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# Combination of pinoxaden with other herbicides against complex weed flora in wheat

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**ABSTRACT**

A field experiment was conducted during 2010-11 and 2011-12 to evaluate the efficacy of pinoxaden alone and in combination with other herbicides against complex weed flora in wheat. Pinoxaden 50 g/ha alone and as tank mixture with and before metsulfuron-methyl 4 g/ha, carfentrazone-ethyl 20 g/ha and 2,4-D 500 g/ha was compared to isoproturon + 2,4-D, clodinafop *fb* 2,4-D, weed free and weedy check for weed control and grain yield. *Phalaris minor* and *Anagallis arvensis* were the major weeds constituting 59.1 and 20.8% of the total weed population during 2010-11 and 67.6 and 16.9% during 2011-12, respectively. *Avena ludovician, Lolium temulentum, Poa annua* and *Vicia sativa* were the other important weeds found in association with wheat. Weeds reduced grain yield of wheat by 39.5%. Pinoxaden + metsulfuron-methyl (50 + 4 g/ha) and pinoxaden *fb* metsulfuron-methyl (50 *fb* 4 g/ha) were comparable to weed free treatment in reducing the density of *Phalaris minor* and *Anagallis arvensis*. Pinoxaden alone was not effective against broad-leaved weeds, while carfentrazone, metsulfuron-methyl and 2,4-D were not effective against grasses. Combined application of pinoxaden with metsulfuron-methyl/carfentrazone (as tank mixed or as followed by) resulted in significantly lower total weed density and weed biomass. Combined application of pinoxaden with metsulfuron-methyl, carfentrazone and 2,4-D resulted in significantly higher tillers, grains/spike and 1000-seed weight and grain yield as comparable to in weed free.

**Key words:** Carfentrazone, Chemical control, Metsulfuron-methyl, Pinoxaden, 2,4-D, Weeds, Wheat

Wheat is the second most important crop after rice in India. Among different production factors, weeds pose serious threat to the productivity of wheat. They compete with crop plants for light, water and nutrients. Isoproturon was nationwide recommended herbicide in wheat. However, continuous reliance on isoproturon resulted in a heavy build-up of *Phalaris minor* (Malik and Singh 1995) and the problem of its resistance to isoproturon. Clodinafop and sulfosulfuron were recommended as alternate herbicides against isoproturon resistant *Phalaris minor*. But resistance against these herbicides was also reported (Dhawan *et al.* 2009) necessitating the search for new herbicide molecules. Pinoxaden, belonging to phenylpyrazolin group with acetyl-COA-carboxylase (ACCase) has inhibiting action (Hoffer *et al.* 2006). It is a selective grass killer with foliar action. Since grass killers don't control the broad-leaved weeds, the present study was conducted to evaluate the bioefficacy of pinoxaden in combination with herbicides that were reported to be effective against broad-leaved weeds such as metsulfuron-methyl, carfentrazone and 2,4-D for managing complex weed flora in wheat.

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## MATERIALS AND METHODS

Wheat variety '*HPW 155*' was sown during the first fortnight of November for two consecutive years (2010-11 and 2011-12) with recommended package of practices except weed control. The soil of experimental field was silty clay loam in texture, acidic in reaction, medium in available nitrogen, phosphorus and high in available potassium. Fifteen weed control treatments, *viz*. pinoxaden (50 g/ha), metsulfuron-methyl (4 g/ha), carfentrazone-ethyl (20 g/ha) and 2,4-D (500 g/ha) alone, pinoxaden (50 g/ha) with and before carfentrazone-ethyl (20 g/ha), metsulfuron-methyl (4 g/ha) and 2,4-D (500 g/ha), isoproturon + 2,4-D (1250 + 500 g/ha), clodinafop *fb* 2,4-D (60 *fb* 1000 g/ha), mesosulfuron + iodosulfuron (13 + 5 g/ha), weed free and weedy check were tested in a randomized block design with 3 replications. All herbicides alone and as combination were applied as post-emergence at 28-35 DAS as per treatment with knapsack power sprayer using 750 litre water per hectare. Application of the second herbicide was made two days after the first. Observations on weed density and biomass were recorded at 90 DAS and at harvest using quadrat of 0.5 x 0.5 m, placed at two random spots in each plot. Weed density and biomass data showed variation and were subjected to square root transformation ($\sqrt{x+1}$). Wheat grain yield and yield attributes were recorded at maturity. Economics of the treatments was computed based on the prevalent prices of the inputs used and outputs obtained. The crop was harvested in the first fortnight of May. The different impact indices were worked out after Walia (2003).

## RESULTS AND DISCUSSION

### Effect on weeds

Wheat field was infested with both grassy and broad-leaved weeds. However, the flora was dominated by grassy weeds (*Phalaris minor*, *Avena ludoviciana*, *Lolium temulentum* and *Poa annua*) constituting 70.1 and 76.1% of total weed flora during 2010-11 and 2011-12, respectively. *Phalaris minor* had the highest proportion (59.1 and 67.6%) of total weed flora in 2010-11 and 2011-12, respectively. *Avena ludoviciana* and *Lolium temulentum* have shown their occurrence during both the years, however, *Poa annua* was present only during 2010-11. Among broad-leaved weed species,viz. *Vicia sativa*, *Anagallis arvensis*, *Stellaria media*, *Ranunculus arvensis* and *Convolvulus arvensis*), *Anagallis arvensis* was the major weed constituting 20.8% during 2010-11 and 16.9% of total weed flora during 2011-12. All treatments were significantly superior to weedy check in reducing the count of *P. minor* at 90 DAS during both the years (Table 1). However, 2,4-D 500 g/ha, metsulfuron-methyl 4 g/ha and carfentrazone-ethyl 20 g/ha could not significantly re-

**Table 1. Effect of weed management treatments on density (no./m$^2$) of grassy weeds**

| Treatment | Dose (g/ha) | *P. minor* | | | | *A. ludoviciana* | | | | *L. temulentum* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2010-11 | | 2011-12 | | 2010-11 | | 2011-12 | | 2010-11 | | 2011-12 | |
| | | 90 DAS | At harvest | 90 DAS | At harvest | 90 DAS | At harvest | 90 DAS | At harvest | 90 DAS | At harvest | 90 DAS | At harvest |
| Pinoxaden | 50 | 2.8 | 3.6 | 1.8 | 1.7 | 1.0 | 1.8 | 1.0 | 1.4 | 2.1 | 1.8 | 1.8 | 2.1 |
| | | (6.7) | (12.0) | (2.6) | (2.7) | (0.0) | (2.7) | (0.0) | (1.3) | (4.0) | (2.7) | (2.6) | (4.0) |
| Metsulfuron methyl | 4 | 12.4 | 6.3 | 11.3 | 6.8 | 3.4 | 3s.2 | 3.4 | 3.4 | 3.8 | s2.5 | 3.7 | 3.4 |
| | | (156.0) | (40.0) | (126.0) | (45.3) | (10.7) | (9.3) | (10.7) | (10.7) | (13.3) | (6.7) | (13.3) | (10.7) |
| Pinoxaden + carfentrazone-ethyl | 50 + 20 | 2.5 | 4.9 | 1.4 | 2.9 | 1.0 | 2.1 | 1.0 | 2.2 | 2.3 | 1.8 | 2.6 | 1.9 |
| | | (5.3) | (22.7) | (1.3) | (9.3) | (0.0) | (4.0) | (0.0) | (4.0) | (5.3) | (2.7) | (8.0) | (4.0) |
| Pinoxaden + metsulfuron-methyl | 50 + 4 | 2.1 | 4.7 | 1.4 | 2.4 | 1.0 | 1.4 | 2.0 | 1.7 | 1.4 | 1.4 | 1.4 | 1.0 |
| | | (4.0) | (21.3) | (1.3) | (6.6) | (0.0) | (1.3) | (5.3) | (2.7) | (1.3) | (1.3) | (1.3) | (0.0) |
| Pinoxaden + 2,4-D | 50 + 500 | 2.3 | 4.2 | 2.0 | 3.4 | 1.0 | 2.2 | 1.0 | 2.9 | 2.1 | 1.7 | 2.1 | 2.3 |
| | | (5.3) | (17.3) | (5.3) | (13.3) | (0.0) | (4.0) | (0.0) | (5.3) | (4.0) | (2.7) | (4.0) | (5.3) |
| Pinoxaden *fb* carfentrazone-ethyl | 50 *fb* 20 | 2.3 | 3.7 | 1.8 | 3.2 | 1.0 | 1.8 | 1.0 | 1.7 | 1.7 | 2.3 | 1.7 | 2.5 |
| | | (5.3) | (13.3) | (4.0) | (9.3) | (0.0) | (2.7) | (0.0) | (2.7) | (2.7) | (5.3) | (2.7) | (6.7) |
| Pinoxaden *fb* metsulfuron-methyl | 50 *fb* 4 | 2.5 | 3.8 | 1.8 | 3.0 | 1.0 | 1.8 | 1.4 | 1.7 | 2.2 | 1.4 | 3.2 | 2.3 |
| | | (6.7) | (14.7) | (4.0) | (9.3) | (0.0) | (2.7) | (1.3) | (2.7) | (4.0) | (1.3) | (9.3) | (5.3) |
| Pinoxaden *fb* 2,4-D | 50 *fb* 500 | 2.3 | 3.4 | 1.4 | 1.7 | 1.0 | 1.7 | 1.0 | 1.4 | 1.9 | 1.8 | 1.9 | 1.7 |
| | | (5.3) | (10.7) | (1.3) | (2.7) | (0.0) | (2.7) | (0.0) | (1.3) | (4.0) | (2.7) | (4.0) | (2.7) |
| Carfentrazone-ethyl | 20 | 13.4 | 6.6 | 12.5 | 7.2 | 3.4 | 3.2 | 2.7 | 3.4 | 3.7 | 1.7 | 2.9 | 2.7 |
| | | (184.0) | (44.0) | (156.0) | (52.0) | (10.7) | (9.3) | (8.0) | (10.7) | (13.3) | (2.7) | (9.3) | (8.0) |
| Mesosulfuron + idosulfuron | 13 + 5 | 5.8 | 5.6 | 6.1 | 6.0 | 1.7 | 2.5 | 1.6 | 2.7 | 3.4 | 2.3 | 3.2 | 2.7 |
| | | (33.3) | (30.7) | (37.3) | (34.7) | (2.7) | (6.7) | (2.6) | (8.0) | (10.7) | (5.3) | (9.3) | (8.0) |
| Isoproturon + 2,4-D | 1250 + 500 | 3.0 | 4.0 | 2.8 | 3.7 | 2.3 | 2.5 | 1.4 | 1.7 | 2.3 | 2.2 | 2.5 | 2.5 |
| | | (9.3) | (16.0) | (10.7) | (13.3) | (5.3) | (5.3) | (1.3) | (2.7) | (5.3) | (6.7) | (6.7) | (6.7) |
| Clodinafop *fb* 2,4-D | 60 *fb* 1000 | 3.4 | 3.6 | 3.1 | 3.8 | 2.3 | 2.3 | 2.2 | 2.9 | 1.8 | 1.4 | 1.8 | 2.3 |
| | | (10.7) | (16.0) | (8.7) | (14.7) | (5.3) | (5.3) | (4.0) | (5.3) | (2.7) | (1.3) | (2.7) | (5.3) |
| 2,4-D | 500 | 10.1 | 6.1 | 10.1 | 6.8 | 4.1 | 3.4 | 3.5 | 3.4 | 3.9 | 2.7 | 3.9 | 3.8 |
| | | (108.0) | (37.3) | (101.3) | (45.3) | (16.0) | (10.7) | (12.0) | (10.7) | (14.7) | (6.7) | (14.7) | (13.3) |
| Weed free | | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| | | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) |
| Weedy check | | 16.5 | 7.1 | 15.7 | 6.4 | 4.7 | 4.0 | 4.0 | 3.4 | 4.0 | 3.0 | 3.4 | 3.4 |
| | | (273.3) | (50.7) | (244.7) | (40.0) | (21.3) | (14.7) | (17.3) | (10.7) | (16.0) | (8.0) | (13.3) | (10.7) |
| LSD (P=0.05) | | 2.4 | 1.7 | 2.7 | 2.0 | 1.0 | 1.3 | 1.5 | 1.3 | 1.4 | NS | NS | 1.6 |

Data transformed to square root transformation ($\sqrt{x+1}$). Values given in parentheses are the means of original values, DAS= Days after sowing, *fb*= followed by; Herbicide application was made 28-35 DAS, *fb* application was made 2 DAS after the first.

**Table 2. Effect of weed management treatments on density (no./m$^2$) of broad-leaved weeds**

| Treatment | *Vicia* | | | | *Anagallis* | | | | *Coronopus* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2010-11 | | 2011-12 | | 2010-11 | | 2011-12 | | 2010-11 | | 2011-12 | |
| | 90 DAS | At harvest | 90 DAS | At harvest | 90 DAS | At harvest | 90 DAS | At harvest | 90 DAS | At harvest | 90 DAS | At harvest |
| Pinoxaden | 3.8 | 3.2 | 3.4 | 4.0 | 7.6 | 4.7 | 10.6 | 10.0 | 2.08 | 1.67 | 2.1 | 4.1 |
| | (13.3) | (9.3) | (10.7) | (16.0) | (61.3) | (21.3) | (114.7) | (98.7) | (4.00) | (2.67) | (4.0) | (16.0) |
| Metsulfuron methyl | 2.1 | 2.1 | 2.3 | 2.8 | 1.0 | 1.0 | 1.0 | 1.0 | 1.67 | 1.00 | 1.7 | 1.0 |
| | (4.0) | (4.0) | (5.3) | (6.7) | (0.0) | (0.0) | (0.0) | (0.0) | (2.67) | (0.00) | (2.7) | (0.0) |
| Pinoxaden + carfentrazone-ethyl | 3.4 | 2.5 | 3.4 | 3.2 | 2.9 | 3.0 | 2.9 | 2.8 | 2.33 | 1.41 | 2.3 | 2.0 |
| | (10.7) | (6.7) | (10.7) | (9.3) | (9.3) | (8.0) | (9.3) | (9.1) | (5.33) | (1.33) | (5.3) | (4.3) |
| Pinoxaden + metsulfuron-methyl | 2.1 | 1.8 | 2.1 | 2.8 | 1.0 | 1.0 | 1.0 | 1.0 | 1.00 | 1.00 | 1.0 | 1.0 |
| | (4.0) | (2.7) | (4.0) | (6.7) | (0.0) | (0.0) | (0.0) | (0.0) | (0.00) | (0.00) | (0.0) | (0.0) |
| Pinoxaden + 2,4-D | 2.3 | 2.5 | 2.3 | 3.8 | 4.9 | 3.1 | 4.9 | 5.7 | 1.67 | 1.67 | 1.7 | 2.5 |
| | (5.3) | (5.3) | (5.3) | (13.3) | (24.0) | (10.7) | (24.0) | (32.0) | (2.67) | (2.67) | (2.7) | (6.7) |
| Pinoxaden *fb* carfentrazone-ethyl | 3.2 | 3.2 | 3.6 | 3.9 | 2.9 | 2.8 | 2.9 | 2.8 | 1.82 | 1.41 | 1.8 | 2.6 |
| | (9.3) | (9.3) | (12.0) | (14.7) | (10.7) | (6.7) | (10.7) | (5.7) | (2.67) | (1.33) | (2.7) | (6.9) |
| Pinoxaden *fb* metsulfuron-methyl | 2.3 | 2.5 | 2.3 | 3.7 | 1.0 | 1.0 | 1.0 | 3.3 | 1.87 | 2.08 | 1.9 | 2.2 |
| | (5.3) | (5.3) | (5.3) | (13.3) | (0.0) | (0.0) | (0.0) | (13.3) | (4.00) | (4.00) | (4.0) | (6.7) |
| Pinoxaden *fb* 2,4-D | 3.6 | 3.0 | 3.6 | 3.3 | 4.1 | 3.4 | 4.1 | 8.1 | 1.00 | 1.00 | 1.0 | 2.9 |
| | (12.0) | (8.0) | (12.0) | (10.7) | (21.3) | (10.7) | (21.3) | (73.3) | (0.00) | (0.00) | (0.0) | (9.3) |
| Carfentrazone-ethyl | 2.3 | 2.1 | 2.3 | 3.7 | 1.0 | 2.1 | 1.0 | 2.9 | 1.41 | 1.00 | 1.4 | 1.7 |
| | (5.3) | (4.0) | (5.3) | (13.3) | (0.0) | (4.0) | (0.0) | (9.3) | (1.33) | (0.00) | (1.3) | (2.7) |
| Mesosulfuron + idosulfuron | 2.1 | 1.8 | 1.7 | 3.2 | 2.3 | 2.2 | 1.0 | 1.0 | 1.41 | 1.41 | 1.4 | 1.0 |
| | (4.0) | (2.7) | (2.8) | (9.3) | (5.3) | (4.0) | (0.0) | (0.0) | (1.33) | (1.33) | (1.3) | (0.0) |
| Isoproturon + 2,4-D | 3.0 | 1.7 | 2.3 | 3.8 | 2.9 | 2.7 | 3.1 | 4.9 | 1.00 | 1.00 | 1.00 | 1.00 |
| | (8.0) | (2.7) | (5.3) | (13.3) | (9.3) | (8.0) | (10.7) | (24.0) | (0.00) | (0.00) | (0.00) | (0.00) |
| Clodinafop *fb* 2,4-D | 2.5 | 3.0 | 3.6 | 3.9 | 5.0 | 4.1 | 2.3 | 3.7 | 1.00 | 1.00 | 1.00 | 1.00 |
| | (6.7) | (8.0) | (12.0) | (14.7) | (24.0) | (16.0) | (5.3) | (13.3) | (0.00) | (0.00) | (0.00) | (0.00) |
| 2,4-D | 2.3 | 1.7 | 2.3 | 3.0 | 2.8 | 3.0 | 1.4 | 2.9 | 1.00 | 1.00 | 1.0 | 1.0 |
| | (5.3) | (2.7) | (5.3) | (8.0) | (6.7) | (8.0) | (1.3) | (9.3) | (0.00) | (0.00) | (0.0) | (0.0) |
| Weed free | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.00 | 1.00 | 1.0 | 1.0 |
| | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.00) | (0.00) | (0.0) | (0.0) |
| Weedy check | 3.8 | 3.7 | 3.8 | 4.1 | 9.8 | 5.2 | 7.8 | 6.9 | 2.28 | 2.54 | 2.3 | 4.1 |
| | (13.3) | (13.3) | (13.3) | (16.0) | (96.0) | (26.7) | (61.3) | (48.0) | (5.33) | (6.67) | (5.3) | (16.0) |
| LSD (P=0.05) | 1.5 | 1.3 | 1.5 | 1.1 | 2.3 | 1.4 | 2.29 | 2.3 | NS | NS | NS | 1.9 |

Data transformed to square root transformation ($\sqrt{x+1}$); Values given in parentheses are the means of original values.

duce the count of *P. minor* until harvest during both the years as these wee mainly broad-leaved herbicides. Similarly, mesosulfuron + iodosulfuron (13+5 g/ha) showed little effect on *Phalaris* during both the years. Pinoxaden 50 g/ha alone and with 2,4-D, carfentrazone-ethyl or metsulfuron-methyl (both as tank mixed combination or as sequence application) provided excellent control of *P. minor* and was comparable to weed free check. The activity of pinoxaden against *P. minor* has been well established (Chhokar *et al. 2008*, Yadav *et al.* 2009 and Kumar *et al.* 2010). Isoproturon + 2,4-D and clodinafop *fb* 2,4-D had also effectively controlled *P. minor* but pinoxaden had an edge over both of these treatments. The effectiveness of isoproturon (Chopra *et al.* 2001) and clodinafop (Jat *et al.* 2007) against *P. minor* has also been documented.

Pinoxaden alone or with other broad-leaved herbicides effectively controlled *Avena ludoviciana* and was as good as weed free until harvest during both the years. The broad-leaved herbicides 2,4-D, carfentrazone-ethyl and metsulfuron-methyl did not significantly affect the density of *A. ludoviciana* over weedy check. Isoproturon + 2,4-D and clodinafop *fb* 2,4-D were less effective against *A. ludoviciana* than pinoxaden during 2010-11. The count of *L. temulentum* was significantly affected at 90 DAS during 2010-11 and at harvest during 2011-12. The density of *P. annua* was significantly affected at 90 DAS during 2010-11. Pinoxaden alone and with other herbicides, isoproturon+ 2,4-D and clodinafop *fb* 2,4-D was comparable to weed free in reducing the density of *L. temulentum* and *P. annua* at 90 DAS during 2010-11. However, owing to withering/shedding of the weed by harvest, only weed

**Table 3. Effect of treatments on total weed density (no./m$^2$) and weed biomass (g/m$^2$)**

| Treatment | 2010-11 | | | | 2011-12 | | | |
|---|---|---|---|---|---|---|---|---|
| | 90 DAS | | At harvest | | 90 DAS | | At harvest | |
| | Density | Biomass | Density | Biomass | Density | Biomass | Density | Biomass |
| Pinoxaden | 10.8 | 2.8 | 7.7 | 8.9 | 11.8 | 2.8 | 12.8 | 11.6 |
| | (116.0) | (7.6) | (58.7) | (79.1) | (140.0) | (7.6) | (162.7) | (136.3) |
| Metsulfuron-methyl | 13.8 | 4.0 | 7.8 | 11.6 | 13.6 | 4.0 | 9.2 | 13.0 |
| | (193.3) | (14.7) | (62.7) | (135.5) | (188.0) | (14.7) | (86.7) | (169.6) |
| Pinoxaden + carfentrazone-ethyl | 6.3 | 1.6 | 7.0 | 7.3 | 5.9 | 1.6 | 8.6 | 6.7 |
| | (38.7) | (1.7) | (48.0) | (52.9) | (34.7) | (1.7) | (73.3) | (44.4) |
| Pinoxaden + metsulfuron methyl | 3.2 | 1.2 | 5.2 | 6.5 | 4.6 | 1.2 | 6.2 | 5.9 |
| | (9.3) | (0.5) | (26.7) | (41.6) | (28.0) | (0.5) | (37.3) | (34.4) |
| Pinoxaden + 2,4-D | 6.5 | 1.3 | 6.7 | 6.3 | 6.5 | 1.3 | 8.1 | 5.8 |
| | (41.3) | (0.9) | (44.0) | (40.3) | (41.3) | (0.9) | (72.7) | (37.6) |
| Pinoxaden *fb* carfentrazone-ethyl | 5.5 | 1.9 | 6.4 | 6.9 | 5.6 | 1.9 | 8.7 | 6.5 |
| | (30.7) | (2.6) | (40.0) | (47.7) | (3) | (2.6) | (74.7) | (42.5) |
| Pinoxaden *fb* metsulfuron-methyl | 4.9 | 1.2 | 5.5 | 4.6 | 5.5 | 1.2 | 6.6 | 4.8 |
| | (24.0) | (0.5) | (29.3) | (23.2) | (30.7) | (0.5) | (50.7) | (20.6) |
| Pinoxaden *fb* 2,4-D | 6.5 | 1.4 | 6.0 | 4.0 | 6.0 | 1.4 | 10.4 | 6.5 |
| | (44.0) | (1.0) | (36.0) | (16.2) | (40.0) | (1.0) | (113.3) | (44.7) |
| Carfentrazone-ethyl | 14.8 | 4.9 | 8.1 | 11.2 | 14.4 | 4.9 | 10.0 | 12.4 |
| | (222.7) | (24.2) | (66.7) | (125.4) | (210.7) | (1.2) | (98.7) | (155.0) |
| Mesosulfuron + idosulfuron | 7.6 | 1.4 | 7.5 | 6.7 | 7.1 | 1.4 | 7.8 | 8.7 |
| | (57.3) | (1.2) | (54.7) | (53.1) | (49.3) | (1.2) | (60.0) | (77.2) |
| Isoproturon + 2,4-D | 5.8 | 1.2 | 6.2 | 6.7 | 6.5 | 1.4 | 6.7 | 7.3 |
| | (34.7) | (0.5) | (38.7) | (44.7) | (44.0) | (1.0) | (44.0) | (52.9) |
| Clodinafop *fb* 2,4-D | 7.2 | 2.0 | 7.0 | 9.8 | 6.3 | 1.6 | 7.7 | 11.6 |
| | (50.7) | (3.7) | (50.7) | (98.3) | (38.7) | (1.7) | (58.7) | (135.5) |
| 2,4-D | 12.4 | 4.2 | 8.4 | 10.3 | 11.8 | 4.2 | 9.4 | 14.2 |
| | (156.0) | (16.8) | (69.3) | (106.2) | (141.3) | (16.8) | (86.7) | (203.4) |
| Weed free | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) |
| Weedy check | 21.0 | 5.5 | 11.3 | 13.6 | 19.7 | 5.5 | 12.6 | 15.1 |
| | (445.3) | (31.7) | (126.7) | (194.8) | (390.7) | (31.7) | (158.7) | (228.8) |
| LSD (P=0.05) | 2.2 | 1.2 | 1.3 | 2.9 | 2.7 | 1.4 | 2.1 | 2.4 |

Data transformed to square root transformation ($\sqrt{x+1}$). Values given in parentheses are the means of original values.

free, pinoxaden *fb* 2,4-D and pinoxaden + metsulfuron-methyl could result in significantly lower density of *L. temulentum* over the weedy check. Metsulfuron-methyl, carfentrazone-ethyl, 2,4-D and mesosulfuron + iodosulfuron were not effective against *L. temulentum* and *P. annua*. Pinoxaden was not effective against broad-leaved weeds as their count under the treatment was not significantly different from that under weedy check (Table 2). Application of metsulfuron-methyl alone or in combination with other herbicides, 2,4-D and carfentrazone gave effective control of *A. arvensis* and other broad-leaved weeds during both the years. The effectiveness of metsulfuron-methyl alone or in combination with other herbicides (Kumar *et al*. 2010, Kumar *et al*. 2011) and carfentrazone (Singh *et al*. 2005, Jat *el al*. 2007) against *Anagallis arvensis* has been documented.

Owing to reduction in count of one or more than one species, all the weed control treatments resulted in significant lower total weed density and total weed biomass as compared to weedy check (Table 3). Pinoxaden + metsulfuron-methyl (50 + 4 g/ha) resulted in significantly lowest total weed density and total weed biomass among herbicidal treatments and was comparable to weed free. Pinoxaden + carfentrazone-ethyl (50 + 20 g/ha), pinoxaden + 2,4-D (50 + 500 g/ha), pinoxaden *fb* carfentrazone-ethyl (50 *fb* 20 g/ha), pinoxaden *fb* metsulfuron-methyl (50 *fb* 4 g/ha), pinoxaden *fb* 2,4-D (50 *fb* 500 g/ha), isoproturon + 2,4-D (1250 + 500 g/ha), mesosulfuron + iodosulfuron (13 + 5 g/ha) and clodinafop *fb* 2,4-D (60 *fb* 1000 g/ha) were other superior treatments. 2,4-D (500 g/ha), metsulfuron methyl (4 g/ha) and carfentrazone-ethyl (20 g/ha) were least effective.

**Table 4. Effect of weed management treatments on yield attributes and yield of wheat**

| Treatment | Effective tiller/m$^2$ | | Grains/spike | | Test weight (g) | | Grain yield (t/ha) | |
|---|---|---|---|---|---|---|---|---|
| | 2010-11 | 2011-12 | 2010-11 | 2011-12 | 2010-11 | 2011-12 | 2010-11 | 2011-12 |
| Pinoxaden | 204.2 | 194.7 | 42.6 | 50.5 | 43.4 | 43.2 | 3.68 | 3.55 |
| Metsulfuron-methyl | 179.1 | 167.3 | 42.6 | 48.3 | 42.8 | 42.1 | 3.15 | 3.06 |
| Pinoxaden + carfentrazone-ethyl | 200.5 | 180.7 | 43.8 | 49.8 | 43.2 | 43.4 | 3.70 | 3.66 |
| Pinoxaden + metsulfuron-methyl | 205.7 | 194.7 | 44.2 | 51.3 | 44.0 | 43.6 | 3.83 | 3.81 |
| Pinoxaden + 2,4-D | 198.3 | 186.7 | 45.1 | 51.8 | 42.1 | 42.8 | 3.66 | 3.59 |
| Pinoxaden *fb* carfentrazone-ethyl | 200.5 | 180.0 | 43.3 | 49.1 | 42.4 | 42.0 | 3.58 | 3.49 |
| Pinoxaden *fb* metsulfuron-methyl | 205.0 | 180.0 | 44.9 | 48.9 | 43.6 | 44.0 | 3.73 | 3.75 |
| Pinoxaden *fb* 2,4-D | 198.3 | 199.3 | 43.3 | 50.8 | 42.5 | 42.6 | 3.51 | 3.45 |
| Carfentrazone-ethyl | 177.6 | 186.2 | 42.5 | 48.8 | 42.0 | 42.4 | 3.06 | 3.15 |
| Mesosulfuron + iodosulfuron | 186.5 | 178.7 | 43.3 | 51.1 | 43.3 | 43.4 | 3.38 | 3.40 |
| Isoproturon + 2,4-D | 188.0 | 190.5 | 44.2 | 51.5 | 44.5 | 43.8 | 3.59 | 3.61 |
| Clodinafop *fb* 2,4-D | 195.4 | 191.6 | 43.6 | 50.4 | 43.4 | 43.3 | 3.57 | 3.54 |
| 2,4-D | 174.6 | 198.7 | 42.7 | 49.3 | 42.6 | 42.5 | 3.04 | 2.99 |
| Weed free | 208.7 | 202.7 | 43.9 | 51.3 | 43.8 | 44.5 | 3.86 | 3.90 |
| Weedy check | 166.5 | 145.8 | 37.3 | 40.5 | 39.5 | 40.1 | 2.43 | 2.26 |
| LSD (P=0.05) | 7.4 | 10.5 | 0.8 | 1.1 | 1.8 | 1.9 | 0.43 | 0.46 |

**Table 5. Effectof weed management treatments on economics and impact indices**

| Treatment | Cost of weed control (x10$^3$ ₹/ha) | Gross returns (x10$^3$ ₹/ha) | $GR_{WC}$ (x10$^3$ ₹/ha) | NRwc (x10$^3$ ₹/ha) | MBCR | Weed persistence index (WPI) | Crop resistance index (CRI) | Herbicide efficiency index (HEI) |
|---|---|---|---|---|---|---|---|---|
| Pinoxaden | 0.81 | 64.08 | 22.13 | 21.32 | 26.33 | 1.66 | 2.98 | 1.06 |
| Metsulfuron methyl | 0.79 | 55.23 | 13.28 | 12.49 | 15.71 | 1.58 | 1.82 | 0.45 |
| Pinoxaden + carfentrazone-ethyl | 1.28 | 64.81 | 22.86 | 21.58 | 16.79 | 2.62 | 6.63 | 2.47 |
| Pinoxaden + metsulfuron methyl | 0.88 | 67.13 | 25.18 | 24.29 | 27.46 | 4.02 | 8.77 | 3.50 |
| Pinoxaden + 2, 4-D | 0.94 | 64.11 | 22.16 | 21.22 | 22.53 | 1.86 | 8.21 | 2.97 |
| Pinoxaden *fb* carfentrazone-ethyl | 2.00 | 62.99 | 21.04 | 19.03 | 9.49 | 2.89 | 7.02 | 2.38 |
| Pinoxaden *fb* metsulfuron methyl | 1.60 | 66.34 | 24.40 | 22.79 | 14.20 | 1.58 | 15.17 | 5.75 |
| Pinoxaden *fb* 2, 4-D | 1.66 | 62.00 | 20.05 | 18.39 | 11.07 | 1.43 | 10.25 | 3.36 |
| Carfentrazone-ethyl | 1.19 | 55.77 | 13.82 | 12.62 | 10.57 | 1.28 | 2.02 | 0.49 |
| Mesosulfuron + iodosulfuron | 0.78 | 59.72 | 17.77 | 16.99 | 21.73 | 2.41 | 4.56 | 1.45 |
| Isoproturon + 2, 4-D | 1.33 | 62.74 | 20.79 | 19.46 | 14.67 | 2.45 | 6.32 | 2.32 |
| Clodinafop *fb* 2, 4-D | 1.87 | 62.83 | 20.89 | 19.01 | 10.15 | 5.16 | 2.68 | 0.93 |
| 2, 4-D | 0.85 | 54.21 | 12.26 | 11.41 | 13.40 | 2.06 | 1.78 | 0.39 |
| Weed free | 9.60 | 68.28 | 26.33 | 16.73 | 1.74 | - | - | - |
| Weedy check | - | 41.94 | - | - | - | 1.00 | 1.00 | 0.00 |
| LSD (P=0.05) | | 7.07 | | | | | | |

$GR_{WC}$ - Gross returns due to weed control; NRwc - Net returns due to weed control; MBCR - Marginal benefit cost ratio

## Effect on crop

On an average, weeds in weedy check reduced grain yield of wheat by 39.5% over the weed free. All treatments were significantly superior to weedy check in increasing effective tillers/m$^2$, spikelets per spike, number of grain per spike, test weight and thereby grain yield of wheat (Table 4). The higher yield and yield attributes were owing to superior weed control both in terms of reduction in density and biomass of weeds. Grain and straw yields of wheat were negatively associated with weed biomass (r= -0.891 and -0.866, respectively) and weed count (r=0.940 and -927, respectively). With every g/m$^2$ increase in weed biomass, the grain yield of wheat was expected to decrease by 3.36 kg/ha (Y=3759.4 – 3.362 X, Y being yield in kg/ha and x weed biomass in g/m$^2$, $R^2$ = 0.794). With increase in one weed/m$^2$, the grain yield of wheat may decrease by 5.77 kg/ha (Y= 3905 – 5.744 X, X being weed number/m$^2$, $R^2$= 0.884). Weed free gave highest grain yield. However, pinoxaden + metsulfuron-methyl (50 + 4 g/ha), pinoxaden (50 g/ha), pinoxaden + carfentrazone-ethyl (50 + 20 g/ha), pinoxaden *fb* metsulfuron-methyl (50 *fb* 4 g/ha), isoproturon + 2, 4-D (1250 + 500 g/ha), clodinafop *fb* 2,4-D (60 *fb* 1000 g/ha), pinoxaden + 2,4-D (50 + 500 g/ha), pinoxaden *fb* carfentrazone-ethyl (50 *fb* 20 g/ha) and pinoxaden *fb* 2,4-D (50 *fb* 500 g/ha) were as good as weed free. 2,4-D (500 g/ha), metsulfuron-methyl (4 g/ha), carfentrazone-ethyl (20 g/ha) and mesosulfuron + iodosulfuron (13 + 5 g/ha) being statistically at par were less effective in influencing grain yield of wheat.

**Impact assessment**

Manual weed control is a costly proposition as evident, cost of weed control under weed free was highest (Table 5). Herbicides are the cheap alternatives under all situations. Because of higher grain and straw yields, weed free resulted in highest gross return and gross return due to weed control. However, due to lower control cost, all herbicidal treatments except 2,4-D, carfentrazone ethyl and metsulfuron-methyl alone were superior to weed free in influencing net returns due to weed control. Pinoxaden + metsulfuron methyl resulted in highest net return due to weed control (₹ 24400/ha) and was followed by pinoxaden *fb* metsulfuron-methyl, pinoxaden + carfentrazone ethyl, pinoxaden and pinoxaden + 2,4-D. Marginal benefit cost ratio (MBCR) was also highest under pinoxaden + metsuluron (27.46). This was followed by pinoxaden (26.33) and pinoxaden + 2,4-D (22.53). Weed persistence index (WPI) was highest under clodinafop *fb* 2,4-D and *fb* pinoxaden + metsulfuron-methyl, pinoxaden + carfentrazone-ethyl, and isoproturon + 2,4-D. Crop resistance index (CRI) was highest under pinoxaden *fb* metsulfuron-methyl *fb* pinoxaden *fb* 2,4-D, pinoxaden + metsulfuron-methyl and pinoxaden + 2,4-D. Herbicide efficiency index (HEI) was also highest under pinoxaden *fb* metsulfuron-methyl followed by pinoxaden + metsulfuron-methyl, pinoxaden *fb* 2,4-D, pinoxaden + 2,4-D and pinoxaden + carfentrazone ethyl.

The present investigation conclusively inferred that combined application of pinoxaden and metsulfuron-methyl/carfentrazone/2,4-D either as tank mixed or sequential was the better alternative to isoproturon + 2,4-D or clodinafop *fb*. 2,4-D in controlling weeds and achieving higher wheat yield and economic returns.

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