was laid out in randomized block design with four replications. The results revealed that Readi-mix application of sulfosulfuron + metsulfuron (32 g/ha)) and mesosulfuron + iodosulfuron (14.4 g/ha) gave higher weed control index (95.36, 94.72%), lower weed index (2.00, 2.75%) and weed persistence index (0.349, 0.351) whereas, higher index value of crop resistance index (CRI), weed management index (WMI) and herbicide efficiency index (HEI) (28.61, 0.38 and 5.50). Both of these treatments recorded 34.3 and 33.3 per cent grain yield enhancement along with 49.0% and 47.7% higher net returns over the unweeded control with the highest benefit-cost ratio (2.34 and 2.32). Results from contract analysis indicated significant ($p < 0.0001$) interaction of year x treatments and response of Readi-mix v/s single/sequential herbicide application on grain yield, weed density and dry matter. The joint effect of parameters on grain yield was significant with high magnitude ($R_{GY.\text{Weed density total, Weed dry weight total, Total N, P and K uptake}} = 0.98$; $p < 0.0001$). Additionally, the regression model for grain yield on total weed density ($R^2 = 0.84$), weed dry weight (R^2=0.79), total N uptake (R^2=0.98), P uptake (R^2=0.93) and K uptake (R^2 = 0.97) demonstrated significant dependence. Moreover, no symptoms of phytotoxicity were seen in any of the treatment in the crop at 21 days after herbicide application.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is one the most important food crop of world playing crucial role in global food security by providing food to billions of people and half of the dietary protein and more than half of the calories (Meena *et al*. 2017a and 2017b). Late sowing of wheat is a common practice in rice-wheat, cotton-wheat (Khan *et al*. 2010) sugarcane-wheat, potato-wheat, vegetable pea-wheat cropping systems in Asia. The reasons for late sowing of wheat are late transplanting of rice, late harvest of the preceding crops, use of long-duration rice varieties and heavy rains during later phase of rice. Sowing dates has the greatest effect on weed growth from the stage of initial development to shooting. In the early sowing, the weeds were able to emerge and become established before the onset of winter. But the level of weed infestation is more with the largest number of weeds in the late-sown wheat, where the crop did not form a closed canopy. In a study, Fodor and Palmai (2008) found that wheat produced less biomass after late sowing, while that of weeds was greater due to predominance and more infestation from complex weed flora. In cases where higher nitrogen applied, results showed fewer weeds in early and optimum sowing dates, while it increased weed infestation after late sowing. Late sowing of wheat significantly increased weed population and dry weight and hence reduced the crop growth and yield of wheat by enhancing the weed interference.

The reduction of grain yield in late sown wheat was reported up to 34.3% due to mixed weed flora (Meena *et al*. 2017a). Under these conditions, herbicides are one of the major groups of pesticides which contribute to the increased and economical production of crops. But the repeated applications of herbicides with similar modes of action exert a strong selection pressure on target weed populations that may consequence into herbicide resistance and weed shift.

Keeping all the above facts in view, an attempt was made to find out the efficacy and selectivity of different herbicides as tank-mix or pre-mix against complex weed flora to improve the productivity of wheat.

MATERIALS AND METHODS

This study was conducted for two consecutive years *i.e*. 2015-16 and 2016-17 in *Rabi* (winter) season at the Instructional Farm, Rajasthan College of Agriculture, Udaipur 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). There was no rainfall during the crop growing period during both the years. 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 consisted fifteen treatments. All the treatments were replicated four times indiscriminately in randomized block design on the same unit of cultivation. Before growing of wheat, the soybean crop was taken at the same experimental site during *Kharif* (rainy) season. Wheat variety '*Raj- 3765*' was used as a test crop. 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_2O_5/ha through urea and 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. After sowing, a light irrigation was given to the crop for uniform germination and next day the pre-emergence herbicides were applied.

All the herbicides were sprayed with battery operated knap-sack sprayer fitted with flat-fan nozzle using spray volume of 500 l/ha. Data on density and dry matter of weeds were recorded at 60 DAS with the help of 0.25 m^2 quadrate selected randomly in each plot. After identifying, the weed species were grouped into monocotyledons and dicotyledons separately. Weed density was calculated on the basis of the total number of an individual weed species/m^2. On the basis of weed data, different weed indices were computed using the standard procedure as following details:

Weed control efficiency (WCE)

Weed control efficiency was computed by adopting the following formula given by Mani *et al*. 1973) as follows:

$$\text{WCE (\%)} = \frac{\text{WPc} - \text{WPt}}{\text{WPc}} \text{X } 100$$

Where, WP_C is the weed population in unweeded control (no. of plants per quadrate) and WPt is the weed population in treated plot (no. of plants per quadrate).

Weed control index (WCI)

Weed control index was calculated to compare the different treatments of weed control on the basis of dry weight. It indicates the per cent reduction in the dry weight in treated plots compared to weedy plots. The formula is as follows (Mani *et al*. 1973, Das 2008):

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

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}).

Weed index (WI)

Weed index is the per cent reduction in crop yield under a particular treatment due to the presence of weeds in comparison to weed free plot as suggested by Gill and Kumar (1969). This is used to assess the efficacy of a herbicide. Lesser the weed index, better is the efficiency of a herbicide. It is expressed in percentage and was determined with the help of following formula:

$$\text{WI (\%)} = \frac{\text{X} - \text{Y}}{\text{X}} \text{X } 100$$

Where, WI = Weed index; X = Crop yield from weed free plot (hand weeding) and Y = Crop yield from the treated plot for which weed index is to be worked out.

Weed persistence index (WPI)

This index indicates the resistance in weeds against the tested treatments and confirms the effectiveness of the selected herbicides, and the same was computed using the given formula as suggested by Mishra and Mishra (1997):

$$WPI = \frac{\text{Weed dry weight in treated plot}}{\text{Weed dry weight in control plot}} \text{ x } \frac{\text{Weed count in control plot}}{\text{Weed count in treated plot}}$$

Crop resistance index (CRI)

The relationship between the crop biomass and weed biomass can be correlated with the help of crop resistance index and its shows indirect proportionate relationship to each other. The index can be calculated with the help of below mentioned formula given by Mishra and Mishra (1997) as follows:

$$\text{CRI} = \frac{\text{Crop dry weight in treated plot}}{\text{Crop dry weight in controlplot}} \text{ X } \frac{\text{Weed dry weight in control plot}}{\text{Weed dry weight in treated plot}}$$

Weed management index (WMI)

This index indicates the yield increase with respect to control because of weed management options taken and percent control of weeds by the respective treatment.

$$\text{WMI} = \frac{\text{Per cent crop yield increase over control}}{\text{Percent control of weeds}}$$

Herbicide efficiency index (HEI)

This index represents the potential of a particular herbicide for controlling the weeds along with their phyto-toxicity effect on the crop (Krishnamurthy *et al.* 1975).

$$\text{HEI (\%)} = \frac{\frac{\text{Yt} - \text{Yc}}{\text{Yt}} \text{ X } 100}{\left(\frac{\text{WDMt}}{\text{WDMc}}\right) \text{ X } 100}$$

Where, Yt- crop yield from treated plot, Yc- crop yield from weedy check plot, WDMt-weed dry matter in treated plot and WDMc-weed dry matter in weedy check plot.

Phyto-toxicity in terms of chlorosis, stunting, leaf burning, scorching, hyponasty and epinasty was visually observed at 7, 14 and 21 days after herbicide application (DAA) using rating scale of 0-10 scale, where 0 = indicate no effect on plant and 10 = shows complete death of plant (Rao 2000). Protein content in grain was worked out by multiplying nitrogen content in grain (%) with factor 6.25 (AOAC 1975) and expressed as per cent protein content. The economics of different treatments were worked out to evaluate the benefit accrued from the treatments applied in terms of net return (kg/ha) and benefit-cost ratio as follows:

$$\text{Benefit: Cost} = \frac{\text{Gross returns (`/ha)}}{\text{Total cost [cost of cultivation + treatment (`/ha)]}}$$

Data generated from the field experiments were subjected to the statistical analysis by using SAS 9.3. Analysis of variance was performed using PROC GLM 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. The post hoc test for treatments mean comparisons under each parameter was done on the basis of Duncan's Multiple Range Test (DMRT) at p=0.05. Relationship of wheat grain yield on total weed density, total weed dry weight, total N uptake, total P uptake and total K uptake were studied by the linear bivariate regression analysis and to study the joint/combined effect of parameters on grain yield, multiple correlation study has been accomplished. Cluster analysis was performed using PROC CLUSTER to understand the different herbicides functional groups hierarchically based on dissimilarity/distance and presented by dendogram.

RESULTS AND DISCUSSION

Weed flora

The experimental field was utterly invaded with mixed flora of weeds consisting of both dicots and monocots. Among the total weeds, dicots weeds (91%) were more prominent than monocots (9%). The weed flora under dicots includes many species like *Melilotus indica* (45%), *Fumaria parviflora* (15%), *Chenopodium album* (9%), *Chenopodium murale* (6%), *Convolvulus arvensis* (5%) and others dicots (11%) (*Anagallis arvensis, Spergulla arvensis* and *Coronopus didymus*) whereas *Phalaris minor* (9%) was only grassy weed under monocot.

Effect on density and dry weight of weeds

Pooled analysis of data revealed significant reduction in all the weed control treatments with respect to weed density and dry matter over the unweeded control (**Table 1**). The highest reduction in density and dry matter of weeds were recorded under two hand weeding (18.93 no./m^2 and 6.44 g/m^2) due to complete removal of the weeds whereas sulfosulfuron + metsulfuron found more superior among the herbicides treatments in curtailing the weed population (23.18 no./m^2 and 8.13 g/m^2) followed by mesosulfuron + iodosulfuron (26.07 no./m^2 and 9.24 g/m^2) as compared to unweeded control. Sole application of a single herbicide was less effective in controlling weeds as compared to their readi-mix application but metsulfuron had significant effects on population of broad-leaf weeds (50.26 no./m^2 and 24.86 g/m^2) as compared to other single herbicide. The tank mixtures of broad-leaf and grassy weed killing herbicides provided higher order of performance in terms of weed density and intensity of total weeds (Meena *et al.* 2017a). Tank mix or readi-mix application of sulfosulfuron + metsulfuron provided excellent control of both dicot and monocot weeds. 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). The superiority of tank mix application of broad-leaf weed and grass suppressing herbicides over their individual applications in reducing total weed density and dry matter given better results (Chaudhari *et al.* 2017, Singh *et al.* 2017, Barla *et al.* 2017). 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.

Effect on weed indices

The highest value of weed control indices (WCI) was obtained from hand weeding (96.32%) with respect to unweeded control (**Table 2**). Amongst herbicides, the maximum value of WCI was achieved by sulfosulfuron + metsulfuron (95.36%) closely followed by mesosulfuron + iodosulfuron (94.72%). Both these treatments are comparable to two hand weeding. The sole application of single herbicide registered less WCI. Similarly, the least value of WI and WPI was recorded under sulfosulfuron + metsulfuron (2.00 and 0.349) and mesosulfuron + iodosulfuron (2.75 and 0.351) followed by clodinafop + metsulfuron (3.98 and 0.350) and pinoxaden + metsulfuron (5.02 and 0.347) among the herbicidal treatments indicating broad spectrum effect in controlling the weeds. Whereas, pendimethalin (0.659) and pendimethalin + metribuzin (0.614) have recorded higher persistence of escaped weeds indicating resistance of escaped weeds to control measures. The rest of herbicidal treatments were not so much effective. These results indicate that tank mix application of different herbicides gave better results in comparison to their solitary application. Whereas, the least value of WI and WPI (0.00 and 0.338) was observed under two hand weeding. Furthermore, higher index values of CRI, WMI and HEI (28.61, 0.38 and 5.50) under combined application of sulfosulfuron + metsulfuron indicate potential of herbicides for significant control of weed

Table 1. Effect of weed control treatments on density and dry matter accumulation of weeds (pooled data of two year)

Treatment	Weed density (no./m²)			Weed dry matter accumulation (g/m²)		
	Monocot	Dicot	Total	Monocot	Dicot	Total
Pendimethalin (750 g/ha) PE	5.96(35.1)^{b}	9.83(96.2)^{b}	11.48(131.4)^{b}	5.18(26.3)^{b}	7.95(62.8)^{b}	9.47(89.1)^{b}
Sulfosulfuron (25 g/ha) PoE at 5 WAS	4.37(18.7)^{c}	6.91(47.3)^{d}	8.14(65.9)^{d}	3.14(9.4)^{d}	4.48(19.6)^{d}	5.43(29.0)^{d}
Metribuzin (210 g/ha) PoE at 5 WAS	4.09(16.3)^{d}	6.58(42.9)^{e}	7.72(59.2)^{e}	3.01(8.6)^{de}	4.25(17.5)^{e}	5.16(26.1)^{e}
Clodinafop (60 g/ha) PoE at 5 WAS	4.15(16.8)^{d}	6.46(41.3)^{e}	7.65(58.1)^{e}	3.02(8.6)^{de}	4.15(16.8)^{e}	5.09(25.4)^{e}
Metsulfuron (4 g/ha) PoE at 5 WAS	3.81(14.1)^{e}	6.05(36.2)^{f}	7.11(50.3)^{f}	2.95(8.2)^{e}	4.14(16.7)^{e}	5.04(24.9)^{e}
Pendimethalin + metribuzin (750 + 175 g/ha) PE	3.71(13.2)^{e}	8.68(75.0)^{c}	9.42(88.3)^{c}	4.09(16.2)^{c}	6.61(43.2)^{c}	7.74(59.5)^{c}
Pendimethalin *fb* sulfosulfuron (750 + 20 g/ha) PE *fb* PoE at 5 WAS	3.44(11.4)^{f}	5.63(31.3)^{g}	6.56(42.7)^{g}	2.08(3.8)^{f}	3.80(14.0)^{f}	4.28(17.8)^{f}
Pendimethalin *fb* clodinafop (750 + 50 g/ha) PE *fb* PoE at 5 WAS	3.13(9.4)^{g}	5.22(26.9)^{h}	6.05(36.3)^{h}	2.00(3.5)^{f}	3.64(12.8)^{fg}	4.10(16.3)^{fg}
Pendimethalin *fb* metsulfosulfuron (750 + 4 g/ha) PE *fb* PoE at 5 WAS	3.09(9.1)^{g}	4.95(24.1)^{i}	5.80(33.2)^{i}	1.98(3.5)^{fg}	3.48(11.6)^{g}	3.95(15.1)^{g}
Sulfosulfuron + metsulfuron (30 +2 g/ha) PoE at 5 WAS	2.59(6.3)^{i}	4.15(16.8)^{l}	4.85(23.2)^{l}	1.64(2.2)^{i}	2.52(5.9)^{i}	2.94(8.1)^{i}
Pinoxaden + metsulfuron (60 =4 g/ha) PoE at 5 WAS	3.03(8.8)^{g}	4.61(20.8)^{j}	5.47(29.6)^{j}	1.85(3.0)^{hg}	2.78(7.2)^{h}	3.27(10.2)^{h}
Mesosulfuron + iodosulfuron (12 + 2.4 g/ha) PoE at 5 WAS	2.81(7.5)^{h}	4.35(18.5)^{k}	5.14(26.1)^{k}	1.79(2.8)^{h}	2.64(6.5)^{hi}	3.12(9.2)^{hi}
Clodinafop + metsulfuron (60 +4 g/ha) PoE at 5 WAS	2.87(7.8)^{h}	4.50(19.9)^{jk}	5.30(27.7)^{jk}	1.82(2.8)^{h}	2.73(6.9)^{h}	3.20(9.8)^{h}
Two hand weeding at 30 and 45 DAS	2.36(5.2)^{j}	3.76(13.7)^{m}	4.38(18.9)^{m}	1.58(2.1)^{i}	2.21(4.4)^{j}	2.63(6.4)^{j}
Unweeded control	6.56(42.6)^{a}	13.35(177.8)^{a}	14.86(220.4)^{a}	5.40(28.7)^{a}	12.12(146.4)^{a}	13.25(175.1)^{a}

*Data subjected to $\sqrt{x+0.5}$ transformation and figures in parentheses are original weed count/m²

**Means with the same letter are not significantly different based on DMRT (p=0.05), PE - Pre-emergence; POE - Post-emergence; WAS - Weeks after sowing; *fb* - Followed by population to increase the per cent yield over the control treatment. The results with respect to CRI, WMI and HEI obtained from joint application of mesosulfuron + iodosulfuron (24.88, 0.37 and 4.73) were comparable with sulfosulfuron + metsulfuron. Sulfosulfuron and metsulfuron when applied alone failed to control the *Rumex dentatus* and other grassy weeds but their combined application as Readi-mix results in broad spectrum weed kill due to increased efficacy (Chhokar *et al.* 2011). Effective control of weeds under combined application of sulfosulfuron + metsulfuron and mesosulfuron + iodosulfuron could be assigned to the reason for superior weed indices. But identically reverse was true in case of rest of the herbicidal treatments (Mishra *et al.* 2016).

Effect on yield, net returns, BC ratio and harvest index

Pooled analysis exhibited that the treatment effect on yield (grain, biological and straw) was highly significant (p<0.0001) as well for both the years under all the weed control treatments. Two hand weeding recorded highest grain, straw and biological yield as compared to unweeded control which accounted for least of these values followed by pendimethalin alone (**Table 3**). Further data explicated that collective application of herbicides either as premix, tank mix or sequentially, gave significantly higher grain, straw and biological yield of wheat over singly applied herbicides. Among herbicides, the higher value of yield and nutrient uptake were

Table 2. Effect of weed control treatments on various weed indices in wheat

Treatment	Weed indices						
	WCE	WCI	WI	WPI	CRI	WMI	HEI
Pendimethalin (750 g/ha) PE	42.56	49.40	18.75	0.659	2.22	0.27	0.20
Sulfosulfuron (25 g/ha) PoE at 5 WAS	71.74	83.44	14.53	0.438	7.09	0.24	0.88
Metribuzin (210 g/ha) PoE at 5 WAS	74.43	85.08	14.90	0.436	7.83	0.22	0.96
Clodinafop (60 g/ha) PoE at 5 WAS	74.91	85.50	14.22	0.432	8.13	0.23	1.03
Metsulfuron (4 g/ha) PoE at 5 WAS	78.40	85.80	13.33	0.492	8.36	0.24	1.11
Pendimethalin + metribuzin (750 + 175 g/ha) PE	58.61	66.04	15.26	0.614	3.38	0.28	0.41
Pendimethalin *fb* sulfosulfuron (750 + 20 g/ha) PE *fb* PoE at 5 WAS	81.65	89.83	10.17	0.414	12.33	0.28	1.85
Pendimethalin *fb* clodinafop (750 + 50 g/ha) PE *fb* PoE at 5 WAS	84.46	90.69	11.68	0.448	13.53	0.25	1.87
Pendimethalin *fb* metsulfosulfuron (750 + 4 g/ha) PE *fb* PoE at 5 WAS	85.84	91.38	10.62	0.455	14.81	0.26	2.13
Sulfosulfuron + metsulfuron (30 +2 g/ha) PoE at 5 WAS	90.05	95.36	2.00	0.349	28.61	0.38	5.50
Pinoxaden + metsulfuron (60 =4 g/ha) PoE at 5 WAS	87.44	94.17	5.02	0.347	22.34	0.35	3.98
Mesosulfuron + iodosulfuron (12 + 2.4 g/ha) PoE at 5 WAS	88.76	94.72	2.75	0.351	24.88	0.37	4.73
Clodinafop + metsulfuron (60 +4 g/ha) PoE at 5 WAS	88.08	94.43	3.98	0.350	23.46	0.36	4.31
Two hand Weeding at 30 and 45 DAS	91.87	96.32	0.00	0.338	37.35	0.40	-
Unweeded control	0.00	0.00	27.03	-	1.00	-	-

Table 3. Effect of weed control treatments on yield (grain, straw and biological) and harvest index of wheat

Treatment	Yield (t/ha)						Net returns (x10^3 `/ha)			BC ratio			HI (%)		
	Grain			Straw											
	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
Pendimethalin (750 g/ha) PE	3.52^{n}	3.80^{n}	3.66^{m}	5.21^{n}	5.35^{m}	5.28^{j}	46.61^{f}	51.74^{f}	49.17^{f}	1.74^{h}	1.94^{h}	1.84^{h}	40.33^{c}	41.54^{c}	40.94^{c}
Sulfosulfuron (25 g/ha) PoE at 5 WAS	3.71^{k}	3.99^{k}	3.85^{jk}	5.32^{m}	5.48^{l}	5.49^{i}	49.55^{e}	54.71^{e}	52.35^{e}	1.81^{g}	2.00^{g}	1.92^{g}	41.05^{a}	42.13^{a}	41.23^{a}
Metribuzin (210 g/ha) PoE at 5 WAS	3.69^{l}	3.97^{l}	3.83^{kl}	5.40^{l}	5.65^{k}	5.50^{h}	49.99^{de}	55.40^{de}	52.65^{de}	1.87^{f}	2.07^{f}	1.97^{f}	40.61^{c}	41.30^{c}	41.05^{c}
Clodinafop (60 g/ha) PoE at 5 WAS	3.72^{j}	4.00^{j}	3.86^{j}	5.42^{k}	5.72^{j}	5.57^{gh}	50.42^{cde}	55.95^{cde}	53.19^{cde}	1.87^{f}	2.08^{f}	1.97^{f}	40.70^{c}	41.17^{c}	40.94^{c}
Metsulfuron (4 g/ha) PoE at 5 WAS	3.76^{i}	4.04^{i}	3.90^{i}	5.46^{j}	5.77^{i}	5.62^{fgh}	51.41^{cde}	56.97^{cde}	54.19^{cde}	1.92^{e}	2.13^{e}	2.03^{e}	40.78^{bc}	41.20^{bc}	41.00^{bc}
Pendimethalin + metribuzin (750 + 175 g/ha) PE	3.68^{m}	3.96^{m}	3.82^{l}	5.51^{i}	5.80^{h}	5.65^{efg}	49.99^{de}	55.50^{de}	52.26^{de}	1.87^{f}	2.07^{f}	1.95^{f}	40.03^{d}	40.56^{d}	41.12^{d}
Pendimethalin *fb* sulfosulfuron (750 + 20 g/ha) PE *fb* PoE at 5 WAS	3.83^{h}	4.06^{h}	4.04^{h}	5.53^{h}	5.83^{g}	5.68^{def}	52.58^{cd}	57.15^{cd}	56.57^{cd}	1.95^{d}	2.12^{d}	2.10^{d}	40.91^{c}	41.01^{c}	41.57^{c}
Pendimethalin *fb* clodinafop (750 + 50 g/ha) PE *fb* PoE at 5 WAS	3.84^{g}	4.11^{g}	3.98^{g}	5.58^{g}	5.88^{f}	5.73^{de}	52.81^{c}	58.09^{c}	55.46^{c}	1.95^{d}	2.15^{d}	2.05^{d}	40.80^{c}	41.15^{c}	40.98^{c}
Pendimethalin *fb* metsulfosulfuron (750 + 4 g/ha) PE *fb* PoE at 5 WAS	3.86^{f}	4.15^{f}	4.02^{f}	5.64^{f}	5.92^{e}	5.78^{d}	53.02^{c}	58.79^{c}	56.26^{c}	1.95^{d}	2.16^{d}	2.07^{d}	40.62^{c}	41.24^{c}	41.06^{c}
Sulfosulfuron + metsulfuron (30 +2 g/ha) PoE at 5 WAS	4.27^{b}	4.55^{b}	4.41^{b}	6.06^{b}	6.35^{b}	6.20^{b}	61.07^{a}	66.58^{a}	63.83^{a}	2.24^{a}	2.44^{a}	2.34^{a}	41.36^{a}	41.77^{a}	41.57^{a}
Pinoxaden + metsulfuron (60 =4 g/ha) PoE at 5 WAS	4.14^{e}	4.42^{e}	4.28^{e}	5.93^{e}	6.27^{d}	6.10^{c}	58.63^{ab}	64.28^{ab}	61.45^{ab}	2.16^{b}	2.37^{b}	2.27^{b}	41.08^{abc}	41.32^{abc}	41.21^{abc}
Mesosulfuron + iodosulfuron (12 + 2.4 g/ha) PoE at 5 WAS	4.24^{c}	4.52^{c}	4.38^{c}	6.00^{c}	6.34^{b}	6.17^{bc}	60.40^{a}	66.05^{a}	63.22^{a}	2.22^{a}	2.42^{a}	2.32^{a}	41.38^{ab}	41.60^{ab}	41.49^{ab}
Clodinafop + metsulfuron (60 +4 g/ha) PoE at 5 WAS	4.18^{d}	4.46^{d}	4.32^{d}	5.94^{d}	6.28^{c}	6.11^{bc}	58.71^{ab}	64.35^{ab}	61.53^{ab}	2.11^{c}	2.31^{c}	2.21^{c}	41.31^{abc}	41.54^{abc}	41.43^{abc}
Two hand weeding at 30 and 45 DAS	4.36^{a}	4.64^{a}	4.50^{a}	6.18^{a}	6.46^{a}	6.31^{a}	56.88^{b}	62.37^{b}	59.58^{b}	1.71^{i}	1.87^{i}	1.79^{i}	41.36^{a}	41.80^{a}	41.65^{a}
Unweeded control	3.15^{o}	3.43^{o}	3.29^{n}	4.95^{o}	5.29^{n}	5.12^{k}	39.99^{g}	45.64^{g}	42.81^{g}	1.52^{j}	1.73^{j}	1.62^{j}	38.84^{e}	39.29^{e}	39.07^{e}

Means with the same letter are not significantly different based on DMRT (p=0.05);WAS - Weeks after sowing obtained with weed controlling through sulfosulfuron + metsulfuron (4.41 t/ha and 102.55, 24.92 and 105.51 kg NPK/ha) and mesosulfuron + iodosulfuron (4.38 t/ha and 99.95, 24.38 and 104.38 kg NPK/ha) due to better control of total weeds in wheat over rest of the treatments and being at par with two hand weeding. Pooled data showed that both these treatments recorded significant increase of 34.3% and 33.3% in grain yield over unweeded control. This might be due to inhibition of the enzyme acetolactate synthase (ALS) which acts as the catalyst in the first step of the biosynthesis of essential amino acids (valine, leucine and isoleucine). Better expression of yield attributes due to reduced weed infestation through these treatments might have helped the crop plants to accumulate more dry matter through greater nutrient uptake that might have provided more quantity of photosynthates to developing sink in crop plants produced more yield. The grain yield improvement and weed control has already been reported with different herbicide combinations (Walia *et al.* 2010, Singh *et al.* 2017, Chaudhari *et al.* 2017, Punia *et al.* 2017). The other treatments in order of merit were clodinafop + metsulfuron and pinoxaden + metsulfuron which brought about 31.6 and 30.2% increase in pooled grain yield. Application of pendimethalin *fb* metsulfuron, pendimethalin *fb* clodinafop and pendimethalin *fb* sulfosulfuron were another order of significance. The solitary application of single herbicide resulted in lesser grain yield. Similar trend of increments were also followed with respect to straw yield.

All the weed control treatments tended to significantly surpass unweeded control in terms of gross returns, net returns and B-C ratio. Although, hand weeding recorded maximum yield, but the net returns and B-C ratio (` 63827/ha and 2.34) was higher with application of sulfosulfuron + metsulfuron and mesosulfuron + iodosulfuron (` 63226/ha and 2.32), which was around 49.1 and 47.7 per cent (net returns) more over unweeded control. Thus, results clearly endorsed to better economic feasibility of treatment linked with higher production potential over unweeded control (Meena *et al.* 2017a, Punia *et al.* 2017, Chauhan *et al.* 2017). Higher dry matter production by the crop is attributed to more uptake of nutrients (Kaur *et al.* 2017), which is positively correlated with each other. More nutrient availability for the crop under weed free environment might have increased nutrient concentration in plants which ascribed to more translocation from source to sink due to reduced crop-weed competition, which ultimately resulted in more biomass production by wheat that in turn to greater uptake of nutrients (Kumar *et al.* 2017, Meena *et al.* 2017a, Chauhan *et al.* 2017). Similar results were also found with respect to harvest index among the treatments.

Contrast analysis for weed control treatments

Combined results indicated significant ($p < 0.0001$) interaction of year x weed control treatments on wheat grain yield as well as total weed density and total weed dry matter along with the effect of year and weed control treatments (**Table 4**). Further, contrast analysis of the pooled data against the year x weed control treatments interaction clearly reflected significant ($p < 0.0001$) response of readi-mix v/s single herbicide, single herbicide v/s sequential and redi-mix v/s sequential to grain yield as well as total weed density and total weed dry matter.

Correlation and regression studies

The correlation matrix (**Table 5**) illustrated the linear association among the parameters with emphasizing that individual parameter, *viz.* total weed density, total weed dry weight, total N uptake, total P uptake and total K uptake significantly ($p < 0.0001$) influenced wheat grain yield under different weed control treatments. The matrix clearly indicated that wheat grain yield had strong negative relation with total density (r = - 0.92) and dry weight (r = - 0.89) of weeds whereas; high positive correlation was exhibited with total N (r = 0.99), P (r = 0.97) and K (r = 0.98) uptake. On the other hand, total density and dry weight of weeds had negative strong significant association with total N (r = - 0.91 and – 0.88), P (r = - 0.88 and - 0.85) and K (r = - 0.87 and – 0.84) uptake. The joint effect of the above said parameters

Table 4. Probability level of significance for pooled and contrast analysis of wheat grain yield and weeds

Source	Wheat grain yield	Total weed density	Total weed dry matter
Year	<0.0001	<0.0001	<0.0001
Weed control treatment	<0.0001	<0.0001	<0.0001
Year x Weed control treatment	<0.0001	<0.0001	<0.0001
Redimix v/s Single herbicide	<0.0001	<0.0001	<0.0001
Single herbicide v/s Sequential	<0.0001	<0.0001	<0.0001
Redimix v/s Sequential	<0.0001	<0.0001	<0.0001

Probability values <0.05 and 0.01 signify that the sources of variation are significantly different at 5 and 1% level of significance, respectively also influenced the grain yield. The multiple correlation coefficient that combined the effects of the parameters on grain yield was statistically significant with high magnitude ($R_{GY.Weed\ density\ total,\ Weed\ dry\ weight\ total,\ Total\ N,\ P\ and\ K\ uptake}$ = 0.98; p < 0.0001). The regression analysis clearly indicated that wheat grain yield was inversely proportional to the total density and dry weight of the weeds (monocot and dicot). Whereas, the positive linear relationship of grain yield was revealed with crop total N, P and K uptake (**Table 6**). The degree of goodness of the fitted regression model for grain yield on total weed density (R^2 = 0.84; p < 0.0001), total weed dry weight (R^2 = 0.79; p < 0.0001), total N uptake (R^2 = 0.98; p < 0.0001), total P uptake (R^2 = 0.93; p < 0.0001) and total K uptake (R^2 = 0.97; p < 0.0001) demonstrated the strong dependence of grain yield on the said parameters under different weed control treatments in robust sense.

Cluster analysis for functional group of herbicides

The herbicides used for weed control in the experiment belongs to the six functional groups *viz.* dinitroaniline (DNT), triazinones (TZ), aryloxyphenoxy propionate pyridines (APP), sulfonyl urea (SU), phenylpyrazolin (PP) and imidazolinone (IZ). The result of cluster analysis was illustrated through the dendogram (**Figure 1**) exhibiting different functional group of herbicides in the form of cluster based on the dissimilarity/distance. The functional group APP and TZ were constituted a cluster A at the distance of 0.05. Similarly, cluster A joined with DNT and formed a cluster B at the distance of 0.12. Furthermore, the functional group IZ and PP were structured a cluster C at the distance of 0.24. The functional group SU behaved differently from the other groups up to the distance < 0.64 and combined with cluster C at the distance of 0.64 and formed a new cluster D. At most distance of 1.25, all the functional groups formed one cluster and at the minimum distance of 0.00, all the functional groups individually formed a cluster.

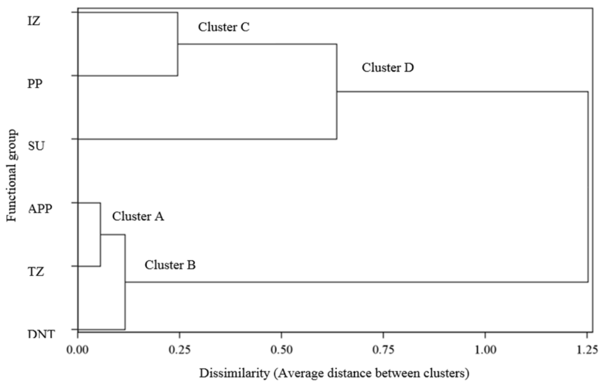

Figure 1. Dendogram from cluster analysis showing different herbicide functional groups hierarchically (DNT- Dinitroaniline; TZ- Triazinones; APP-Aryloxyphenoxy propionate pyridines; SU- Sulfonyl urea; PP-Phenylpyrazolin; IZ- Imidazolinone)

Table 5. Correlation coefficient (n = 60) with exact probability level of significance

Pearson correlation coefficients	GY	WDT	WDWT	TNU	TPU	TKU
Grain yield (GY)	1.00000	-0.91624 (<0.0001)	-0.89094 (<.0001)	0.99166 (<.0001)	0.96732 (<.0001)	0.98371 (<.0001)
Weed density total (WDT)		1.00000	0.99362 (<.0001)	-0.91011 (<.0001)	-0.88121 (<.0001)	-0.87431 (<.0001)
Weed dry weight total (WDWT)			1.00000	-0.87858 (<.0001)	-0.84713 (<.0001)	-0.83658 (<.0001)
Total N uptake (TNU)				1.00000	0.98488 (<.0001)	0.99226 (<.0001)
Total P uptake (TPU)					1.00000	0.98140 (<.0001)
Total K uptake (TKU)						1.00000

Table 6. Regression relationship of grain yield with independent variables

Independent variables	Estimated regression line	Adjusted R^2 value
Weed density total (TWD)	GY=4779.15** – 106.14** X TWD	0.84**
Weed dry weight total (TWDM)	GY=4526.72** – 100.41** X TWDM	0.79**
Total N uptake (TNU)	GY=1285.67** + 30.62** X TNU	0.98**
Total P uptake (TPU)	GY=1730.65** + 107.37** X TPU	0.93**
Total K uptake (TKU)	GY=648.85** + 34.49** X TKU	0.97**

**Parameters estimate are significant at p=0.01

Phytotoxicity

The herbicide toxicity on crop stand and growth was recorded at 7, 14 and 21 days after herbicide application (DAA) by rating it in the scale of 0 to 10, where zero rating represented no injury to crop plants and 10 represented complete destruction . Phytotoxicity scoring revealed that at 7 DAA metribuzin gave setback to wheat crop by causing moderate but persistent injury to wheat putting the plants under doubtful recovery zone. At 7 DAA sulfosulfuron, metsulfuron and pendimethalin + metribuzin caused slight injury or some stand loss and discolouration of wheat plants. With the progression of time, phytotoxicity cause by these herbicides was reversed. At 14 DAA, manifested some stunting of wheat plants under the effect of metribuzin, which showed slight injury only or discolouration. At 21 DAA, the crop plants under all these treatments had recovered and no symptoms of phytotoxicity were seen at this stage and onwards. However, in contradiction, mesosulfuron + iodosulfuron showed phytotoxic effect on the plant for a limited period (Chaudhari *et al.* 2017). Herbicide carryover effect was not observed in any of the treatment. No phytotoxicity was seen in the crop plant at 21 days after herbicide application (Chhokar *et al.* 2011).

It was concluded that in late sown wheat, weeds should be controlled by the post-emergence application of either sulfosulfuron + metsulfuron (30 + 2 g/ha) RM or mesosulfuron + iodosulfuron (12 + 2.4 g/ha) RM at five weeks after sowing for getting higher yield and monetary benefits. Use of RM herbicides may help in effective and eco-friendly weed management in wheat and also to minimize the risk of weed resistance evolution in wheat field.

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