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Evaluation of herbicide combinations for controlling complex weed flora in wheat

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ABSTRACT

A field experiment was conducted during the *Rabi* seasons of 2014-15 and 2015-16 on a silty clay loam soil at Palampur. *Avena ludoviciana* (36.3%), *Phalaris minor* (27.5%), *Lolium temulentum* (13.9%), *Anagallis arvensis* (10%) and *Coronopus didymus* (6.9) were the major weeds. Herbicide combinations (pendimethalin 1.0 kg/ha + metribuzin 175 g/ha, pendimethalin 1.0 kg/ha *fb* sulfosulfuron 18 g/ha, sulfosulfuron 20 g/ha + metsulfuron 4 g/ha, pinoxaden 60 g/ha + metsulfuron 4 g/ha, clodinafop 60 g/ha + metsulfuron 4 g/ha, isoproturon 1.0 kg/ha + 2,4-D 0.5 kg/ha) were superior to sole application of herbicides (pendimethalin 1.25 kg/ha, sulfosulfuron 25 g/ha, metribuzin 210 g/ha and clodinafop 60 g/ha) in reducing weed count and dry weight and increasing plant height, number of tillers, crop dry matter, yield attributes and yield of wheat. Clodinafop + metsulfuron, pinoxaden + metsulfuron and pendimethalin *fb* metsulfuron being better than other combinations gave 28.6, 22.5 and 23.1% higher grain yield of wheat over hand weeding twice. Weeds reduced the grain yield by 51.9%. With unit increase in weed count per m^2, the wheat grain yield was decreased by 13.3 kg/ha. The cost of weed control under herbicidal treatments was 9.0-28.9% of that under hand weeding lowest being under metribuzin and highest under pendimethalin *fb* sulfosulfuron. Clodinafop + metsulfuron gave the highest net returns due to weed control and marginal benefit: cost ratio (MBCR). Clodinafop + metsulfuron resulted in highest weed control efficiency (WCE), weed control index (WCI), crop resistance index (CRI), treatment efficiency index, crop intensity index and weed index. Weed management index, agronomic management index and integrated weed management index were highest under sulfosulfuron followed by clodinafop + metsulfuron. Based on overall impact index clodinafop + metsulfuron, pinoxaden + metsulfuron, sulfosulfuron + metsulfuron, pendimethalin *fb* sulfosulfuron and pendimethalin + metribuzin were recommended for effective weed management in wheat under mid hill conditions of Himachal Pradesh.

Key words: Herbicide combinations, Wheat, Weeds, Threshold, Impact assessment, Economics

Wheat is the most important staple food contributing 30-35% to total food-grain basket of the country (Singh *et al.* 2013). Weed infestation is the major biotic constraint for higher productivity. Herbicidal control of weeds is preferred because of its better efficiency, lower cost and lesser time involvement. Effective weed control depends on the proper selection of herbicides depending on the type of weed flora infesting the crop, optimum dose and time using proper application technology (Kumar *et al.* 2009). Wheat is infested with plurispecific weed flora as it is grown under diverse agroclimatic conditions. But the major challenge offered is by grass weeds especially *Phalaris*, *Avena* and *Lolium*. Generally post-emergence herbicides are adopted by the growers (Kumar *et al.* 2011a&b, 2012a), which are mainly applied 7-10 days after first irrigation. Pre-emergence application of pendimethalin provides selective weed control in wheat (Kumar *et al.* 2005). The continuous use of a single herbicide leads to resistance in weeds. Herbicides effective against isoproturon resistance biotypes of *P. minor* are sulfosulfuron, clodinafop, pendimethalin, mesosulfuron + iodosulfuron and pinoxaden. Sulfosulfuron, mesosulfuron + iodosulfuron and pendimethalin are effective against both grass and non-grass weeds, whereas, clodinafop and pinoxaden are specific to grasses. However, sulfosulfuron and pendimethalin are not effective against *Rumex dentatus* and *Avena ludoviciana*, respectively. For control of broadleaved weeds in wheat, three major herbicides used are metsulfuron, 2,4-D and carfentrazone. For the control of complex weed flora and to provide season-long weed control, combination of herbicides are needed. Therefore, the combination approach either as tank- mixed or as double nock (one herbicide after the other) takes care of the mixed populations of the weeds associated with wheat. Tank-mix combinations or ready

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mixtures are advantageous over sequential application due to saving in application timing and cost. Keeping above facts in mind, different herbicide combinations were evaluated against complex weed flora in wheat.

MATERIALS AND METHODS

A field trial was conducted during the *Rabi* seasons of 2014-15 and 2015-16 on a silty clay loam soil at Palampur (32°62 N latitude, 76°32 E longitude and 1290.8 m altitude). The site (Palampur) lies in sub-temperate humid zone of Himachal Pradesh (NARP zone II), which is characterized by mild summers and severe winters. The area experiences occasional snowfall during winter. The average total annual rainfall received at the centre is around 2693.4 mm, out of which 74.4% is received during monsoon period (June to Sept.), 17.3% during December to March and 8.3% during October-November. The soil of the experimental site was silty clay loam in texture, acidic (pH 5.6) in reaction and medium in available N (333 kg/ha), P (9.6 kg/ha) and K (221 kg/ha). Thirteen weed control treatments were tested in randomized block design with three replications (**Table 1**). Wheat variety '*HPW-236*' was sown at 100 kg/ha on 12 November 2014 and 04 November 2015 keeping row to row spacing of 22.5 cm. The crop was fertilized with 120 kg N, 60 kg P_2O_5 and 30 kg K_2O/ha through urea, single super phosphate and muriate of potash, respectively. The required quantity of half N and whole P_2O_5 and K_2O was drilled at sowing. The remaining half N was broadcasted in two equal splits at tillering and flag-leaf stages. Herbicides as per treatment were applied with backpack power sprayer using 600 litre water/ha.

Weed count and dry weight were recorded at two spots using a quadrate of 50 x 50 cm. Yields were harvested from net plot (4.5 x 3.6 m) on 8 May 2015 and 5 May 2016. The data obtained were subjected to statistical analysis by analysis of variance (ANOVA) to test the significance of the overall differences among the treatments by the "F" test and conclusion was drawn at 5% probability.

The economic threshold (=economic injury levels), the weed density at which the cost of treatment equals the economic benefit obtained from that treatment, was calculated after Uygur & Mennan (1995) as well as those given by Stone and Pedigo (1972) as below:

Uygur and Mennan:

$$Y = [\{(100/He*Hc)+A_C\}/(Gp*Yg)]*100$$

where, Y is percent yield losses at a different weed density; He, herbicide efficiency; Hc, herbicide cost; Ac, application cost of herbicide; Gp, grain price and Ywf, yield of weed free.

Stone and Pedigo:

Economic threshold = Gain threshold/Regression coefficient

where, gain threshold = cost of weed control (Hc+Ac)/price of produce (Gp), and regression coefficient (b) is the outcome of simple linear relationship between yield (Y) and weed density/biomass (x), Y = a + bx.

The different impact indices were worked out after Rana and Kumar (2014).

'Overall impact index' was determined, by calculating firstly the 'unit value' where the value under a particular treatment of a parameter was divided by the respective arithmetic mean of treatments for that parameter as given below:

$$U_{ij} = \frac{V_{ij}}{AM_j}$$

where Uij is the unit value for ith treatment corresponding to jth parameter, Vij is the actual measured value for ith treatment and jth parameter and AMj is the arithmetic mean value for jth parameter.

The overall impact index was calculated as an average of unit values (Uij) of all the parameters under consideration:

$$OI_i = \frac{1}{N}\sum_{i=1}^{N} U_{ij}$$

where OIi is the overall impact index for ith treatment and N is the number of parameters used in deriving overall impact index.

RESULTS AND DISCUSSION

Effect on weeds

In the unweeded check, *Avena ludoviciana* (36.3%), *Phalaris minor* (27.5%), *Lolium temulentum* (13.9%), *Anagallis arvensis* (10.0%) and *Coronopus didymus* (6.9%) were the main weeds. *Vicia sativa* (10.2%) had infestations during 2014-15 only.

Weed control treatments gave significant suppression of *A. ludoviciana* over weedy check (**Table 1**). The control of *A. ludoviciana* with pinoxaden alone (Kumar *et al.* 2013) and with metsulfuron-methyl (Katara *et al.* 2012), sulfosulfuron (Kumar and Rana 2013) alone and with metsulfuron, metribizin (Kumar *et al.* 2013), isoproturon (Kumar *et al.* 2013) and clodinafop alone

(Kumar *et al.* 2012a) and with metsulfuron or 2,4-D (Kumar *et al.* 2012a, 2013) has been reported. Herbicide combinations, *viz*. pendimethalin + metribuzin, pendimethalin followed by (*fb*) sulfosulfuron, sulfosulfuron + metsulfuron, penoxaden + metsulfuron and clodinafop + metsulfuron were as good as hand weeding twice in reducing its count and dry weight. Similarly these herbicide combinations had better efficacy against *P. minor* than sole application of herbicides. Superiority of clodinafop + metsulfuron against *P. minor* over clodinafop or metsulfuron-methyl alone has been documented (Kumar *et al.* 2011a). All weed control treatments were significantly superior to weedy check in reducing the count and dry weight of *L. temulentum*. The effectiveness of sulfosulfuron, metribuzin, pinoxaden, clodinafop and isoproturon (Kumat *et al.* 2011, 2013a&b) and combinations based on these herbicides (Kumar *et al.* 2011, 2013a&b, Rana *et al.* 2016) against *L. temulentum* has been documented. The combinations, *viz*. pendimethalin + metribuzin, pendimethalin *fb* sulfosulfuron, sulfosulfuron + metsulfuron, pinoxaden + metsulfuron were superior to sole application of herbicides for season-long control of *Lolium*. Count and dry weight of *A. arvensis* were also significantly lower under weed control treatments over the weedy check. Counts and dry weight of *Vicia* sp were also significantly lower under weed control treatments than weedy check. Combinations in general were superior to sole application of herbicides.

Effect on crop

All the weed control treatments were significantly superior to weedy check in increasing plant height, tillers and dry matter accumulation (**Table 2**). The new herbicide combinations, *viz*. pendimethalin + metribuzin, pendimethalin *fb* sulfosulfuron, sulfosulfuron + metsulfuron and penoxaden + metsulfuron were as good as clodinafop + metsulfuron.

Better growth due to control of weeds had its significant effect on yield performance of wheat. Post-emergence application of clodinafop 60 g/ha + metsulfuron 4 g/ha being at par with pinoxaden 60 g/ha + metsulfuron 4 g/ha and pendimethalin 1.0 kg/ha *fb* metsulfuron 2 g/ha gave significantly higher

Table 1. Effect of treatments on count (no./m²) and dry weight (g/m²) of weeds at maximum population and dry matter stage (90-120 DAS) in wheat (data transformed to square root transformation)

Treatment	Dose (g/ha)	Time (DAS)	*A. ludoviciana* 2014-15	*A. ludoviciana* 2015-16	*P. minor* 2014-15	*P. minor* 2015-16	*L. temulentum* 2014-15	*L. temulentum* 2015-16	*A. arvensis* 2014-15	*A. arvensis* 2015-16	*V. sativa* 2014-15
Count											
Pendemethalin	1250	Pre	4.7(21.6)	4.4(18.6)	4.0(15.2)	3.9(14.3)	2.8(7.1)	2.2(4.0)	2.7(6.6)	2.5(5.2)	2.7(6.2)
Sulfosulfuron	25	Post	5.5(28.9)	5.4(27.8)	4.6(20.4)	4.5(19.6)	3.2(9.5)	2.9(7.3)	3.1(8.8)	2.9(7.5)	3.1(8.3)
Metribuzin	210	Pre	4.6(20.4)	4.7(21.4)	3.9(14.4)	3.7(13.0)	2.8(6.7)	2.3(4.3)	2.7(6.2)	2.5(5.4)	2.6(5.9)
Clodinafop	60	Post	5.2(26.6)	5.1(24.7)	4.4(18.7)	4.1(16.0)	3.1(8.8)	2.7(6.5)	3.0(8.1)	2.9(7.6)	2.9(7.6)
Pendimethalin + metribuzin	1000+175	Pre	3.6(12.3)	3.9(13.9)	3.1(8.7)	3.1(8.5)	2.2(4.1)	1.9(2.5)	2.2(3.7)	2.0(2.9)	2.1(3.5)
Pendimethalin *fb* sulfosulfuron	1000 *fb* 18	Pre *fb* post	3.3(10.0)	3.6(11.8)	2.8(7.1)	2.9(7.5)	2.1(3.3)	1.7(2.0)	2.0(3.1)	1.9(2.8)	2.0(2.9)
Sulfosulfuron + metsulfuron	20+4	Post	3.3(10.1)	3.5(11.3)	2.8(7.1)	2.8(7.0)	2.1(3.3)	1.8(2.4)	2.0(3.1)	2.0(2.9)	2.0(2.9)
Pinoxaden + metsulfuron	60+4	Post	3.1(8.7)	3.2(9.5)	2.7(6.1)	2.7(6.1)	2.0(2.9)	1.8(2.1)	1.9(2.6)	1.9(2.5)	1.9(2.5)
Mesosulfuron + iodosulfuron	12+2.4	Post	4.3(17.3)	4.4(18.4)	3.6(12.2)	3.2(9.5)	2.6(5.7)	2.0(2.9)	2.5(5.3)	2.4(4.6)	2.4(5.0)
Clodinafop + metsulfuron	60+4	Post	2.9(7.4)	3.0(8.0)	2.5(5.2)	2.2(3.9)	1.9(2.4)	1.7(1.8)	1.8(2.2)	1.6(1.5)	1.8(2.1)
Isoproturon + 2,4-D	1000+500	Post	5.2(26.0)	5.0(24.0)	4.4(18.3)	3.8(13.7)	3.1(8.6)	2.7(6.5)	3.0(7.9)	2.4(4.6)	2.9(7.5)
Hand weeding	-	30 & 60	3.6(11.8)	2.7(6.5)	3.1(8.3)	3.2(9.0)	2.2(3.9)	1.9(2.5)	2.1(3.6)	2.0(3.2)	2.1(3.4)
Weedy check	-	-	8.2(66.8)	8.1(63.9)	6.9(47.1)	7.3(52.1)	4.8(22.0)	5.4(28.1)	4.6(20.3)	4.1(15.7)	4.5(19.2)
LSD (p=0.05)			2.9	2.6	2.0	1.4	1.0	0.5	0.9	0.6	0.8
Dry weight											
Pendemethalin	1250	Pre	5.2(25.6)	4.9(23.2)	4.4(18.3)	3.9(14.3)	3.0 (8.0)	1.7 (1.8)	2.8 (7.0)	2.0 (2.9)	2.7 (6.2)
Sulfosulfuron	25	Post	6.7(43.9)	6.4(40.1)	5.7(31.3)	5.6(30.3)	3.8(13.8)	1.7 (1.8)	3.6(11.9)	1.9(2.5)	3.4(10.6)
Metribuzin	210	Pre	4.9(22.6)	5.2(26.5)	4.1(16.2)	3.9(14.2)	2.9 (7.1)	1.6 (1.7)	2.7 (6.1)	1.8 (2.2)	2.5 (5.5)
Clodinafop	60	Post	5.3(26.9)	5.5(29.6)	4.5(19.2)	4.3(17.5)	3.1 (8.4)	1.6 (1.5)	2.9 (7.3)	1.9 (2.8)	2.7 (6.5)
Pendimethalin + metribuzin	1000+175	Pre	4.2(16.4)	4.5(18.9)	3.6(11.7)	3.6(12.0)	2.5 (5.1)	1.4 (1.1)	2.3 (4.4)	17 (1.9)	2.2 (4.0)
Pendimethalin *fb* sulfosulfuron	1000 *fb* 18	Pre *fb* post	3.8(13.6)	4.1(15.7)	3.3(9.7)	3.5(11.0)	2.3 (4.3)	1.4 (1.0)	2.2 (3.7)	1.7 (2.0)	2.1 (3.3)
Sulfosulfuron + metsulfuron	20+4	Post	3.9(14.3)	4.0(15.0)	3.4(10.2)	3.3(10.0)	2.3 (4.5)	1.5 (1.3)	2.2 (3.9)	1.8 (2.4)	2.1 (3.5)
Pinoxaden + metsulfuron	60+4	Post	3.7(12.9)	3.8(13.7)	3.2 (9.2)	3.2(9.1)	2.2 (4.0)	1.4 (1.0)	2.1 (3.5)	1.5 (1.2)	2.0 (3.1)
Mesosulfuron + iodosulfuron	12+2.4	Post	4.5(19.2)	4.5(19.0)	3.8(13.7)	3.9(13.9)	2.7 (6.1)	1.4 (1.0)	2.5 (5.2)	2.0(3.0)	2.4 (4.7)
Clodinafop + metsulfuron	60+4	Post	3.5(10.9)	3.1(8.9)	3.0 (7.8)	2.8(6.8)	2.1 (3.5)	1.4 (0.9)	2.0 (3.0)	1.3 (2.8)	1.9 (2.7)
Isoproturon + 2,4-D	1000+500	Post	5.9(33.3)	5.7(31.6)	5.0(23.8)	5.1(25.4)	3.4(10.4)	1.6(1.6)	3.2 (9.0)	2.9 (7.5)	3.0 (8.1)
Hand weeding	-	30 & 60	4.4(18.0)	4.2(16.5)	3.7(12.9)	3.5(11.3)	2.6 (5.7)	1.3 (0.8)	2.4 (4.9)	2.2(3.9)	2.3 (4.4)
Weedy check	-	-	9.1(81.9)	8.6(79.2)	7.7(58.5)	7.8(60.3)	5.2(25.7)	4.6(20.1)	4.8(22.2)	4.4(18.5)	4.6(19.9)
LSD (p=0.05)			2.4	2.0	1.7	0.2	0.7	0.2	0.6	0.4	0.6

Data in parentheses are the means of original values grain and straw yield of wheat. These treatments gave 98-108% higher grain yield of wheat over weedy check and 23-28% over farmers practice of hand weeding twice. Weeds in weedy check reduced the yield by 51.9%.

Wheat grain yield was found to be negatively associated with total weed count (r = -0.885**) and total weed dry weight (r = -0.887**) and was positively associated with crop height (r = 0.974**), number of tillers (r = 0.979**), crop dry matter (r = 0.966**), spikelets/spike (r= 0.976**), spike length (0.981**), spikes/m^2 (0.942**), grains/spike (r= 0.939**) and 100- seed weight (r = 0.930**). The increase in yield attributes and yield due to effective control of weeds with herbicides alone, in combination and hand weeding has been documented (Katara *et al.* 2012, Kumar and Rana 2013, Rana *et al.* 2016). The linear relationship between weed count and dry weight (x) and yield (Y) of wheat is given here as under:

Weed count

Y = 4299 – 13.3x (R^2= 0.782).......................(1)

Weed dry weight

Y = 4337 – 11.5x (R^2= 0.787)........................(2)

Equations 1 and 2 explain 78.2 and 78.7% of the variation in wheat grain yield due to count and dry weight of weeds, respectively. With unit increase in weed count per m^2, the wheat grain yield reduced by 13.3 kg/ha. Similarly with every unit increase in weed weight, the wheat grain yield decreased by 11.5 kg/ha.

Economic threshold

The economic threshold levels of weeds at the current prices of treatment application and the crop production on the basis of weed infestation in wheat (**Table 3**). The economic threshold levels in terms of count (no./m^2) and dry weight (g/m^2) with the weed management practices studied varied between 7.6 – 84.7/m^2 and 8.8-97.9 g/m^2 when determined after Stone and Pedigo and 3.0 to 28.9/m^2 and 2.9 – 28.9 g/m^2, respectively, after Uygur and Mennan. The former method determined higher values of economic thresholds than the later, but the trends were similar under both the methods of determination. It is indicated that any increase in cost of weed control would lead to higher values of economic threshold, whereas an increase in price of crop produce would result in low economic threshold. Hand weeding had higher values of economic threshold than the herbicidal treatments due to higher wages. Herbicidal treatments had lower application cost and thus had lower values of economic threshold.

Economics

The cost of weed control under herbicidal treatments varied from 9.0 to 28.9% of that under hand weeding treatment lowest being under pre-emergence metribuzin 210 g/ha and highest under pre-emergence pendimethalin *fb* sulfosulfuron (**Table 3**). Gross returns due to weed control were highest under clodinafop + metsulfuron followed by pinoxaden + metsulfuron, pendimethalin *fb* sulfosulfuron, sulfosulfuron + metsulfuron and pendimethalin + metribuzin. All treatments except sulfosulfuron were superior to hand weeding twice in increasing net returns due to weed control. These were highest under clodinafop + metsulfuron followed by penoxaden + metsulfuron, sulfosulfuron + metsulfuron, pendimethalin *fb* sulfosulfuron and pendimethalin + metribuzin. Due to low cost of application, all herbicidal treatments were superior to

Table 2. Effect of treatments on growth, yield attributes and yield of wheat

Treatment	Dose (g/ha)	Time (DAS)	Emergence count (no./m^2)	Plant height (cm)	Tillers (no./m^2)	Crop dry matter (g/m^2)	Spikes (no./m^2)		Grains /spike		Grain weight/ spike (g)		Grain yield (t/ha)		Straw yield (t/ha)	
			2014-15	2014-15	2014-15	2014-15	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
Pendemethalin	1250	Pre	43.3	98.5	183.6	963.5	172.0	193.0	46.1	45.6	2.4	2.3	2.99	3.75	5.67	5.39
Sulfosulfuron	25	Post	44.2	94.3	169.8	906.9	157.8	188.1	44.3	41.0	2.2	2.1	2.52	3.31	4.37	4.85
Metribuzin	210	Pre	45.3	99.4	186.7	974.1	174.7	194.0	47.5	46.3	2.5	2.4	3.31	3.43	6.62	5.06
Clodinafop	60	Post	43.5	96.9	174.7	955.7	163.1	185.0	46.4	46.0	2.4	2.5	2.82	3.96	5.23	5.54
Pendimethalin metribuzin	1000+175	Pre	44.7	103.4	195.6	1042.9	182.2	177.0	50.5	49.0	2.8	2.7	3.82	3.75	7.46	5.46
Pendimethalin *fb* sulfosulfuron	1000 *fb* 18	Pre *fb* post	46.2	104.1	210.2	1107.6	198.7	199.5	51.9	51.3	2.9	2.7	4.19	4.03	7.79	6.05
Sulfosulfuron + metsulfuron	20+4	Post	45.3	104.0	203.6	1072.9	192.0	200.0	50.5	48.6	2.8	27	4.10	4.12	7.50	6.15
Pinoxaden + metsulfuron	60+4	Post	46.2	105.9	216.9	1197.0	205.3	210.5	51.7	50.0	3.0	3.1	4.17	4.49	7.83	6.66
Mesosulfuron + iodosulfuron	12+2.4	Post	44.3	102.5	200.9	1020.3	188.9	198.1	50.0	50.0	2.7	2.6	3.61	3.75	6.50	6.32
Clodinafop + metsulfuron	60+4	Post	47.5	107.4	222.2	1274.8	210.2	212.0	52.6	51.0	3.1	3.2	4.38	4.87	8.40	6.85
Isoproturon + 2,4-D	1000+500	Post	44.0	96.8	167.6	952.5	156.9	186.0	45.5	45.0	2.3	2.4	2.64	3.59	4.64	6.09
Hand weeding	-	30 & 60	44.3	101.2	193.3	1009.4	181.3	189.0	49.2	46.3	2.7	2.5	3.40	3.94	6.53	6.33
Weedy check	-	-	42.5	92.1	133.3	808.0	121.3	133.0	38.2	31.0	1.6	1.7	2.11	2.36	4.17	4.02
LSD (p=0.05)	-	-	0.3	2.9	28.0	62.9	21.3	9.6	1.4	1.8	0.2	0.06	0.38	0.36	0.70	0.60

hand weeding twice in terms of marginal benefit cost ratio (MBCR). The highest MBCR was obtained under clodinafop + metsulfuron, sulfosulfuron + metsulfuron, metribuzin and pinoxaden + metsulfuron.

Impact assessment

Weed control efficiency (WCE) and weed control index (WCI) were significantly and positively associated with grain yield of wheat. Clodinafop + metsulfuron resulted in highest WCE and WCI followed by pinoxaden + metsulfuron, sulfosulfuron + metsulfuron, and pendimethalin *fb* sulfosulfuron (**Table 4**). Weed flora was of diverse nature with added phenotypic plasticity and competitive ability even after their survival after a treatment. That is why weed persistence index (WPI) was more in treatments where better control was achieved. Hand weeding had the highest WPI followed by clodinafop + metuslfuron, sulfosulfuron, and pinoxaden + metsulfuron. Crop competitive ability relative to those of weeds is shown by crop resistance index (CRI). The highest CRI and treatment/herbicide efficiency index (HEI) was worked out for clodinafop + metsulfuron followed by pinoxaden + metsulfuron, pendimethalin *fb* sulfosulfuron and sulfosulfuron + metsulfuron. WMI, AMI and IWMI were highest under sulfosulfuron followed by clodinafop +

Table 3. Economics of weed control and economic threshold of weeds

Treatment	Dose (g/ha)	Time	Gt	Et (S&P)		Et (U&M)		CWC	GR	GRwc	NRwc	MBCR
				Count	Weight	Count	Weight					
Pendemethalin	1250	Pre	260	19.6	22.6	8.8	8.6	4162	81548	25343	21180	5.1
Sulfosulfuron	25	Post	118	8.9	10.3	3.9	4.3	1889	69702	13496	11607	6.1
Metribuzin	210	Pre	101	7.6	8.8	3.0	2.9	1622	83120	26915	25293	15.6
Clodinafop	60	Post	142	10.7	12.4	4.8	4.5	2274	81185	24979	22705	10.0
Pendimethalin + metribuzin	1000+175	Pre	250	18.8	21.7	7.4	7.6	3997	92847	36642	32645	8.2
Pendimethalin *fb* sulfosulfuron	1000 *fb* 18	Pre *fb* post	326	24.5	28.3	9.2	9.4	5209	100368	44162	38953	7.5
Sulfosulfuron + metsulfuron	20+4	Post	132	10.0	11.5	3.7	3.7	2117	99856	43651	41533	19.6
Pinoxaden + metsulfuron	60+4	Post	209	15.7	18.2	5.9	6.0	3347	105489	49283	45936	13.7
Mesosulfuron + iodosulfuron	12+2.4	Post	157	11.8	13.6	4.8	4.7	2511	90938	34733	32222	12.8
Clodinafop + metsulfuron	60+4	Post	166	12.5	14.5	4.6	4.6	2664	112085	55880	53216	20.0
Isoproturon + 2,4-D	1000+500	Post	156	11.7	13.6	5.2	5.5	2496	76667	20462	17966	7.2
Hand weeding	-	30 & 60	1126	84.7	97.9	28.9	28.9	18020	90902	34696	16676	0.9
Weedy check	-	-	0	0.0	0.0	-	-	0	56206	0	0	0.0
LSD (p=0.05)	-	-										

Gt, gain threshold; Et, Economic threshold; Et (S&P), economic threshold after Stone and Pedigo; Et (U&M), Economic threshold after Uyger & Mennan; GR, Gross return (INR/ha); GRwc, Gross return over weedy check (INR/ha); CWC, cost of weed control (INR/ha); NRwc, Net return over weedy check; MBCR, marginal benefit cost ratio

Table 4. Impact assessment indices

Treatment	Dose (kg/ha)	Time (DAS)	WCE	WCI	WPI	CRI	WMI	AMI	IWMI	HEI	WI	Win	Cin	OIi
Pendemethalin	1250	Pre	70.5	72.0	0.95	5.01	2.10	1.10	1.60	1.81	8.3	22.5	77.5	0.83
Sulfosulfuron	25	Post	58.9	51.4	1.18	2.45	2.54	1.54	2.04	0.63	20.6	30.0	70.0	0.63
Metribuzin	210	Pre	70.9	73.3	0.92	5.45	2.06	1.06	1.56	1.91	8.2	22.1	77.9	0.98
Clodinafop	60	Post	62.9	68.7	0.84	4.43	2.21	1.21	1.71	1.66	7.6	27.7	72.3	0.85
Pendimethalin + metribuzin	1000+175	Pre	82.0	80.2	1.10	8.16	2.11	1.11	1.61	3.50	-3.1	15.3	84.7	1.09
Pendimethalin *fb* sulfosulfuron	1000 *fb* 18	Pre *fb* post	84.9	83.1	1.12	10.34	2.21	1.21	1.71	4.99	-11.9	12.0	88.0	1.22
Sulfosulfuron + metsulfuron	20+4	Post	85.1	83.0	1.14	10.15	2.22	1.22	1.72	4.93	-11.9	12.1	87.9	1.36
Pinoxaden + metsulfuron	60+4	Post	87.2	85.0	1.17	12.22	2.28	1.28	1.78	6.27	-17.9	10.0	90.0	1.42
Mesosulfuron + iodosulfuron	12+2.4	Post	75.8	77.4	0.93	7.06	2.13	1.13	1.63	2.87	-0.2	18.4	81.6	1.07
Clodinafop + metsulfuron	60+4	Post	89.7	87.7	1.19	15.77	2.36	1.36	1.86	8.72	-25.9	8.1	91.9	1.68
Isoproturon + 2,4-D	1000+500	Post	65.0	60.8	1.12	3.42	2.30	1.30	1.80	1.01	15.2	26.9	73.1	0.74
Hand weeding	-	30 & 60	84.3	79.5	1.30	7.79	2.07	1.07	1.57	3.14	0.0	13.3	86.7	0.92
Weedy check	-	-	0.0	0.0	1.00	1.00				0.00	39.2	58.6	41.4	0.22
LSD (P=0.05)	-	-												

WCE, weed control efficiency (%); WPI, Weed persistence index; CRI, Crop resistance index; WMI, Weed management index; AMI, Agronomic management index; IWMI, Integrated Weed management index; HEI, Treatment/Herbicide efficiency index; WI, weed index; Win, Weed intensity; Cin, Crop intensity; OIi, overall impact index metsulfuron, isoproturon + metsulfuron, penoxaden + metsulfuron, sulfosulfuron + 2,4-D and clodinafop. Weed index was lowest under clodinafop + metsulfuron followed by pinoxaden + metsulfuron, sulfosulfuron + metsulfuron, pendimethalin + metsulfuron and pendimethalin + metribuzin. The other treatments had positive values of WI indicating lower yield relative to hand weeding twice. Weed intensity was the lowest and crop intensity was the highest under clodinafop + metsulfuron followed by penoxaden + metsulfuron, pendimethalin *fb* sulfosulfuron, sulfosulfuron + metuslfuron and hand weeding twice. Grain yield of wheat was positively associated with CRI (r= 0.965**), TEI (r= 0.941**) and crop intensity (r= 0.931**). To have a valid inference from the present investigation an overall impact index was worked out by taking into consideration growth, yield attributes, yield and economics as well as different impact indices together. **Table 4** showing higher values of OIi for all herbicidal combinations than the threshold value of 1. The other treatments had values of OIi lower than the threshold value.

It can be inferred that clodinafop + metsulfuron, penoxaden + metsulfuron, sulfosulfuron + metsulfuron, pendimethalin *fb* sulfosulfuron and pendimethalin + metribuzin may be preferred against sole application of herbicides for effective weed management in wheat under mid hills condition of Himachal Pradesh.

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