Indian Journal of Agronomy **60** (1): 104–108 (March 2015)

Research Paper

Bioefficacy of sole and tankmix of pinoxaden and clodinafop with carfentrazone and metsulfuron for control of complex weed flora in wheat (*Triticum aestivum*)

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Received : October 2014; Revised accepted : February 2015

ABSTRACT

A field investigation was carried out during the winter season of 2011–12 and 2012–13 at Karnal, to evaluate the effect of different grass and broad-leaf herbicides as sole and their tankmix application on weed control in wheat [*Triticum aestivum* (L.) emend. Fiori & Paol.]. Sole application of pinoxaden both at 50 and 75 g/ha and clodinafop (60 g/ha) were found to be effective only on grasses, whereas both carfentrazone (20 g/ha) and metsulfuron (4 g/ha) showed selectivity towards broad-leaf weeds. Sole application of pinoxaden, clodinafop, carfentrazone and metsulfuron recorded lower weed-control efficiency and higher weed index compared to tankmix application of pinoxaden and clodinafop with carfentrazone and metsulfuron. Both metsulfuron and carfentrazone were compatible with pinoxaden and clodinafop and there was no adverse effect on the efficacy of both the herbicides. Significantly the highest grain yield of 5.16 and 5.00 t/ha was recorded with tankmix pinoxaden + carfentrazone (50 + 20 g/ha) and clodinafop + carfentrazone (60 + 20 g/ha), which was at par with weed-free treatment. There was an increase of 13.6,16.7 and 21.1% in grain yield with pinoxaden + carfentrazone compared to sole application of clodinafop (60 g/ha), pinoxaden, (50 g/ha) and carfentrazone (20 g/ha) respectively. Uncontrolled weeds caused an average reduction of 36.8% in wheat grain yield. Maximum net returns and benefit: cost ratio (29.2×10^3 ₹/ha and 0.90) were recorded with pinoxaden + carfentrazone followed by clodinafop + carfentrazone (27.8×10^3 ₹/ha, 0.85), respectively.

Key words: Carfentrazone, Clodinafop, Economics, Metsulfuron, Net returns, Pinoxaden, Tankmix, Weed control, Wheat

Weeds are a major impediment to crop production through their ability to compete for resources and their impact on product quality and are the major factors which cause yield reduction of 15–50%, depending on weed density and type of weed flora and makes the weed control more complex. Under Haryana conditions wheat fields are heavily infested with grassy and broad-leaf weeds notably little canary grass (*Phalaris minor* Retz.), golden dock (*Rumex dentaus* L.), Indian sweet clover [*Melilotus indica* (L.) All.], swine grass (*Coronopus didymus* L.), common lambsquarter (*Chenopodium album* L.), scarlet pimpernel (*Anagallis arvensis* L.) and bur clover (*Medicago denticulata* L.). After the development of resistance in *Phalaris minor* against isoproturon, clodinafop-propargyl and fenoxaprop-p-ethyl were recommended to combat the resistant biotypes. Over the years, efficacy of these herbicides has started declining and there is possibility of development of cross resistance, an increase in GR_{50} values of clodinafop and fenoxaprop under continuous use of these herbicides (Dhawan *et al.,* 2009). Pinoxaden is a new herbicide belonging to phenyl pyrazolin group with acetyl-CoA-carboxylase (ACCase) inhibiting action for broad-spectrum grass weed management in cereal crops (Holfer *et al.,* 2006). Use of these grass herbicides have been found ineffective towards broad-leaf weeds, which has resulted in proliferation of non-grassy weeds like *Rumex dentatus, Coronopus dydimus, Medicago denticulata, Anagallis arvensis, Lathyrus apacha* and *Melilotus indica.* New molecules of broad-leaf herbicides like metsulfuron methyl and carfentrazone ethyl control the broad-leaf weeds satisfactory but were ineffective towards grassy weeds (Singh and Singh, 2005; Chopra and Chopra, 2005). To manage the dynamic and complex weed flora in wheat there is need to evaluate different herbicides as tank mixtures to have a broad-spectrum weed control. Keeping these problems in view, a field experiment was conducted to examine the possibility of suitable broad-leaf herbicide to be used as tank mixture with

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pinoxaden and clodinafop and to widen the weed-control spectrum including grasses and non-grassy weeds and effect on wheat productivity.

MATERIALS AND METHODS

The field experiment was conducted during the winter seasons of 2011–12 and 2012–13 at research farm of Indian Agricultural Research Institute, Regional Station Karnal (76°E, 29°43'N, 243 m above mean sea-level). The soil was clay loam with pH 7.9. The available N, P and K were 180, 21.2 and 300 kg/ha, respectively. Eleven treatments consisting of clodinafop (60 g/ha), clodinafop + metsulfuron (60 + 4 g/ha), clodinafop + carfentrazone (60 + 20 g/ha) pinoxaden 50 g/ha, pinoxaden 75 g/ha, pinoxaden + metsulfuron (50 + 4 g/ha), pinoxaden + carfentrazone (50 + 20 g/ha) carfentrazone (20 g/ha), metsulfuron (4 g/ha), weed-free and weedy check, were tried in randomized block design with 4 replications. Wheat variety 'HD 2894' was sown in rows 22.5 cm apart on 24 and 27 November in 2011–12 and 2012–13, respectively. Recommended dose of fertilizers as 120 kg N, 26.4 kg P and 33.2 kg K/ha in both the years were applied uniformly to all the plots. All the herbicides were sprayed by knapsack sprayer using a spray volume of 500 litres/ha, 35 days after sowing. Data on weed count and weed biomass from an area enclosed in a quadrate of 1 m^2 under different herbicides treatments were recorded 60 days after sowing (DAS). The total number of weeds falling with in quadrate were counted species-wise. All the weeds inside the quadrate were cut closer to ground level and collected for dry-matter accumulation. Weed-control efficiency was calculated at 60 days after sowing in relation to the total weed dry matter and expressed in percentage. Weed index was calculated in relation to the seed yield in weed-free treatment and expressed in percentage. Data on individual and total weed density and weed dry weight were subjected to square root transformation $\sqrt{x+1}$.

RESULTS AND DISCUSSION

Density and dry weight of weeds

The experimental field was infested with complex weed flora, consisting of grasses and broad-leaf weeds. The average major weed flora comprised *Phalaris minor* (11.1%), *Rumex dentatus* (13.0%), *Coronopus dydimus* (65.5%), *Medicago denticulata* (4.5%) and *Anagallis arvensis* (5.8%). Besides, small numbers of *Poa annua, Sprergula arvensis* and *Vicia hirsuta* were also observed in the experimental field. In both the years, density of broadleaf weeds out numbered the grassy weeds.

Among the applied herbicides, clodinafop at 60 g/ha, clodinafop + metsulfuron (60 + 4 g/ha), clodinafop + carfentrazone (60 + 20 g/ha), pinoxaden (50 and 75 g/ha), pinoxaden + metsulfuron (50 + 4 g/ha) and pinoxaden + carfentrazone (50 + 20 g/ha) reduced the density of *Phalaris minor* significantly compared to weedy check, metsulfuron (4 g/ha) and carfentrazone (20 g/ha) (Table1). Broad-leaf weeds *Rumex dentatus, Coronopus dydimus, Medicago denticulata* and *Anagalis arvensis* were significantly reduced with sole application of metsulfuron, and carfentrazone and tankmix application of clodinafop and pinoxaden with metsulfuron and carfentrazone compared to sole application of clodinafop, pinoxaden and weedy check. This may be due to their differential selectivity towards grassy and broadleaf weeds. The results are in agreement with the findings of Bharat and Kachroo (2010) and Chopra and Chopra (2010). Data on density of weeds under tankmix treatments of clodinafop and pinoxaden with metsulfuron and carfentrazone indicated their compatibility as tankmixture. Tankmixture of clodinafop and pinoxaden with metsulfuron and carfentrazone resulted in density of *Phalaris minor* at par with sole application of clodinafop and pinoxaden, indicating their compatibility as tankmix for the control of *Phalaris minor*. Our results confirm those of Singh *et al.* (2010). The tank mixtures of clodinafop and pinoxaden with metsulfuron and carfentrazone were at par with sole application of metsulfuron and carfentrazone for the control of broadleaf weeds like *Rumex dentatus, Coronopus* dydimus, *Medicago denticulata* and *Anagallis arvensis,* indicating the compatibility of tank mixture. There was no antagonistic effect of clodinafop and pinoxaden on control of broadleaf weeds by metsulfuron and carfentrazone. Such results on compatibility of tankmix of clodinafop with carfentrazone and metsulfuron reported by Singh and Singh (2005) and Chopra and Chopra (2012). Tankmix application of clodinafop and pinoxaden with metsulfuron and carfentrazone recorded significantly lower total weed density compared to weedy check, sole application of clodinafop, pinoxaden, metsulfuron and carfentrazone due to effective control of mixed weed flora (Tables 1 and 2) owing to their synergistic interactions and compatibility (Punia *et al.,* 2004). Total weed dry weight was significantly reduced under all the herbicidal treatments compared to weedy check. Clodinafop + carfentrazone and pinoxaden + carfentrazone recorded significantly lower weed dry weight and higher weed-control efficiency than sole application of clodinafop 60 g/ha, pinoxaden at 50 and 75 g/ha, metsulfuron methyl 4 g/ha and carfentrazone 20 g/ha owing to effective control of complex weed flora (Table 1). Higher weed dry weight and lower weed-control efficiency in sole application of clodinafop 60 g/ha, pinoxaden at 50 and 75 g/ha, metsulfuron methyl 4 g/ha and carfentrazone 20 g/ha is due to their ineffectiveness in controlling complex weed flora. Katara *et al.* (2012) also recorded lower weed biomass with tank mix of pinoxaden with carfentrazone/metsulfuron.

Yield attributes and yield

Plant height of wheat was not influenced significantly among treatments weed-free, sole and tankmix application of clodinafop, pinoxaden, carfentazone and metsulfuron. Lower plant height was recorded with weedy check compared to weed-free and herbicidal treatments, but the differences were non-significant. Weed-free and pinoxaden + carfentrazone treatments recorded significantly higher effective tillers than weedy check, sole application of clodinafop, pinoxaden, carfentrazone and metsulfuron. There was an increase of 14.9, 17.2, 21.5 and 22.7% of effective tillers/meter row length in pinoxaden + carfentrazone compared to sole application of clodinafop, pinoxaden, carfentrazone and metsulfuron, respectively (Table 2) which may be attributed to low weed competition and clean cultivation. Ear length remained at par between weed free and herbicide mixture of clodinafop and pinoxaden with carfentrazone and metsulfuron and was significantly higher than sole application of metsulfuron, caefentrazone and weedy check. The 1,000-seed weight was at par between weed-free and tankmix of clodinafop and pinoxaden with carfentrazone and metsulfuron and was significantly higher than weedy check (Table 2). Weed-free conditions increased the availability of nutrients, space and light to the wheat crop due to absence of crop-weed competition which resulted in increased yield attributes.

The complex weed flora comprised grasses and broadleaf weeds showed reduction of 36.8% in grain yield in weedy check as compared to weed free. Pinoxaden + carfentrazone, pinoxaden + metsulfuron, clodinafop + metsulfuron and clodinafop + carfentrazone resulted in an average increase of 53.5, 47.6, 48.8 and 47.6% in grain yield as compared to weedy check. All the tankmix treatments of pinoxaden and clodinafop with metsulfuron and carfentrazone were at par with weed free treatment due to control of complex weed flora (Table 2). Sole application of metsulfuron and carfentrazone recorded significantly lower grain yield as compared to tankmix of clodinafop and pinoxaden with metsulfuron and carfentrazone which was possibly due to their ineffectiveness to control *Phalaris minor,* resulting in lower weed-control efficiency (Table 1). Since, both metsulfuron (4 g/ha) and carfentrazone (20 g/ha) were highly effective towards the broadleaf weeds, the significant reduction of 15.7, 15.7, 14.8 and 17.4% of grain yield in these treatments compared to tankmix of clodinafop and pinoxaden with metsulfuron and carfentrazone was due to presence of *Phalaris minor* respectively. The plots treated with clodinafop (60 g/ha)

Table 1. Effect of different herbicides and their mixtures on differential weed density and dynamics at 60 days in wheat (pooled data of 2 years)

Treatment	*Phalaris minor*	*Rumex dentatus*	*Coronopus dydimus*	*Medicago denticulata*	*Anagallis arvensis*	Total weed density (No./m²)	Total weed dry weight (g/m²)	Weed-control efficiency (%)	Weed index
Clodinafop 60 g/ha	(0.00) 1.00	(35.5) 5.55	(159.0) 11.86	(16.0) 3.92	(15.5) 3.89	(226) 14.8	(56.8) 6.78	49.7	14.7
Clodinafop + Metsulfuron 60 + 4 g/ha	(2.00) 1.39	(7.50) 2.25	(0.75) 1.27	(5.25) 2.06	(5.00) 2.00	(20.5) 3.83	(25.9) 4.36	77.0	6.7
Clodinafop + Carfentrazone 60 + 20 g/ha	(2.00) 1.50	(6.00) 2.14	(0.75) 1.24	(4.75) 2.00	(3.75) 1.74	(17.2) 3.85	(16.1) 3.69	85.7	6.0
Pinoxaden 50 g/ha	(0.25) 1.09	(26.5) 4.90	(123.5) 10.44	(11.5) 2.92	(15.5) 3.61	(177) 13.08	(39.4) 6.33	65.1	16.7
Pinoxaden 75 g/ha	(0.0) 1.00	(31.5) 5.30	(157.5) 11.35	(6.00) 2.26	(5.00) 2.20	(200) 14.04	(42.5) 6.46	62.3	17.3
Pinoxaden + Metsulfuron 50 + 4 g/ha	(1.0) 1.31	(7.25) 2.60	(1.25) 1.40	(0.00) 1.00	(2.50) 1.71	(12.0) 3.55	(19.5) 3.93	82.7	6.8
Pinoxaden + Carfentrazone 50 + 20 g/ha	(3.75) 1.75	(6.00) 7.18	(1.25) 1.40	(0.50) 1.15	(2.75) 1.73	(14.2) 3.43	(15.8) 3.52	86.0	3.00
Carfentrazone 20 g/ha	(35.6) 5.42	(1.12) 1.37	(0.50) 1.18	(0.00) 1.00	(2.00) 1.39	(39.2) 6.30	(46.9) 6.54	58.4	19.9
Metsulfuron 4 g/ha	(33.9) 5.64	(1.50) 1.40	(0.87) 1.31	(0.00) 1.00	(0.50) 1.15	(36.7) 6.13	(42.9) 6.40	62.0	21.4
Weed-free	(0.00) 1.00	(0.00) 1.00	(0.00) 1.00	(0.00) 1.00	(0.00) 1.00	(0.0) 1.00	(0.00) 1.00	100.0	0.00
Weedy check	(38.5) 6.05	(45.0) 6.30	(226.0) 14.94	(15.5) 3.83	(20.0) 4.30	(345) 18.55	(113) 10.43	0.00	36.8
SEm±	0.28	0.55	0.81	0.41	0.40	0.90	0.59		
CD (P=0.05)	0.81	1.61	2.36	1.20	1.18	2.65	1.73		

Original figures in parentheses were subjected to square-root transformation (√X+1) before statistical analysis

Table 2. Effect of weed-management treatments on yield attributes and yield of wheat (pooled data of 2 years)

Treatment	Plant height (cm)	Effective tiller/*mrl	Ear length (cm)	1,000-seed weight (g)	Grain yield (t/ha)
Clodinafop 60 g/ha	79.8	93.5	9.05	41.82	4.54
Clodinafop + Metsulfuron 60 + 4 g/ha	79.7	102.6	9.23	42.72	4.96
Clodinafop + Carfentrazone 60 + 20 g/ha	80.6	105.0	9.20	42.70	5.00
Pinoxaden 50 g/ha	79.6	91.7	8.90	40.06	4.42
Pinoxaden 75 g/ha	79.2	93.8	8.98	41.75	4.38
Pinoxaden + Metsulfuron 50 + 4 g/ha	79.3	100.2	8.89	43.18	4.96
Pinoxaden + Carfentrazone 50 + 20 g/ha	81.2	107.5	9.01	42.63	5.16
Carfentrazone 20 g/ha	78.9	88.5	8.57	39.71	4.26
Metsulfuron 4 g/ha	80.0	87.6	8.78	41.38	4.18
Weed-free	81.50	108.8	9.19	42.98	5.32
Weedy check	75.9	76.0	8.26	37.27	3.36
SEm±	1.09	4.63	0.14	0.70	0.20
CD (P=0.05)	NS	13.39	0.39	2.05	0.57

and pinoxaden (50 g/ha), where there was almost complete control of *Phalaris minor* was observed, a 8.9 and 10.7% grain yield reduction was observed as compared to tankmix application of clodinafop and pinoxaden with metsulfuron and 9.2 and 14.1% yield reduction compared to clodinafop and pinoxaden with carfentrazone, respectively, which was mainly due to the competition offered by the presence of broad-leaf weeds. Yadav *et al.* (2009) also reported that clodinafop and pinoxaden did not provide any control of broad-leaf weeds. Tank mix application of pinoxaden and clodinafop with carfentrazone and metsulfuron resulted in significantly higher yield than sole application of carfentrazone and metsulfuron which may be due to control of both grasses and broadleaf weeds. Grain yield among different tankmix treatments of coldinafop and pinoxaden with metsulfuron and carfentrazone remained statistically at par among themselves and with weed-free treatment. Carfentrazone and metsulfuron were compatible with clodinafop and pinoxaden as there was no adverse effect on efficacy of both the herbicides. Better performance of these treatments in terms of yield could be owing to better control of complex weed flora tilting the crop-weed competition in favour of the crop.

There was significant negative correlation of weed density and weed dry weight with grain yield (r=–0.77 and r = –0.94). Mean seed yield showed a reduction of 0. 003 t/ha (y =–0.003 × + 4.963 (Fig. 1), y being yield of wheat t/ha and x is weed number/m^2) with increase in 1 weed/m^2 and with every g/m^2 increase in weed dry weight the grain yield of wheat was expected to decrease by 0.176 t/ha of grain yield (Fig. 2). Association of weeds and grain yield confirm the findings of Katara *et al.* (2012) and Singh (2013).

Economics

All the herbicides alone or in tankmix application re-

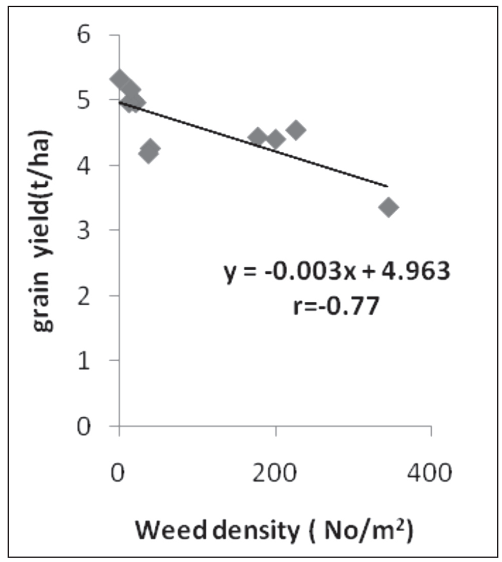

Fig. 1. Relationship between yield and weed density in wheat

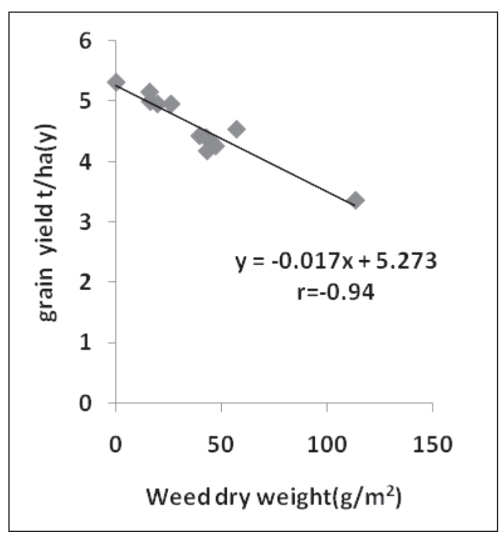

Fig. 2. Relationship between yield and weed dry weight in wheat

Table 3. Effect of weed- management treatments on relative economics of different herbicide treatments (pooled data of 2 years)

Treatment	Seed yield (t/ha)	Gross returns (×10³ ₹/ha)	Cost of cultivation (×10³ ₹/ha)	Net returns (×10³ ₹/ha)	Benefit: cost ratio
Clodinafop 60 g/ha	4.54	54.6	31.9	22.7	0.71
Clodinafop + Metsulfuron 60 + 4 g/ha	4.96	59.6	32.2	27.4	0.85
Clodinafop + Carfentrazone 60 + 20 g/ha	5.00	60.1	32.3	27.8	0.86
Pinoxaden 50 g/ha	4.42	53.1	32.4	20.7	0.64
Pinoxaden 75 g/ha	4.38	52.6	33.1	19.5	0.59
Pinoxaden + Metsulfuron 50 + 4 g/ha	4.96	59.6	32.7	26.9	0.82
Pinoxaden + Carfentrazone 50 + 20 g/ha	5.16	62.0	32.8	29.2	0.90
Carfentrazone 20 g/ha	4.26	51.2	31.5	19.7	0.62
Metsulfuron 4 g/ha	4.18	50.2	31.4	18.8	0.60
Weed-free	5.32	63.9	38.2	25.7	0.67
Weedy check	3.36	40.4	30.6	9.8	0.32

corded higher monetary returns than weedy check. Among the weed-control treatments, pinoxaden + carfentrazone (50 + 20 g/ha) gave the maximum net returns and benefit: cost ratio (0.90) followed by clodinafop + carfentrazone (60 + 20 g/ha) owing to excellent control of complex weed flora without any adverse effect on crop growth (Table 3). Weed free treatment though registered higher grain yield recorded lower monetary returns due to high cost incurred on weeding to keep the crop weed-free. All the herbicide mixtures resulted in higher monetary returns than their sole application.

It was concluded that pinoxaden and clodinafop were found compatible with carfentrazone and metsulfuron and there was no adverse effect on efficacy of both the herbicides against the complex weed flora in wheat. Pinoxaden + carfentrazone and clodinafop + carfentrazone were the most remunerative and effective herbicide mixture for controlling the complex weed flora in wheat for achieving maximum weed-control efficiency and grain yields.

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