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Control of mixed weed flora with different herbicides in barley

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ABSTRACT

A field experiment was conducted during 2014-15 and 2015-16 to study the efficacy of herbicides for control of diverse weeds in barley. Herbicides were sprayed alone or in combinations. The highest grain yield (5.54-6.07 t/ha) was recorded in weed-free treatment which was at par with isoproturon 750 g/ha + 2,4-D 500 g/ha and pinoxaden 40 g/ha + carfentrazone 20 g/ha. Uncontrolled weed competition caused an average 8-54% yield reductions compared to weed-free treatment. The magnitude of net returns and the benefit-cost ratio was higher with the applications of isoproturon 750 g/ha + 2,4-D (Na salt) 500 g/ha, pinoxaden 40 g/ha + carfentrazone 20 g/ha, isoproturon 750 g/ha + metsulfuron 4 g/ha and pinoxaden 40 g/ha followed by metsulfuron 4 g/ha and in weed-free.

INTRODUCTION

Barley (*Hordeum vulgare* L.) is cultivated mainly for green forage and malt production. It is grown worldwide, ranging from sub-Arctic to subtropical climates, including developing countries of Central Asia, which contributes about 32 million ha of land under barley cultivation (Grando and Mcpherson 2005). In India, barley is cultivated over 0.59 million ha land with an average production of 1.51 million tons (Anonymous 2016). However, barley production is severely constrained in India due to cultivation on poor soils, low input usage and higher weed infestations. The infestations of grass and broad-leaf weeds can reduce barley yields by 6-79% (Watson *et al.* 2006, Scursoni and Satorre 2005) depending on weed densities and duration of weed competition. Weeds also caused a reduction in protein content and grain size leading to loss of valuable malting premiums (Gerhards *et al.* 2005).

In barley, very limited herbicides have been evaluated and recommended. Among herbicides, 2,4-D is widely used in barley to control broad-leaf weeds. However, the major concern with the over-dependence on single herbicide is buildup of herbicide-resistant weeds and shift in weed flora. Bhullar *et al.* (2013) reported that extensive use of 2,4-D in barley has increased the abundance of some of the broad-leaf weeds like *Rumex spinosus* and *Malva.* Therefore, herbicides having a different mode of actions in various combinations, are mainly needed as one of the strategies for integrated weed management in barley. Herbicides such as metsulfuron-methyl and carfentrazone-ethyl have shown excellent efficacy in the control of broad-leaf weeds in wheat and barley (Howatt 2005, Tiwari *et al.* 2005, Zand *et al.* 2010). Moreover, these herbicides have a different mode of action and hence, their rotational use with 2,4-D can be done to reduce the selection pressure for the evolution of herbicide-resistant weeds. Keeping these facts in view, an experiment was planned to study the efficacy of alternative herbicides either alone or in combination, for weed control in barley to minimize the yield and quality losses.

MATERIALS AND METHODS

Studies were conducted at the Punjab Agricultural University, Ludhiana (38°56′ N, 75° 52′ E longitude, 247 metres ASL) India during 2014-15 and 2015-16. The experiment was laid out in RCBD with four replications and eleven treatments *viz.* pinoxaden 0.030 kg/ha, pinoxaden 0.040 kg/ha, pinoxaden 0.050 kg/ha, pinoxaden 0.040 kg/ha + metsulfuron 0.004 kg/ha, pinoxaden 0.040 kg/ha followed by metsulfuron 0.004 kg/ha, pinoxaden 0.040 kg/ha + carfentrazone 0.020 kg/ha, isoproturon 1 kg/ha, isoproturon 0.75 kg/ha + 2,4-D (Na salt) 0.5 kg/ha, isoproturon 0.75 kg/ha + metsulfuron 0.004 kg/ha, weedy check and weed-free. Malt barley (variety *'DWRUB 52'*) was sown in the first week of

November as per standard agronomic practices in a plot size of 10 m^2. All the post-emergence herbicides were applied at 40 days after sowing (DAS) at maximum tillering stage. Weed density and dry matter data were recorded at 60 days after sowing (DAS), 90 DAS, and at the harvest. Collected samples were first sun-dried and then dried in an oven at 60±2^{0}C for 4-5 days till constant dry weight was achieved. Weed control efficiency (WCE) and weed index (WI) were calculated as per standard methods. For measurement of chlorophyll index, a middle portion of the leaf was exposed to *atLEAF* chlorophyll meter (Wilmington, USA). The number of effective tillers was recorded at harvest time. The number of grains per ear were recorded from manually threshed five ears. Crop biomass yield of a net plot was weighted after harvesting at physiological maturity and expressed in tons per hectare. Grain yield was calculated by threshing of total plot biomass and presented in tons per hectare. Economics of different treatments was worked out by taking the prevailing market prices of inputs and produce under consideration. Analysis of variance is calculated using Proc GLM (SAS software 9.1, SAS institute Ltd, USA). The differences between means were compared with Fisher's least significant difference test (LSD) at the 0.05 probability level.

RESULTS AND DISCUSSION

Effect on weeds

Various weed species such as *Phalaris minor, Chenopodium album, Malva neglecta,* and *Anagallis arvensis,* etc. were found in a barley crop. Maximum weed count was found in weedy check at 60 days after sowing (DAS) and 90 DAS, which was statistically higher than weed-free treatment (**Table 1**). The lowest weed count (63.6, 57.3/m^2) in 2014-15 was recorded in isoproturon 750 g/ha + 2,4-D 500 g/ha and it was statistically at par with isoproturon 750 g/ha + metsulfuron 4 g/ha, pinoxaden 40 g/ha followed by metsulfuron 4 g/ha, pinoxaden 40 g/ha + metsulfuron 4 g/ha, pinoxaden 50 g/ha and isoproturon 1000 g/ha. During 2015-16, the lowest weed density was recorded in pinoxaden 40 g/ha + metsulfuron 4 g/ha which was significantly lower than weedy check and other herbicide treatments at 60 DAS. Pinoxaden 40 g/ha + metsulfuron 4 g/ha was statistically similar to isoproturon 750 g/ha + metsulfuron 4 g/ha, pinoxaden 40 g/ha followed by metsulfuron 4 g/ha. Weed dry matter recorded at the 90 DAS and at harvest revealed that the weedy check had the highest weed dry matter (**Table 1**). The lowest weed dry matter was recorded in isoproturon 750 g/ha + 2,4-D 500 g/ha in 2014-15 and in pinoxaden 40 g/ha + carfentrazone 20 g/ha in 2015-16 at 90 DAS and at harvest. In 2014-15, dry matter recorded in isoproturon 750 g/ha + 2,4-D 500 g/ha was statistically similar to isoproturon 750 g/ha + metsulfuron 4 g/ha, pinoxaden 40 g/ha + carfentrazone 20 g/ha, pinoxaden 40 g/ha followed by metsulfuron 4 g/ha, pinoxaden 40 g/ha + metsulfuron 4 g/ha and pinoxaden 40 g/ha at both the time of observation. However, in 2015-16, the lowest weed dry matter recorded in pinoxaden 40 g/ha + carfentrazone 20 g/ha at 90 DAS and at harvest which was statistically similar to isoproturon 750 g/ha + metsulfuron 4 g/ha, pinoxaden 40 g/ha followed by metsulfuron 4 g/ha and pinoxaden 40 g/ha + metsulfuron 4 g/ha. The herbicides like isoproturon 750 g/ha + 2,4-D 500 g/ha, isoproturon 750 g/ha + metsulfuron 4 g/ha, pinoxaden 40 g/ha followed by metsulfuron 4 g/ha, pinoxaden 40 g/ha + metsulfuron 4 g/ha, pinoxaden 50 g/ha and isoproturon 1000 g/ha were effective in reducing weed density and dry matter due to better weed control. The herbicide

Table 1. Effect of various weed control treatments on weed density, weed dry matter and weed control efficiency in barley

Treatment	Total weed density (no./m^2)				Weed dry matter (g/m^2)				WCE (%)	
	60 DAS		90 DAS		(90 DAS)		At harvest			
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
Pinoxaden 30 g/ha	9.3(88)	8.8(78)	8.9(81)	8.1(65)	7.6(57)	5.5(31)	13.8(189)	10.5(111)	29.6	53.4
Pinoxaden 40 g/ha	9.5(90)	8.4(71)	8.8(77)	7.7(59)	7.1(50)	5.4(29)	12.9(164)	10.2(104)	42.9	56.6
Pinoxaden 50 g/ha	8.6(74)	8.1(65)	8.2(67)	7.4(54)	6.2(38)	5.2(26)	11.0(124)	9.6(91)	61.6	61.8
Pinoxaden 40 g/ha + metsulfuron 4 g/ha	8.3(70)	6.5(42)	8.0(65)	6.7(45)	6.0(36)	3.8(15)	10.9(119)	6.7(44)	55.0	81.9
Pinoxaden 40 g/ha *fb* metsulfuron 4 g/ha	8.3(68)	7.8(61)	7.9(62)	7.1(50)	5.7(33)	4.8(23)	10.5(110)	9.0(80)	59.9	66.3
Pinoxaden 40 g/ha + carfentrazone 20 g/ha	9.9(98)	7.3(54)	9.5(91)	5.9(35)	5.5(33)	3.6(12)	10.0(108)	6.7(44)	47.2	81.4
Isoproturon 1000 g/ha	8.8(77)	9.3(86)	8.3(69)	8.5(71)	7.0(49)	5.6(33)	12.7(162)	10.6(121)	48.4	50.1
Isoproturon 750 g/ha + 2,4-D 500 g/ha	8.0(64)	8.5(72)	7.6(57)	7.8(60)	5.4(29)	5.4(30)	9.7(96)	10.3(107)	70.5	54.9
Isoproturon 750 g/ha + metsulfuron 4 g/ha	8.3(69)	7.7(60)	7.9(63)	7.1(50)	6.4(42)	4.7(22)	11.7(139)	9.0(81)	57.9	65.7
Weedy check	11.9(142)	10.1(103)	11.5(131)	9.3(86)	9.2(84)	8.0(64)	16.8(281)	15.5(240)	-	-
Weed free	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1(0)	1(0)	1(0)	1.0(0)	100.0	100.0
LSD (p=0.05)	1.02	0.2	1.1	1.2	1.5	1.2	2.82	2.41	14.1	22.7

The data were square root transformed and values in the parentheses are original values combinations performed better than individual herbicides, which was due to complex weed flora in the experimental fields. Ram and Singh (2009) also reported that isoproturon 1000 g + metsulfuron 4 g/ha, isoproturon 1000 g/ha, isoproturon 1000 g + carfentrazone 20 g/ha and isoproturon 1000 g + 2,4-D 500 g/ha were effective in controlling the mixed weed flora. The herbicide combinations are more effective to control complex weed flora (Bhullar *et al.* 2013, Tiwari *et al.* 2005, Howatt 2005, Zand *et al.* 2010).

Among the herbicide treatments, the highest WCE (70.5%) was recorded in isoproturon 750 g/ha + 2,4-D 500 g/ha during 2014-15 which was similar to isoproturon 750 g/ha + metsulfuron 4 g/ha, pinoxaden 40 g/ha + metsulfuron 4 g/ha and pinoxaden 50 g/ha. In 2016-17 pinoxaden 40 g/ha + metsulfuron 4 g/ha recorded the highest WCE (81.9%) which was at par to isoproturon 750 g/ha + metsulfuron 4 g/ha, in pinoxaden 40 g/ha + carfentrazone 20 g/ha and in pinoxaden 50 g/ha. Lower WI and higher WCE recorded in isoproturon 750 g/ha + 2,4-D 500 g/ha, pinoxaden 40 g/ha + carfentrazone 20 g/ha was due to better weed management achieved in these treatments. Bhullar *et al.* (2013) reported that the application of carfentrazone-ethyl or metsulfuron-methyl was effective in reducing density and biomass of broad-leaf weeds.

Effect on crop growth and yield

Among herbicide treatments, isoproturon 750 g/ha + 2,4-D 500 g/ha had lower WI, which was 16.3% less than the weedy check. During the second year, WI of 6.4% was recorded in pinoxaden 40 g/ha + carfentrazone 20 g/ha, which was 43.7% less than weedy check (**Table 2**). Chlorophyll index ranged from 52.2-57.1 in 2014-15 and 53.9-64.1 in 2015-16. Weedy check and isoproturon 1000 g/ha recorded a significant reduction in chlorophyll index. Weedy check reduced chlorophyll index by about 7.53-16.4%, depicting less nutrient in this plot. Weedy check, isoproturon 1000 g/ha, pinoxaden 40 g/ha + metsulfuron 4 g/ha reduced chlorophyll index in barley leaves which was due to their toxic effect on the leaves which was recovered later on. There may be other physiological processes like nutrient and water absorption, light interception, carbon fixation, and root architecture, which might be hampered by crop weed interference.

A significant decline of 9.5-12.4% was observed in the number of effective tillers per square metre in weedy check conditions as compared to weed-free (p=0.05, **Table 2**). The highest number of effective tillers in weed-free treatment was at par with pinoxaden 50 g/ha, pinoxaden 40 g/ha, followed by metsulfuron 4 g/ha and pinoxaden 40 g/ha + carfentrazone 20 g/ha. In addition to the above, a combination of isoproturon 750 g/ha + 2,4-D 500 g/ha in 2014-15, and isoproturon 750 g/ha + metsulfuron 4 g/ha in 2015-16 also resulted in effective tillers similar to weed free treatment. In 2015-16, the number of effective tillers recorded in isoproturon 1000 g/ha were similar to the weedy check. The reduction of 9.6-12.4% effective tillers in weedy check indicated that weeds stole the nutrient, water, space, and light. The herbicide treatments of pinoxaden 50 g/ha, pinoxaden 40 g/ha followed by metsulfuron 4 g/ha and pinoxaden 40 g/ha + carfentrazone 20 g/ha, isoproturon 750 g/ha + 2,4-D

Table 2. Effect of weed control treatments on weed index (WI), chlorophyll index, yield attribute, biomass yield and grain yield of barley

Treatment	WI (%)		Chlorophyll index		Effective tillers (/m^2)		Grains /Ear[1]		Biomass yield (t/ha)		Grain yield (t/ha)	
	14-15	15-16	14-15	15-16	14-15	15-16	14-15	15-16	14-15	15-16	14-15	15-16
Pinoxaden 30 g/ha	25.7(19.0)	32.2(29.1)	55.9	57.3	381.7	362.7	29.8	19.1	12.17	11.25	4.90	3.88
Pinoxaden 40 g/ha	23.0(16.7)	27.5(24.7)	56.2	60.6	378.0	364.0	30.8	22.0	12.17	11.83	5.03	4.08
Pinoxaden 50 g/ha	21.6(14.7)	28.9(24.0)	55.5	56.3	387.0	367.7	30.1	20.4	12.67	10.63	5.15	4.17
Pinoxaden 40 g/ha + metsulfuron 4 g/ha	32.5(29.1)	24.4(18.1)	56.7	55.2	375.7	354.7	26.1	22.3	10.67	12.75	4.28	4.50
Pinoxaden 40 g/ha *fb* metsulfuron 4 g/ha	12.2(06.8)	18.1(10.7)	54.7	57.9	389.3	373.0	34.0	23.5	13.67	14.00	5.63	4.92
Pinoxaden 40 g/ha + carfentrazone 20 g/ha	13.6(08.6)	6.4(02.9)	55.3	59.6	388.3	381.3	32.3	25.7	13.17	15.33	5.52	5.50
Isoproturon 1000 g/ha	29.0(24.3)	27.9(23.3)	52.2	54.2	377.3	345.7	27.9	21.7	11.50	11.83	4.57	4.19
Isoproturon 750 g/ha + 2,4-D 500 g/ha	9.6(04.0)	26.4(27.2)	55.0	59.5	395.7	357.3	33.0	20.2	14.00	11.50	5.82	5.17
Isoproturon 750 g/ha + metsulfuron 4 g/ha	23.5(16.7)	20.6(15.0)	53.9	56.2	380.3	366.7	30.8	22.9	12.17	10.83	5.05	4.67
Weedy check	25.9(19.3)	50.1(58.8)	52.8	53.9	365.0	336.0	31.8	13.8	13.00	11.79	4.90	2.25
Weed free	0.8(0.0)	0.8(0.0)	57.1	64.1	403.7	383.7	34.3	24.7	14.00	13.54	6.0	5.54
LSD (p=0.05)	11.3	18.2	4.1	8.3	17.5	16.0	4.6	5.6	1.41	2.78	0.7	0.7

Weed index data were square root transformed and values in the parentheses are original values

500 g/ha and isoproturon 750 g/ha + metsulfuron 4 g/ha in 2014-15 were able to improve the effective tillers comparable to weed free treatment. It might be due to effective control of weeds by reducing the weed density and dry matter and improving the WCE, which provided more space and growth factors to the crop. Chhokar *et al.* (2008) and Ram and Singh (2009) also reported a similar finding.

Number of grains per ear head in pinoxaden 40 g/ha + metsulfuron 4 g/ha and isoproturon 1000 g/ha during 2014-15 were 23.9 - 44.1% less than the weed-free treatment. In 2015-16, pinoxaden 40 g/ha + carfentrazone 20 g/ha recorded the highest value for grains per earhead, which was significantly higher than weedy check but statistically at par to all the herbicide treatments. Weedy check reduced the crop biomass by 7.14% in 2014-15 and 12.9% in 2015-16. The highest biomass was recorded in weed-free during 2014-15 and in pinoxaden 40 g/ha + carfentrazone 20 g/ha during 2015-16. The biomass yield recorded in pinoxaden 50 g/ha, pinoxaden 40 g/ha followed by metsulfuron 4 g/ha, pinoxaden 40 g/ha + carfentrazone 20 g/ha and isoproturon 750 g/ha + 2,4-D 500 g/ha was similar to weed-free treatment during 2014-15. In 2015-16, pinoxaden 40 g/ha + carfentrazone 20 g/ha recorded similar biomass as recorded in pinoxaden 40 g/ha + metsulfuron 4 g/ha, pinoxaden 40 g/ha followed by metsulfuron 4 g/ha and weed-free treatment. Magnitude of expansion in the biomass yield recorded in pinoxaden 50 g/ha, pinoxaden 40 g/ha followed by metsulfuron 4 g/ha, pinoxaden 40 g/ha + carfentrazone 20 g/ha and isoproturon 750 g/ha + 2,4-D 500 g/ha and pinoxaden 40 g/ha + metsulfuron 4 g/ha was similar to weed-free treatment. It was due to less weed density, weed dry matter, WI, and higher yield attributes in these treatments.

Weed-free treatment recorded 6.07 t and 5.54 t/ha grain yield in consecutive years, which was 23.9 and 146.2% higher than the weedy check. All the herbicidal treatments improved the grain yield significantly as compared to weedy check during 2015-16. Still, only isoproturon 750 g/ha + 2,4-D 500 g/ha, and pinoxaden 40 g/ha, followed by metsulfuron 4 g/ha· could improve the grain yield significantly than the weedy check. The herbicides treatments like isoproturon 750 g/ha + 2,4-D 500 g/ha, pinoxaden 40 g/ha, followed by metsulfuron 4 g/ha and pinoxaden 40 g/ha + carfentrazone 20 g/ha recorded grain yield similar to weed-free treatment. The herbicide combinations like isoproturon 750 g/ha + 2,4-D 500 g/ha and pinoxaden 40 g/ha followed by metsulfuron 4 g/ha, pinoxaden 40 g/ha + carfentrazone 20 g/ha recorded similar grain yield as recorded in weed-free due to elimination of weeds which provided sufficient space, moisture, nutrient and light to the crop, which in turn, improved the effective tillers, grains per earhead, and 1000-grain weight, and ultimately the grain yield. Metsulfuron-methyl and carfentrazone-ethyl effectively controlled the broad-leaf weeds in wheat and barley (Howatt 2005, Tiwari *et al.* 2005, Zand *et al.* 2010) as these herbicides have a different mode of action so these can be used as alternative herbicides with 2,4-D to control resistant weeds. Ram and Singh (2009) while working on barley crop also reported that isoproturon 1000 g + metsulfuron 4 g/ha, isoproturon 1000 g/ha, isoproturon 1000 g + carfentrazone 20 g/ha and isoproturon 1000 g + 2,4-D 500 g/ha herbicides enhanced the crop yield by controlling the mixed weed flora. Bhullar *et al.* (2013) reported that the application of carfentrazone-ethyl or metsulfuron-methyl effectively controlled the broad-leaf weeds and enhanced the grain yield of barley.

Economics

Pooled partial budget analysis indicated that the highest gross returns were found in the weed-free treatment (**Table 3**) which was statistically at par with pinoxaden 40 g/ha followed by metsulfuron 4 g/ha and pinoxaden 40 g/ha + carfentrazone 20 g/ha and isoproturon 750 g/ha + 2,4-D 500 g/ha, but significantly higher than other treatments. The net returns and B:C ratio in isoproturon 750 g/ha + 2,4-D 500 g/ha were the highest, and statistically similar to pinoxaden 40 g/ha, followed by metsulfuron 4 g/ha, isoproturon 750 g/ha + metsulfuron 4 g/ha and pinoxaden 40 g/ha + carfentrazone 20 g/ha and weed-free treatment. Chhokar *et al.* (2008) concluded that pinoxaden 30-35 g/ha is highly effective against grass weeds like *Phalaris minor*, *Avena ludoviciana*, and *Polypogon monspeliensis* under North Indian conditions. Higher net returns with isoproturon 750 g/ha + 2,4-D 500 g/ha, pinoxaden 40 g/ha followed by metsulfuron 4 g/ha and pinoxaden 40 g/ha + carfentrazone 20 g/ha and isoproturon 750 g/ha + metsulfuron 4 g/ha was due to better weed management and higher gross income.

Therefore, it was concluded that isoproturon 750 g/ha + 2,4-D (Na salt) 500 g/ha, pinoxaden 40 g/ha followed by metsulfuron 4 g/ha and pinoxaden 40 g/ha + carfentrazone 20 g/ha and isoproturon 750 g/ha + metsulfuron 4 g/ha can be used for weed control in barley.

Table 3. Pooled partial budget analysis of barley as influenced by different weed management practices

Treatment	Cost of cultivation ($\times10^3$ ₹/ha)	Gross returns ($\times10^3$ ₹/ha)	Net returns ($\times10^3$ ₹/ha)	Benefit: cost ratio
Pinoxaden 30 g/ha	36.80	95.70	58.90	1.60
Pinoxaden 40 g/ha	37.25	99.30	62.05	1.67
Pinoxaden 50 g/ha	37.85	101.60	63.75	1.68
Pinoxaden 40 g/ha + metsulfuron 4 g/ha	37.90	96.15	58.25	1.54
Pinoxaden 40 g/ha followed by metsulfuron 4 g/ha	37.90	115.15	77.25	2.04
Pinoxaden 40 g/ha + carfentrazone 20 g/ha	37.70	120.55	82.85	2.20
Isoproturon 1000 g/ha	36.20	95.70	59.50	1.64
Isoproturon 750 g/ha + 2,4-D 500 g/ha	36.45	120.00	83.55	2.29
Isoproturon 750 g/ha + metsulfuron 4 g/ha	36.45	106.20	69.75	1.91
Weedy check	35.35	77.30	41.95	1.19
Weed free	43.95	126.80	82.85	1.89
LSD (p=0.05)	-	15.20	15.20	0.40

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