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Evaluation of Combinations of Herbicides to Manage Mixed Weed Flora in Wheat

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Abstract: ***Sixteen weed control treatments viz. pinoxaden (40 g ha^{-1}), isoproturon (1250 g ha^{-1}) alone, isoproturon + pinoxaden (1000 + 40 g ha^{-1}), isoproturon + pinoxaden (750 + 30 g ha^{-1}), isoproturon + 2,4-D (1000 + 500 g ha^{-1}), isoproturon + metsulfuron-methyl (1000 + 4 g ha^{-1}), pinoxaden + 2,4-D (40 + 1000 g ha^{-1}), pinoxaden + metsulfuron-methyl (40 + 4 g ha^{-1}), isoproturon fb pinoxaden (1000 fb 40 g ha^{-1}), isoproturon fb pinoxaden (750 fb 30 g ha^{-1}), pinoxaden fb isoproturon (40 fb 1000 g ha^{-1}), pinoxaden fb isoproturon (30 fb 750 g ha^{-1}), pinoxaden fb 2,4-D (40 fb 1000 g ha^{-1}), pinoxaden fb metsulfuron-methyl (40 fb 4 g ha^{-1}), hand weeding (30 & 60 DAS) and weedy check were evaluated for the control of mixed weed flora in wheat at Palampur. Soil of the test site was silty clay loam in texture, acidic in reaction, medium in available nitrogen, available phosphorus and available potassium status. Avenaludoviciana and Phalaris minor were the major weeds constituting 35 and 25.1 per cent, respectively, of total weed flora at 90 DAS. The broad-leaf weeds (Anagallis arvensis, Vicia sativa and Coronopus didymus) as a whole constituted 28.6 per cent of total weed flora. Results of the study revealed that pinoxaden fb metsulfuron methyl (40 fb 4 g ha^{-1}) and pinoxaden + metsulfuron methyl (40 + 4 g ha^{-1}) were superir to hand weeding and resulted in significantly lower population of Avena ludoviciana, Phalaris minor, Lolium temulentum, Anagallis arvensis, Vicia sativa and Coronopus didymus. Sequential application of pinoxaden fb metsulfuron methyl (40 fb 4 g ha^{-1}) resulted in significantly higher grain yield, net returns (47489 ` ha^{-1}) and net returns per rupee invested (1.97). However, pinoxaden + metsulfuron methyl (40 + 4 g ha^{-1}) was comparable to pinoxaden fb metsulfuron methyl (40 fb 4 g ha^{-1}) in increasing the grain yield of wheat.***

Keywords: ***pinoxaden, isoproturon, combinations, weed count, yield, economics, wheat***

Introduction

Isoproturon is nationwide recommended herbicide to control complex weed flora in wheat. However, the continuous adoption of rice-wheat cropping system and application of isoproturon led to the problem of isoproturon resistant *Phalaris minor*. Continuous reliance on isoproturon after the evolution of resistance resulted in a heavy build-up of *P. minor* population, as competition from other weeds was removed. There were instances when wheat growers were forced to harvest their immature crop as fodder in absence of effective alternative herbicides (Malik and Singh 1995). Pinoxaden 40-60 g ha^{-1} is very effective against *Avena ludoviciana* and resistant population of *Phalaris minor* without any phytotoxicity, but is ineffective against broad-leaf weeds (Singh and Punia 2007; Chhokar *et al.* 2008a). Herbicide 2,4-D provides effective control of broad-leaf weeds in barley but 2,4-D if used with phenylpyrazolin group of herbicides antagonizes the effect of graminicides in wheat (Balyan *et al.* 1993). Herbicides with differential selectivity can be applied sequentially, but it involves application in two rounds, resulting in enhancing the cost. Therefore, mixing two different herbicides and applying them simultaneously widens the spectrum of weed-control, saves time and application cost. Therefore, a need remains to evaluate new herbicides with different modes of action to tackle the ever increasing problem of complex weed flora. Keeping this in view, the present investigation was carried out.

Materials and Methods

Sixteen weed control treatments *viz.* pinoxaden (40 g ha^{-1}), isoproturon (1250 g ha^{-1}) alone, isoproturon + pinoxaden (1000 + 40 g ha^{-1}), isoproturon + pinoxaden (750 + 30 g ha^{-1}), isoproturon + 2,4-D (1000 + 500 g ha^{-1}), isoproturon + metsulfuron-methyl (1000 + 4 g ha^{-1}), pinoxaden + 2,4-D (40 + 1000 g ha^{-1}), pinoxaden + metsulfuron-methyl (40 + 4 g ha^{-1}), isoproturon *fb* pinoxaden (1000 *fb* 40 g ha^{-1}), isoproturon *fb* pinoxaden (750 *fb* 30 g ha^{-1}), pinoxaden *fb* isoproturon (40 *fb* 1000 g ha^{-1}), pinoxaden *fb* isoproturon (30 *fb* 750 g ha^{-1}), pinoxaden *fb* 2,4-D (40 *fb* 1000 g ha^{-1}), pinoxaden *fb* metsulfuron-methyl (40 *fb* 4 g ha^{-1}), handweeding (30 & 60 DAS) and weedy check (Table 1) were tested in a Randomized Block Design with three replications at Palampur on a silty clay loam. The soil was acidic in reaction and medium in available nitrogen, phosphorus and potassium status. Wheat variety HPW- 155 was sown on 20 November 2010 in plough furrows 22.5 cm apart using 100 kg seed ha^{-1}. The crop was fertilized with 120 kg N, 60 kg P_2O_5 and 30 kg K_2O per hectare. Nitrogen, phosphorus and potassium were applied through urea (46% N), single super phosphate (16% P_2O_5) and muriate of potash (60% K_2O), respectively. One third N and whole P_2O_5 and K_2O were applied at the time of sowing. The remaining N was applied in two equal splits, first at maximum tillering and second at flower initiation stage. The hand weedings (T_{15}) were done as per schedule i.e. at 30 and 60 DAS. Herbicides as per treatments were applied with knapsack power sprayer using 600 liters water per hectare. The crop was harvested on May 21 2011. The species-wise weed count was recorded at 60, 90, 120, 150 DAS and at harvest. Yield attributes and yield were recorded at harvest. Economics o the treatments was computed based on prevalent market prices.

Results and Discussion

Avena ludoviciana and *Phalaris minor* were the major weeds constituting 35% and 25.1%, respectively, of the total weed population at 90 DAS. *Lolium temulentum*, *Anagallis arvensis, Vicia sativa* and *Coronopus didymus* constituted 11.3%, 11.3%, 10.7% and 6.6%, respectively of the total weed population.

Weed count

The data on weed count have been recorded at 60, 90, 120, 150 DAS and at harvest. The count of all grassy weeds and *V. sativa* was maximum at 90 DAS and then gradually decreased. The count of *A. arvensis* and *C. didymus* was maximum at 120 DAS and then gradually decreased. Since grassy weeds were more competitive and assumed maximum population by 90 DAS, the data on count with respect to all weeds individually have been described at 90 DAS. All weed control treatments except isoproturon (1.25 kg ha^{-1}), isoproturon + 2,4-D (1000 + 500 g ha^{-1}) and isoproturon + metsulfuron methyl (MSM) (1000 + 4 g ha^{-1}) significantly reduced the population of *A. ludoviciana* over weedy check (Table 1). The rest of the treatments (including pinoxaden) were comparable to each other in reducing the population of *A. ludoviciana*. This clearly indicated that pinoxaden at 35-40 DAS was quite effective against *A. ludoviciana* as against isoproturon which did not control this weed at this stage. Similar observations with respect to pinoxaden alone and in combination with other herbicides on count of *A. ludoviciana* have been reported (Chhokar *et al*. 2008a&b and Kumar *et al*. 2010).

Table 1. Effect of weed control treatments on weed density (No. m^{-2}) at maximum weed population stage *i.e.* 90 DAS

Treatment	Dose (g ha^{-1})	Time of Application (DAS)	*A. ludoviciaa*	*P. minor*	*L. temulentum*	*V. sativa*	*A. arvensis*	*C. didymus*	Total weed count (90 DAS)
Pinoxaden	40	35	2.2(4)	2.9(8)	1.9 (2.7)	5.5(29.3)	4.6(20)	3.4 (11)	27.8 (75)
Isoproturon	1250	30	7.0(48)	3.0(8)	2.8 (6.7)	2.2(4.0)	2.7(7)	2.7 (7)	25.7 (81)
Isoproturon + pinoxaden	1000 + 40	35	1.8(3)	2.5(5)	1.5 (1.3)	2.5(5.3)	3.0(8)	2.3 (5)	16.7 (28)
Isoproturon + pinoxaden	750 + 30	35	2.2(4)	2.7(5)	1.9 (2.7)	2.7(6.7)	3.2(9)	2.7 (7)	19.5 (35)
Isoproturon + 2,4-D	1000 + 500	35	7.3(52)	2.9(8)	3.0 (8.0)	2.5(5.3)	2.5(5)	1.7 (3)	20.9 (81)
Isoproturon + MSM	1000 + 4	35	7.2(51)	3.0(8)	2.9 (8.0)	1.8 (2.7)	2.2(4)	1.8 (3)	19.8 (76)
Pinoxaden + 2, 4-D	40 + 1000	35	2.1(4)	3.0(8)	2.2 (4.0)	2.5 (5.3)	2.7(7)	2.3 (5)	17.9 (33)
Pinoxaden + MSM	40 + 4	35	2.1(4)	2.9(8)	1.9 (2.7)	2.2 (4.0)	2.5(5)	2.1 (4)	15.6 (28)
Isoproturon *fb* pinoxaden	1000 *fb* 40	30 *fb* 40	1.8(3)	2.2(4)	1.5 (1.3)	2.5 (5.3)	3.0(8)	2.5 (5)	16.4 (27)
Isoproturon *fb* pinoxaden	750 *fb* 30	30 *fb* 40	2.2(4)	2.5(5)	2.2 (4.0)	2.7 (6.7)	3.4(11)	3.4 (11)	23.7 (41)
Pinoxaden *fb* isoproturon	40 *fb* 1000	35 *fb* 40	1.8(3)	2.2(4)	1.9 (2.7)	2.7 (6.7)	2.7(7)	2.5 (5)	15.9 (25)
Pinoxaden *fb* isoproturon	30 *fb* 750	35 *fb* 40	2.2(4)	2.5(5)	1.9 (2.7)	3.0 (8.0)	3.0(8)	2.7 (7)	19.3 (35)
Pinoxaden *fb* 2,4-D	40 *fb* 1000	35 *fb* 40	2.2(4)	2.7(8)	1.9 (2.7)	2.2 (4.0)	2.7(7)	2.1 (4)	15.8 (29)
Pinoxaden *fb* MSM	40 *fb* 4	35 *fb* 40	2.2(4)	2.3(5)	1.5 (1.3)	1.8 (2.7)	2.2(4)	1.4 (1)	11.5 (19)
Handweeding	----	30 & 60	2.1(4)	2.2(4)	1.9 (2.7)	1.8 (2.7)	2.2(4)	2.9 (8)	19.7 (32)
Weedy check	----	---	8.7(75)	7.4(53)	5.0 (24)	5.9 (33.3)	4.9(24)	3.7 (13)	45.1(223)
LSD (P=0.05)			0.7	1.0	1.0	0.6	0.8	2.0	2.5

Data transformed to square root transformation ($\sqrt{x+1}$), Values given in parenthesis are the means of original values, DAS= Days after sowing, *fb*= followed by, MSM= metsulfuron methyl

All treatments involving isoproturon and pinoxaden were equally good in reducing the count of *P. minor* at 90 DAS over weedy check. The activity of pinoxaden (Kumar *et al.* 2010) and isoproturon (Chopra *et al.* 2001) against *P. minor* has been well established. Metsulfuron-methyl and 2, 4-D are mainly broad-leaf herbicides and both showed their little effect on *Phalaris minor*. All weed control treatments brought about significant reduction in conut of *L. temulentum* over weedy check. Pinoxaden *fb* MSM (40 *fb* 4 g ha^{-1}) resulted in significantly lower population of *C. didymus* over isoproturon (1250 g ha^{-1}), isoproturon + 2, 4-D (1000 + 500 g ha^{-1}) and isoproturon + MSM (1000 + 4 g ha^{-1}. While, rest of the treatments were comparable to pinoxaden *fb* MSM 40 *fb* 4 g ha^{-1}. Application of pinoxaden *fb* MSM (40 *fb* 4 g ha^{-1}) remaining at par with isoproturon (1250 g ha^{-1}), isoproturon + 2,4-D (1000 + 500 g ha^{-1}), pinoxaden + MSM (40 + 4 g ha^{-1}), pinoxaden *fb* 2,4-D (40 *fb* 1000 g ha^{-1}) and hand weeding resulted in significantly lower population of *V. sativa*. The effective control of this weed with metsulfuron methyl has been reported by Walia and Singh (2007). Pinoxaden (40 g ha^{-1}) was less effective in reducing population of *V. sativa*. The main flushes of *A. arvensis* i.e. the broad-leaf species appeared around 60-90 DAS and 90-120 DAS *i.e.* after the application of post-emergence herbicides, 2, 4-D and MSM still adjudged to be effective against the weed. It may be seen from the fact that the treatments including 2, 4-D [Pinoxaden + 2, 4-D and pinoxaden *fb* 2, 4-D] and MSM were effective against *A. arvensis*. However, pinoxaden (40 g ha^{-1}) did not differ significantly from weedy check in influencing the population of this weed. The activity of metsulfuron methyl alone or in combination with other herbicides (Kumar *et al*. 2010) against *A. arvensis* has been well established.

Owing to reduction in species-wise weed count, all the weed control treatments resulted in significant reduction in total weed count as compared to weedy check. Application of pinoxaden *fb* MSM (40 *fb* 4g ha^{-1}) resulted in lowest total weed count. The superiority of pinoxaden + metsulfuron methyl mixture in controlling weeds has been documented (Kumar *et al* 2010). Owing to synergistic enhancement or additive effects, herbicidal combinations in general were better than sole application of herbicides in effectively reducing the total weed count.

Yield attributes and yield

Owing to removal/reduction of competition right at early stages of crop growth, all treatments were significantly superior to weedy check in increasing number of grains per spike and 1000-grain weight. All treatments except isoproturon + pinoxaden (750 + 30 g ha^{-1}) were equally effective in influencing 1000-grain weight over weedy check. Pinoxaden *fb* MSM (40 *fb* 4 g ha^{-1}) remaining at par with pinoxaden +MSM (40 + 4 g ha^{-1}) and pinoxaden *fb* 2,4-D (40 *fb* 1000 g ha^{-1}) resulted in significantly higher grains per spike over other treatments. Application of pinoxaden *fb* MSM (40 *fb* 4 g ha^{-1}) being at par with pinoxaden *fb* 2,4-D (40 *fb* 1000 g ha^{-1}), pinoxaden + MSM (40 + 4 g ha^{-1}), pinoxaden +2,4-D (40

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+1000 g ha^{-1}) and pinoxaden *fb* isoproturon (40 *fb* 1000 g ha^{-1}) was significantly superior to other treatments in influencing effective tiller m^{-2}. However, pinoxaden (40 g ha^{-1}), isoproturon (1250 g ha^{-1}), isoproturon + pinoxaden (750 +30 g ha^{-1}), isoproturon + MSM (1000 + 4 g ha^{-1}), pinoxaden *fb* isoproturon (30 *fb* 750 g ha^{-1}) and handweeding could not significantly increase effective tillers over weedy check. The superiority of herbicide combinations over alone application of herbicides in increasing yield attributes has been documented (Kumar *et al*. 2010).

Table 2. Effect of different treatments on yield attributes and yield of wheat

Treatment	Dose (g ha^{-1})	Time of application (DAS)	Effective tiller m^{-2}	Grains /spike	1000 grain weight (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest Index	Weed Index (%)
Pinoxaden	40	35	170.9	46.1	51.8	3295	6049	0.35	23.9
Isoproturon	1250	30	170.2	45.7	51.8	3124	6014	0.34	27.6
Isoproturon + pinoxaden	1000 + 40	35	182.3	47.1	51.3	3656	6330	0.37	15.9
Isoproturon + pinoxaden	750 + 30	35	172.2	46.5	48.6	3514	6219	0.36	19.1
Isoproturon + 2,4-D	1000 + 500	35	171.9	46.6	52.1	3357	6066	0.36	22.3
Isoproturon + MSM	1000 + 4	35	174.6	45.7	50.1	3371	6160	0.35	22.4
Pinoxaden + 2, 4-D	40 + 1000	35	193.1	46.9	53.1	3799	6895	0.36	12.4
Pinoxaden + MSM	40 + 4	35	200.5	47.0	53.6	4140	6995	0.37	4.5
Isoproturon *fb* pinoxaden	1000 *fb* 40	30 *fb* 40	184.3	46.6	51.1	3713	6368	0.37	14.5
Isoproturon *fb* pinoxaden	750 *fb* 30	30 *fb* 40	178.3	46.5	50.7	3561	6236	0.36	17.9
Pinoxaden *fb* isoproturon	40 *fb* 1000	35 *fb* 40	180.9	46.8	52.0	3775	6373	0.37	12.5
Pinoxaden *fb* isoproturon	30 *fb* 750	35 *fb* 40	182.0	46.0	52.2	3538	6165	0.36	18.4
Pinoxaden *fb* 2,4-D	40 *fb* 1000	35 *fb* 40	196.8	46.7	53.1	3980	6922	0.37	8.2
Pinoxaden *fb* MSM	40 *fb* 4	35 *fb* 40	206.5	47.1	53.7	4340	7070	0.38	0.0
Handweeding	---	30 & 60	180.0	45.6	51.5	3522	6230	0.36	18.7
Weedy check	---	---	156.9	41.3	39.5	2280	4804	0.32	47.3
LSD (P=0.05)			12.4	0.5	5.1	310	340	0.02	6.7

DAS= Days after sowing, *fb*= followed by and MSM= metsulfuron methyl

The complete or partial reduction in competition by weeds and subsequent increase in yield attributes were reflected in yield of wheat. Weed control treatments resulted in significantly higher grain yield over weedy check. Pinoxaden *fb* MSM (40 *fb* 4 g ha^{-1}) remaining at par with pinoxaden + MSM (40

+ 4 g ha^{-1}) gave significantly higher grain yield over rest of the treatments. Similar observations with respect to pinoxaden in combination with metsulfuron -methyl on yield attributes and yield were recorded at Hisar (Kumar *et al*. 2010). Weeds in weedy check reduced grain yield of wheat by 47.5%. Straw yield in general followed the trend of grain yield. Application of pinoxaden *fb* MSM (40 *fb* 4 g ha^{-1}) remaining at par with pinoxaden + MSM (40 + 4 g ha^{-1}), pinoxaden *fb* 2,4-D (40 *fb* 1000 g ha^{-1}), pinoxaden + 2,4-D (40 + 1000 g ha^{-1}) and pinoxaden (40 g ha^{-1}) resulted in significantly higher wheat straw yield over other treatments. Straw is an important feed stuff for feeding livestock and weeds in weedy check reduced straw yield by 47.2% over pinoxaden *fb* MSM (40 *fb* 4 g ha^{-1}).

Application of pinoxaden *fb* MSM (40 *fb* 4 g ha^{-1}) remaining at par with isoproturon + pinoxaden (1000 + 40 g ha^{-1}), pinoxaden + MSM (40 + 4 g ha^{-1}), isoproturon *fb* pinoxaden (1000 *fb* 40 g ha^{-1}), pinoxaden *fb* isoproturon (40 *fb* 1000 g ha^{-1}),isoproturon *fb* pinoxaden (1000 *fb* 40 g ha^{-1}) and pinoxaden *fb* 2,4-D (40 *fb* 1000 g ha^{-1}) resulted in significantly higher harvest index over other treatments. Weed index is a measure of yield depression due to the presence of weeds relative to weed free where competition was tended to be eliminated. Pinoxaden + MSM (40 + 4 g ha^{-1}) had comparable yield as under pinoxaden *fb* MSM (40 *fb* 4 g ha^{-1}), thus also had comparable weed index i.e. minimum reduction in yield due to presence of weeds. However, pinoxaden + MSM (40 + 4 g ha^{-1}) was statistically at par with pinoxaden *fb* 2, 4-D (40 *fb* 1000 g ha^{-1}).

Economics

Because of higher grain and straw yield, pinoxaden *fb* MSM (40 *fb* 4 g ha^{-1} (` 71537 ha^{-1}) being at par with pinoxaden + MSM (40 + 4 g ha^{-1}) resulted in higher gross returns as compared to rest of treatments. In general, herbicide combinations were better than herbicides alone, but grass killers had an edge over broad-leaf killers because grassy weeds constituted more proportion of total weeds in the experimental field. Net returns accrued under different treatments followed almost the similar trend as gross returns. Application of pinoxaden *fb* MSM (40 *fb* 4 g ha^{-1}) (` 47489 $ha^{-1}$) being at par with pinoxaden + MSM (40 + 4 g $ha^{-1}$) resulted in 160.1% higher net returns over weedy check. Pinoxaden + MSM (40 + 4 g $ha^{-1}$) (` 45487 ha^{-1}) increased net returns to the tune of 150.3% over weedy check. The other treatments which significantly increased net returns over handweeding twice were pinoxaden + 2, 4 –D (40 + 1000 g ha^{-1}) and pinoxaden *fb* 2, 4-D (40 *fb* 1000 g ha^{-1}). Weed control treatments were superior to weedy check in influencing net returns per rupee invested. Application of pinoxaden *fb* MSM (40 *fb* 4 g ha^{-1}) resulted in highest net returns per rupee invested (1.97) followed by pinoxaden + MSM [(40 + 4 g ha^{-1}) (1.93)].

Table 3. Economics of weed control treatments

Treatment	Doses (g ha^{-1})	Time of Application (DAS)	Gross returns (` ha^{-1})	Cost of cultivation (` ha^{-1})	Net returns (` ha^{-1})	Net returns per rupee invested
Pinoxaden	40	35	56564	23243	33321	1.43
Isoproturon	1250	30	54540	23156	31383	1.36
Isoproturon + pinoxaden	1000 + 40	35	61521	23750	37771	1.59
Isoproturon + pinoxaden	750 + 30	35	59565	23443	36122	1.54
Isoproturon + 2,4-D	1000 + 500	35	57314	23195	34119	1.47
Isoproturon + MSM	1000 + 4	35	57771	23405	34366	1.47
Pinoxaden + 2, 4-D	40 + 1000	35	64954	23573	41381	1.76
Pinoxaden + MSM	40 + 4	35	69105	23618	45487	1.93
Isoproturon *fb* pinoxaden	1000 *fb* 40	30 *fb* 40	62280	24230	38050	1.57
Isoproturon *fb* pinoxaden	750 *fb* 30	30 *fb* 40	60152	23923	36229	1.51
Pinoxaden *fb* isoproturon	40 *fb* 1000	35 *fb* 40	62993	24230	38763	1.60
Pinoxaden *fb* isoproturon	30 *fb* 750	35 *fb* 40	60766	23923	36843	1.54
Pinoxaden *fb* 2,4-D	40 *fb* 1000	35 *fb* 40	67074	24053	43020	1.79
Pinoxaden *fb* MSM	40 *fb* 4	35 *fb* 40	71587	24098	47489	1.97
Handweeding	---	30 & 60	59689	28043	31646	1.13
Weedy check	---	---	91148	22043	19105	0.37
LSD (P=0.05)			3863	---	3863	0.16

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