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Effect of herbicide and their combinations on growth and productivity of wheat (*Triticum aestivum* L.) under late sown condition

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Abstract
Two years field experiment was conducted during *rabi* seasons of 2015-16 and 2016-17 at Instructional Farm (Agronomy), Rajasthan College of Agriculture, MPUAT, Udaipur. The experiment comprised of fifteen treatments *viz.* pendimethalin 0.75 kg ha^{-1}; sulfosulfuron 0.025 kg ha^{-1}; metribuzin 0.21 kg ha^{-1}; clodinafop 0.06 kg ha^{-1}; metsulfuron 0.004 kg ha^{-1}; pendimethalin + metribuzin 0.75+0.175 kg ha^{-1}; pendimethalin *fb* sulfosulfuron 0.75+0.02 kg ha^{-1}; pendimethalin *fb* clodinafop 0.75+0.05 kg ha^{-1}; pendimethalin *fb* metsulfuron 0.75+0.004 kg ha^{-1}; metsulfuron + sulfosulfuron 0.003+0.02 kg ha^{-1}; pinoxaden + metsulfuron 0.06+0.004 kg ha^{-1}; mesosulfuron + iodosulfuron 0.012+0.0024 kg ha^{-1}; clodinafop + metsulfuron 0.06+0.004 g ha^{-1}, two hand weeding at 30 & 45 DAS and unweeded control, replicated four times in Randomized Block Design. Wheat variety Raj.- 3765 was used as a test crop. Application of metsulfuron + sulfosulfuron significantly increased the plant height and dry matter accumulation at different growth stages over unweeded control resulted into higher yield attributes *viz.* effective tillers m^{-1} row length (93.97), grain ear^{-1} (44.82) and 1000 grain weight (44.14g). Consequently, highest grain (4412 kg ha^{-1}), straw (6201 kg ha^{-1}) and biological yield (10898 kg ha^{-1}) were obtained through controlling weeds by metsulfuron + sulfosulfuron after two hand weeding which was at par with mesosulfuron + iodosulfuron (4378, 6173 and 10861 kg ha^{-1}) followed by clodinofop + metsulfuron and pinoxaden + metsulfuron and proved significantly superior over rest of the treatments. As a consequence, significantly higher net return (₹ 63827 ha^{-1}) and B-C ratio (2.34) were also acquired by metsulfuron + sulfosulfuron followed by mesosulfuron + iodosulfuron (₹ 63226 ha^{-1} and 2.32).

Keywords: Herbicide, Pre mix, Tank mix, Weed flora, Wheat, Yield

Introduction

Wheat is most important staple food crop in India, serves as backbone of food security in the country. In India, it is the second most important cereal after rice contributing substantially to the national food security by providing more than 50 per cent of the calories to the people. In India, wheat contributed an annual production of 98.38 Mt from an area of 31.8 Mha with a productivity of 3.09 t ha^{-1} during 2016- 17 (Annual Report-DACFW, 2016-17) [4]. The five major wheat growing States of Uttar Pradesh, Punjab, Madhya Pradesh, Haryana and Rajasthan contributed nearly 86.0 percent to the total production in the country. Late sowing of wheat is a common practice in various cropping systems like rice-wheat; cotton-wheat; sugarcane-wheat, potato-wheat, vegetable pea-wheat etc. in Asia. Late transplanting of rice, late harvest of the preceding crops, use of long-duration varieties and heavy rains during later phase of rice crop are the main reasons for delayed sowing of wheat. Delay in sowing in wheat results in reduction of about 26.8 kg ha^{-1} day^{-1} of grain yield (Tripathi *et al.*, 2005) [14].

Besides other factors, weed infestation is a major bottleneck to higher productivity under late sown wheat that competes with crop for water, nutrients, space, light and furthermore release of allelochemicals into the rhizosphere (Khaliq *et al*., 2014b) [9]. Wheat crop is badly infested with grass as well as broad-leaf weeds. All types of weeds are not controlled by a single herbicide and the continuous use of a same herbicide results in weed shifts and evolution of herbicide resistance. The use of integrated chemical control measures is needed for effective control of mixed weed flora. Continuous use of isoproturon for control of *Phalaris minor* resulted in development of resistance in wheat. Now *Phalaris minor* has evolved multiple resistance against fenoxaprop, clodinafop and sulfosulfuron (Singh *et al*. 2010) [11] and recently to pinoxaden (Kaur *et al*. 2015) [6]. More recently, herbicide resistance in *Rumex dentatus*

against metsulfuron-methyl (Chhokar *et al.* 2017) [2] and in *Avena ludoviciana* against clodinafop (Singh 2016) [12] has been reported. Hence there is need for combined use of herbicides with different mode of action in the rotation or sequential application for efficient control of complex weed flora in wheat. Tank-mix or pre-mix or sequential 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.

So, the present experiment was planned to evaluate the bio-efficacy of herbicides, their mixtures and sequential use for management of complex weed flora in wheat under late sown condition to enhance productivity of the wheat.

Materials and Methods

The experiment was carried out during *rabi* season of 2015-16 and 2016-17 at the Instructional Farm, Department of Agronomy, Rajasthan College of Agriculture, Udaipur. The experiment comprised of fifteen treatments *viz*. pendimethalin 0.75 kg ha^{-1}; sulfosulfuron 0.025 kg ha^{-1}; metribuzin 0.21 kg ha^{-1}; clodinafop 0.06 kg ha^{-1}; metsulfuron 0.004 kg ha^{-1}; pendimethalin + metribuzin 0.75+0.175 kg ha^{-1}; pendimethalin *fb* sulfosulfuron 0.75+0.02 kg ha^{-1}; pendimethalin *fb* clodinafop 0.75+0.05 kg ha^{-1}; pendimethalin *fb* metsulfuron 0.75+0.004 kg ha^{-1}; metsulfuron + sulfosulfuron 0.003+0.02 kg ha^{-1}; pinoxaden + metsulfuron 0.06+0.004 kg ha^{-1}; mesosulfuron + iodosulfuron 0.012 + 0.0024 kg ha^{-1}; clodinafop + metsulfuron 0.06+0.004 g ha^{-1}, two hand weeding at 30 & 45 DAS and unweeded control. All the treatments were replicated four times indiscriminately in Randomize Block Design. Wheat variety Raj.- 3765 was used as a test crop. The soil of the experimental site were clay loam in texture, non-saline and slightly alkaline in reaction. They were low in available nitrogen, medium in organic carbon and phosphorus and high in available potassium. The crop was sown on 2nd week of December during *rabi* seasons with a seed rate of 125 kg ha^{-1}. All crop management practices were performed as per recommendation. The crop was fertilized with 90 kg N and 35 kg P_2O_5 ha^{-1} 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. Application of herbicide was sprayed by knapsack sprayer fitted with flat fan nozzle using a spray volume of 500 l/ha. Weedy check plots remained infested with native population of weeds till harvest. The observations were taken on different growth and yield attributes at various growth stages. All the data were subjected to analysis of variance (ANOVA) for RBD using SAS 9.3 software packages.

Results and Discussion

Effect of herbicide and their combination on Growth attributes

All herbicidal treatments whether applied singly or as mixture or in sequence and two hand weedings tended to significant enhancement in growth attributes *viz.* plant height, dry matter accumulation etc. during both the year of experimentation except unweeded control. The degree of pooled increase varied for plant height and dry matter accumulation from 17.1 to 29.6 per cent and 22.0 to 69.3 per cent (Table 1). The minimum values of these parameters were obtained when crop was subjected to complete weed stress (Unweeded control) (47.3 cm & 134.3 g m^{-1} row length). The tallest plant and highest pooled dry matter accumulation was recorded under metsulfuron + sulfosulfuron (66.4 cm and 178.4 g m^{-1} row length) among herbicidal treatments after two hand weedings but variations were at par with mesosulfuron + iodosulfuron, clodinafop + metsulfuron and pinoxaden + metsulfuron and accounted for 40.4, 39.9, 39.1 and 38.0 per cent increase in pooled plant height and 60.9, 58.0, 57.0 and 55.9 per cent increase in pooled dry matter accumulation, respectively over the unweeded control which recorded least plant height and dry biomass. The solitary application of herbicide accounted for less increase in plant height and dry biomass, hence lagged behind mixtures and sequential application of herbicides. This may be attributed to that the treatments reduced the density and dry weight more effectively, provided more favourable micro-environment to enhance the crop growth and ultimately having more crop dry weight in the respective treatments. Similar findings were also obtained by Meena *et al*. (2017) [9]; Chaudhari *et al*., (2017) [1] and Kaur *et al*., (2017) [5].

Yield attributes

Data reveals that different weed control treatments significantly increased the yield attributes *viz*. effective tillers m^{-1} row length, grains ear^{-1}, 1000 grain weight etc. over unweeded control (Table 2). Two hand weedings recorded the highest pooled effective tillers (95.60), grains ear^{-1} (45.45) and 1000 grain weight (44.37 g). Among the herbicides, mixed application of metsulfuron + sulfosulfuron recorded maximum yield attributes (93.97, 44.82 and 44.14) which was closely followed by mesosulfuron + iodosulfuron, clodinafop + metsulfuron and pinoxaden + metsulfuron. The per cent pooled increase under metsulfuron + sulfosulfuron, mesosulfuron + iodosulfuron, clodinafop + metsulfuron and pinoxaden + metsulfuron corresponded to 27.8, 27.0, 25.4 and 24.4 per cent in the effective tillers, 36.9, 35.4, 32.0 and 29.1 per cent in grain ear^{-1}, 21.0, 20.8, 20.1 and 18.7 per cent in 1000 grain weight over unweeded control. However, the variations among these treatments were at par and proved their superiority over other sequential and alone application of single herbicide. The sequential application of other herbicides (pendimethalin *fb* metsulfuron, pendimethalin *fb* clodinafop and pendimethalin *fb* sulfosulfuron) was next in order of significance. Independent usage of single herbicide registered for lower value of these parameters. Unweeded control recorded least yield attributes among all weed control options. Similar findings were also reported by Singh *et al*., (2017) [13], Chaudhari *et al*., (2017) [1] and Punia *et al*., (2017) [10].

Yield and Harvest index

Different weed management options brought about marked increase in the grain, straw and biological yield of wheat over unweeded control. Two hand weeding recorded highest pooled grain, straw and biological yield (4502, 6308 & 10810 kg ha^{-1}) whereas unweeded control accounted for minimum value (3285, 5123 & 8408 kg ha^{-1}) followed by pendimethalin alone (Table 3). Further insight of data explicate that collective application of herbicides either as premix, tank mix or sequentially resulted in significantly higher yield of wheat over singly applied herbicides. Amongst herbicidal treatments, highest pooled grain, straw and biological yield was obtained by controlling weeds through metsulfuron + sulfosulfuron followed by mesosulfuron + iodosulfuron. These two treatments recorded 34.3, 21.0 & 26.2 and 33.3, 20.5 & 25.5 per cent yield enhancement (grain, straw and

biological) over unweeded control and were at par to each other. The other treatment in the order of merit was clodinafop + metsulfuron and pinoxaden + metsulfuron which gave 31.6, 19.3, 24.1 and 30.2, 19.0, 23.4 per cent increase in grain, straw and biological yield. Application of pendimethalin *fb* metsulfuron, pendimethalin *fb* clodinafop and pendimethalin *fb* sulfosulfuron were another in the sequence of significance. The solitary application of single herbicide resulted in lesser grain yield. The weed control treatments did not register any significant variation in the harvest index of wheat. A relatively reduced weed infestation through different treatments might have helped the crop plants to accumulate greater dry matter through greater nutrient uptake which might have provided greater quantity of photosynthates to developing sink in crop plants that were able to produce more yields. Various authors have also reported improved yield attributes with reduced weed density and dry matter (Singh *et al*., 2017; Lekh Chand and Puniya, 2017; Punia *et al*., 2017 and Chouhan *et al*., 2017) [13, 8, 10 3].

Net return and B-C ratio

All weed management treatments resulted in significantly higher net return and B-C ratio from the wheat. The highest pooled net return (₹ 63827 ha^{-1}) was realized by applying metsulfuron + sulfosulfuron and mesosulfuron + iodosulfuron (₹ 63226 ha^{-1}) which was 49.1 and 47.7 per cent higher over unweeded control. Alike net return, the highest pooled B-C ratio (2.34) was obtained by application of metsulfuron + sulfosulfuron (Table 4). However, the B-C ratio obtained through mesosulfuron + iodosulfuron, clodinafop + metsulfuron and pinoxaden + metsulfuron were at par. The unweeded control and two hand weedings lagged behind all the herbicidal weed control treatments, while all the singly applied herbicides were significantly inferior to their conjoint application. These results are in close conformity with Kaur *et al*., (2017) [5], Meena *et al*., (2017) [9] and Chauhan *et al*., (2017) [3].

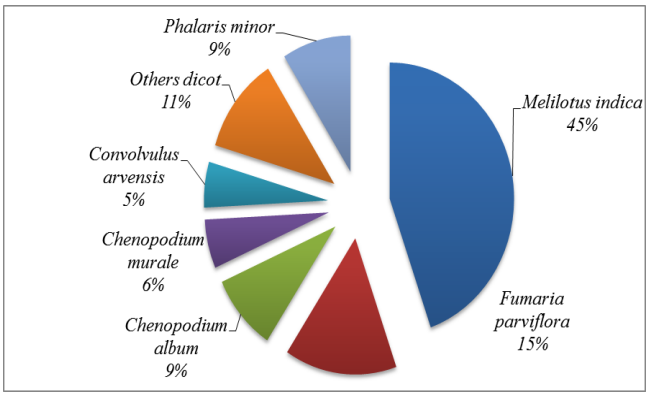

Fig 1: Weed flora in the experimental field

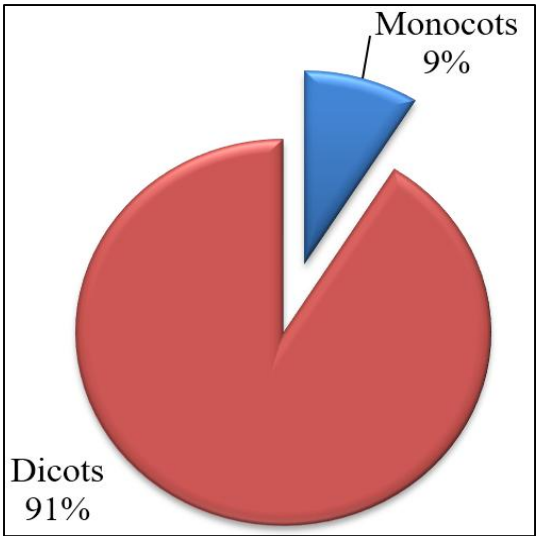

Fig 2: Density of monocot and dicot weeds in unweeded control

Table 1: Effect of weed control treatments on plant height and crop dry matter accumulation of wheat at 60 DAS

Treatments	Plant height (cm)			Crop dry matter accumulation (g m^{-1} row length)		
	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
Pendimethalin 0.75 k g ha^{-1}	55.2	55.6	55.4	151.0	151.6	151.2
Sulfosulfuron 0.025 kg ha^{-1}	60.3	60.7	60.5	157.4	158.0	157.6
Metribuzin 0.21 kg ha^{-1}	60.6	61.0	60.8	156.6	157.2	156.8
Clodinafop 0.06 kg ha^{-1}	61.1	61.5	61.3	158.1	158.7	158.3
Metsulfuron 0.004 kg ha^{-1}	61.8	62.2	62.0	159.2	159.8	159.4
Pendimethalin + Metribuzin (0.75 + 0.175 kg ha^{-1}) TM	62.0	62.4	62.2	154.0	154.6	154.2
Pendimethalin *fb* Sulfosulfuron (0.75 + 0.02 kg ha^{-1})	62.5	62.9	62.7	168.2	168.8	168.4
Pendimethalin *fb* Clodinafop (0.75 + 0.05 kg ha^{-1})	62.7	63.1	62.9	169.0	169.6	169.2
Pendimethalin *fb* Metsulfuron (0.75 + 0.004 kg ha^{-1})	63.4	63.8	63.6	171.3	171.9	171.5
Metsulfuron + Sulfosulfuron (0.003 + 0.02 kg ha^{-1}) TM	66.2	66.6	66.4	178.2	178.8	178.4
Pinoxaden + Metsulfuron (0.06 + 0.004 kg ha^{-1}) RM	65.1	65.5	65.3	174.6	175.2	174.8
Mesosulfuron + Iodosulfuron (0.012 + 0.0024 kg ha^{-1}) TM	66.0	66.4	66.2	176.1	176.7	176.3
Clodinafop + Metsulfuron (0.06 + 0.004 kg ha^{-1}) RM	65.6	66.0	65.8	175.4	176.0	175.6
Two Hand Weedings at 30 and 45 DAS	67.0	67.4	67.2	184.3	184.9	184.5
Unweeded control	47.1	47.5	47.3	134.1	134.7	134.3
SEm±	2.34	2.43	2.37	3.96	3.89	3.91
CD (P=0.05)	6.63	6.80	6.63	11.36	11.29	11.32

Table 2: Effect of weed control treatments on yield attributes of wheat at harvest

Treatments	Effective tillers (m^{-1} row length)			Grains ear^{-1}			1000 grain weight (g)		
	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
Pendimethalin 0.75 k g ha^{-1}	76.94	79.00	77.97	34.79	35.93	35.36	36.60	37.30	36.95
Sulfosulfuron 0.025 kg ha^{-1}	82.06	84.12	83.09	36.86	38.00	37.43	37.21	37.91	37.56
Metribuzin 0.21 kg ha^{-1}	81.09	83.15	82.12	37.07	38.21	37.64	37.43	38.13	37.78
Clodinafop 0.06 kg ha^{-1}	84.08	86.14	85.11	37.68	38.82	38.25	38.11	38.81	38.46
Metsulfuron 0.004 kg ha^{-1}	84.77	86.83	85.8	38.95	40.09	39.52	38.18	38.88	38.53
Pendimethalin + Metribuzin (0.75 + 0.175 kg ha^{-1}) TM	81.13	83.19	82.16	36.17	37.31	36.74	36.92	37.62	37.27
Pendimethalin *fb* Sulfosulfuron (0.75 + 0.02 kg ha^{-1})	86.95	89.01	87.98	40.11	41.25	40.68	38.89	39.59	39.24
Pendimethalin *fb* Clodinafop (0.75 + 0.05 kg ha^{-1})	87.5	89.56	88.53	40.87	42.01	41.44	39.61	40.31	39.96
Pendimethalin *fb* Metsulfuron (0.75 + 0.004 kg ha^{-1})	88.46	90.52	89.49	41.16	42.30	41.73	41.74	42.44	42.09
Metsulfuron + Sulfosulfuron (0.003 + 0.02 kg ha^{-1}) TM	92.94	95	93.97	44.25	45.39	44.82	43.79	44.49	44.14
Pinoxaden + Metsulfuron (0.06 + 0.004 kg ha^{-1}) RM	90.41	92.47	91.44	41.69	42.83	42.26	42.93	43.63	43.28
Mesosulfuron + Iodosulfuron (0.012 + 0.0024 kg ha^{-1}) TM	92.29	94.35	93.32	43.74	44.88	44.31	43.7	44.4	44.05
Clodinafop + Metsulfuron (0.06 + 0.004 kg ha^{-1}) RM	91.11	93.17	92.14	42.66	43.8	43.23	43.46	44.16	43.81
Two Hand Weedings at 30 and 45 DAS	94.57	96.63	95.60	44.88	46.02	45.45	44.02	44.72	44.37
Unweeded control	72.47	74.53	73.50	32.16	33.3	32.73	36.12	36.82	36.47
SEm±	2.42	2.22	2.31	1.46	1.38	1.41	1.06	1.08	1.07
CD (P=0.05)	6.94	6.37	6.63	4.18	3.96	4.04	3.04	3.08	3.06

Table 3: Effect of weed control treatments on yield and harvest index of wheat at harvest

Treatments	Yield (kg ha^{-1})											
	Grain			Straw			Biological			HI (%)		
	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
Pendimethalin 0.75 k g ha^{-1}	3518	3798	3658	5206	5346	5276	8724	9144	8934	40.33	41.54	40.94
Sulfosulfuron 0.025 kg ha^{-1}	3708	3988	3848	5324	5478	5486	9032	9466	9334	41.05	42.13	41.23
Metribuzin 0.21 kg ha^{-1}	3691	3971	3831	5397	5645	5502	9088	9616	9333	40.61	41.30	41.05
Clodinafop 0.06 kg ha^{-1}	3722	4002	3862	5423	5718	5571	9145	9720	9433	40.70	41.17	40.94
Metsulfuron 0.004 kg ha^{-1}	3762	4042	3902	5462	5768	5615	9224	9810	9517	40.78	41.20	41.00
Pendimethalin + Metribuzin (0.75 + 0.175 kg ha^{-1}) TM	3675	3955	3815	5506	5796	5463	9181	9751	9278	40.03	40.56	41.12
Pendimethalin *fb* Sulfosulfuron (0.75 + 0.02 kg ha^{-1})	3832	4055	4044	5534	5832	5683	9366	9887	9727	40.91	41.01	41.57
Pendimethalin *fb* Clodinafop (0.75 + 0.05 kg ha^{-1})	3843	4108	3976	5575	5876	5726	9418	9984	9702	40.80	41.15	40.98
Pendimethalin *fb* Metsulfuron (0.75 + 0.004 kg ha^{-1})	3855	4152	4024	5636	5915	5776	9491	10067	9800	40.62	41.24	41.06
Metsulfuron + Sulfosulfuron (0.003 + 0.02 kg ha^{-1}) TM	4272	4552	4412	6056	6346	6201	10328	10898	10613	41.36	41.77	41.57
Pinoxaden + Metsulfuron (0.06 + 0.004 kg ha^{-1}) RM	4136	4416	4276	5931	6271	6101	10067	10687	10377	41.08	41.32	41.21
Mesosulfuron + Iodosulfuron (0.012 + 0.0024 kg ha^{-1}) TM	4238	4518	4378	6003	6343	6173	10241	10861	10551	41.38	41.60	41.49
Clodinafop + Metsulfuron (0.06 + 0.004 kg ha^{-1}) RM	4183	4463	4323	5942	6282	6112	10125	10745	10435	41.31	41.54	41.43
Two Hand Weedings at 30 and 45 DAS	4362	4642	4502	6184	6463	6308	10546	11105	10810	41.36	41.80	41.65
Unweeded control	3145	3425	3285	4953	5293	5123	8098	8718	8408	38.84	39.29	39.07
SEm±	140	131	137	137	132	133	259	285	270	0.35	0.42	0.38
CD (P=0.05)	401	376	392	392	377	382	741	814	774	NS	NS	NS

Table 4: Effect of weed control treatments on Net return and B-C ratio in wheat

Treatments	Net return (₹ ha^{-1})			B-C ratio		
	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
Pendimethalin 0.75 k g ha^{-1}	45527	52821	49174	1.81	1.87	1.84
Sulfosulfuron 0.025 kg ha^{-1}	48708	56002	52355	1.89	1.95	1.92
Metribuzin 0.21 kg ha^{-1}	49000	56294	52647	1.94	2.00	1.97
Clodinafop 0.06 kg ha^{-1}	49540	56834	53187	1.94	2.00	1.97
Metsulfuron 0.004 kg ha^{-1}	50546	57840	54193	2.00	2.06	2.03
Pendimethalin + Metribuzin (0.75 + 0.175 kg ha^{-1}) TM	48612	55906	52259	1.92	1.98	1.95
Pendimethalin *fb* Sulfosulfuron (0.75 + 0.02 kg ha^{-1})	52927	60221	56574	2.07	2.13	2.10
Pendimethalin *fb* Clodinafop (0.75 + 0.05 kg ha^{-1})	51811	59105	55458	2.02	2.08	2.05
Pendimethalin *fb* Metsulfuron (0.75 + 0.004 kg ha^{-1})	52607	59901	56254	2.04	2.10	2.07
Metsulfuron + Sulfosulfuron (0.003 + 0.02 kg ha^{-1}) TM	60180	67474	63827	2.31	2.37	2.34
Pinoxaden + Metsulfuron (0.06 + 0.004 kg ha^{-1}) RM	57808	65102	61455	2.24	2.30	2.27
Mesosulfuron + Iodosulfuron (0.012 + 0.0024 kg ha^{-1}) TM	59579	66873	63226	2.29	2.35	2.32
Clodinafop + Metsulfuron (0.06 + 0.004 kg ha^{-1}) RM	57885	65179	61532	2.18	2.24	2.21
Two Hand Weedings at 30 and 45 DAS	55938	63232	59585	1.76	1.82	1.79
Unweeded control	39168	46462	42815	1.59	1.65	1.62
SEm±	1824	1935	1387	0.07	0.06	0.07
CD (P=0.5)	5224	5543	3968	0.22	0.21	0.22

Conclusion

On the basis of findings of two years investigation it can be concluded that in late sown wheat weed management with the pre mix application either of metsulfuron + sulfosulfuron (0.003 + 0.02 kg ha^{-1}) or mesosulfuron + iodosulfuron (0.012 + 0.0024 kg ha^{-1}) as post-emergence at 5 WAS should be used for the control of complex weed flora in wheat as these resulted in significantly higher grain yield. However, in monetary terms both the herbicides combinations gave higher net return and B-C ratio.

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