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RESEARCH ARTICLE

Pendimethalin plus pyrazosulfuron for pre-emergence control of complex weed flora in dry-seeded rice

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ABSTRACT

Heavy weed infestation is one of the major constraints in dry-seeded rice. In North-West India, farmers use pendimethalin for pre-emergence control of grasses and small-seeded broad-leaf weeds, while bispyribac is used for post-emergence control of grasses. Continuous use of these herbicides has resulted in weed shift from annual grasses to broad-leaf weeds and sedges, and from annual weeds to perennial weeds particularly *Cyperus rotundus*. Field studies were carried out for successive three years (during 2016-18) in *Kharif* (rainy) season to evaluate pendimethalin plus pyrazosulfuron (pre-mix) at variable doses for pre-emergence control of grasses, sedges and broad-leaf weeds in dry-seeded rice. The uncontrolled growth of grasses, sedges and broad-leaf weeds in dry-seeded rice for whole crop season resulted in 68.7% reduction in crop yield. Pre-emergence application of pendimethalin plus pyrazosulfuron 1150 g/ha effectively reduced weed density and biomass of *Digitaria sanguinalis, Dactyloctenium aegyptium, Echinochloa colona, Cyperus rotundus, C. iria, Phyllanthus niruri, Alternanthera philoxeroides, Mollugo nudicaulis* and *Digera arvensis* with weed control efficiency of 85.3% up to 40 DAS. Though grain yield was maximum in weed free, pre-emergence use of pendimethalin plus pyrazosulfuron 1150 g/ha resulted in the highest returns. Therefore, it was concluded that pendimethalin plus pyrazosulfuron 1150 g/ha as pre-emergence herbicide provided economical control of grasses, broad-leaf weeds and sedges in dry-seeded rice during early crop-weed competition period.

Keywords: Broad-leaf weeds, direct-seeded rice, grasses, sedges, weed control efficiency

INTRODUCTION

Conventionally, rice (*Oryza sativa* L.) is transplanted in puddled fields by transplanting nursery seedlings in Indo-Gangetic plains of Indian sub-continent, which requires huge labour and a large amount of water. However, due to water scarcity and rising labour wages, questions of sustainability of rice production system arises (Chauhan *et al.* 2012). Aerobic rice systems are among the most promising approaches for saving water and reduce water application by 44% relative to conventionally transplanted systems by reducing percolation, seepages and evaporative losses, while maintaining yield at an acceptable level. Dry direct-seeded rice (DSR) is one of the technologies that significantly reduce labour and water requirements (Chauhan 2012). Therefore, farmers in some areas are shifting from traditional transplanted rice to mechanized DSR in response to the rising production costs and shortages of labour and water.

Direct-seeded rice is subjected to much higher weed pressure than rice sown under conventional puddled transplanting method due to alternate wetting and drying conditions (Balasubramanian and Hill 2002). Heavy weed infestation is one of the major constraints in DSR, and there is a risk of crop yield loss to the tune of 5-100% (Rao *et al.* 2007). The main reasons for high weed pressure in DSR are the absence of a weed-suppressive effect of standing water at the time of crop emergence and the absence of a seedling size advantage to suppress newly emerged weed seedlings (Chauhan and Johnson 2010, Rao *et al.* 2007). The total biomass attained by weeds was 86-94% higher in aerobic rice systems and the yield losses were 33-57% higher in aerobic rice systems than in conventional flooded rice (Mahajan *et al.* 2009). More than 50 weed species infest direct-seeded rice which is the major bottleneck in DSR cultivation especially in dry field conditions. It has been observed that several cohorts of diverse grasses, broad-leaf weeds and sedges infest DSR. For post-emergence control of grasses, herbicides are recommended specifically for a particular grass weed species. For example, post-emergence herbicides, bispyribac-sodium 25 g/ha for control of *Echinochloa crus-galli*, *E. colona*, *Digitaria sanguinalis* and fenoxaprop-ethyl 67 g/ha for control of *Dactyloctenium aegyptium*, *D.*

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sanguinalis, *Eleusine indica*, *Leptochloa chinensis* at 20-25 DAS is being used in DSR (Bhullar *et al.* 2016). Continuous use of herbicides for control of annual grass weeds has shifted the dominance to broad-leaf weeds and sedges and from annual weeds to perennial weeds particularly *C. rotundus*. Moreover, alternate wetting-drying regimes in DSR favoured aerobic broad-leaf weeds and sedges. Amongst sedges, *Cyperus iria* and *C. rotundus* have become highly competitive with the crop of DSR (Yaduraju and Mishra 2008). Several sulfonyl urea herbicides and pre-mixes such as metsulfuron-methyl 15 g/ha, bensulfuron 60 g/ha (Peterson *et al.* 1990), metsulfuron plus chlorimuron 4 g/ha (Gopinath and Kundu 2008, Singh *et al.* 2008), ethoxysulfuron 18.75 g/ha (Bhullar *et al.* 2016), azimsulfuron 0.020 kg/ha (Mahajan and Chauhan 2013) is being used as post-emergence weed control option for controlling sedges and broad-leaf weeds in rice paddies.

For pre-emergence control of grass and small-seeded broad-leaf weeds, pendimethalin 750 g/ha is recommended in DSR. However, there is no pre-emergence option for controlling complex weed flora comprising of grasses, sedges and broad-leaf weeds. To control complex weed flora, herbicide combinations can give effective weed control than single herbicide application. Keeping in view the above ideas, field experiment was conducted for three consecutive years to evaluate the bio-efficacy of pendimethalin plus pyrazosulfuron, a pre-mix herbicide for managing grasses, sedges and broad-leaf weeds and achieving highest productivity from dry seeded rice.

MATERIALS AND METHODS

Experimental sites and treatment details

Field experiment was conducted at Agronomy research farm, Punjab Agricultural University, Ludhiana, India located in central plain zone which is characterized by sub-tropical semi-arid type of climate with hot summers (maximum temperature above 38 °C is common during summer) and very cold winters. The variable doses of pre-mix/ready-mix herbicide, pendimethalin plus pyrazosulfuron were evaluated in field studies for three consecutive *Kharif* (June to November) season during 2016, 2017 and 2018. The experimental field was selected where DSR was continuously being cultivated from last 5 years so that representative weed flora must be ensured in the field. The soil of experimental field was normal in soil reaction (pH 7.5-8.0) and electrical conductivity (0.13-0.18 dS/m), medium in organic carbon (0.39-0.41%), nitrogen (243.3-263.9 kg/ha), high in phosphorus (18.8-19.2 kg/ha) and potassium (316-337 kg/ha). The experiment was conducted in randomized complete block design with nine treatments namely, pendimethalin plus pyrazosulfuron 690 g/ha (675+15 g), 920 g/ha (900+20 g) and 1150 g/ha (1125+25 g), pyrazosulfuron 20 g/ha and 25 g/ha, pendimethalin 750 g/ha and 1125 g/ha, weedy (unsprayed) and weedfree. Herbicides were applied as pre-emergence after sowing on moist field with battery-operated knap sack sprayer using 500 litres of water. In weedy plots, weeds were allowed to grow for whole season while in weed free plots, weeds were controlled with the help of integrated weed control methods (both, chemical and mechanical) for whole crop season.

Crop husbandry

The seed of rice cultivar '*PR 126*' was treated with carbendazim 50 g/ha and was air-dried under shade. After seedbed preparation in moist field, treated seed was sown with single-row seed drill at 20 cm row spacing in the first week of June (*Kharif* season) during three years of study. Nitrogen (187.5 kg/ha N) was applied as broadcast in four equal splits at 2, 4, 7 and 10 weeks after sowing. Phosphorus (30 kg/ha P), potassium (30 kg/ha K) and zinc sulphate heptahydrate (62.5 kg/ha) were applied at the time of seedbed preparation by broadcasting. The iron deficiency was corrected with three sprays of 0.5% $FeSO_4$ done at weekly interval starting at 15 days after sowing. The plots of direct-seeded rice were kept moist at least for 2 weeks with light irrigation after sowing was completed. Thereafter, irrigation was applied at 5-7 days intervals to avoid water stress to the crop. No irrigation was applied on rainy days. Irrigation was stopped 15 days before harvesting of the crop. Plant protection measures for insect-pests and diseases were taken to grow healthy crop. The crop was harvested manually from net plot area when grains were mature and straw had turned yellow in first week of November.

Weed, crop growth and yield observations

Observation on weed density was recorded at 20 and 60 DAS from a randomly selected quadrat at two spots in each plot at both the location. Grasses, broad-leaf weeds and sedges were collected separately from the same area at 40 DAS for recording the weed biomass of grasses, sedges and broad-leaf weeds. Weed samples were oven dried before weighing at 60±2°C till constant weight was achieved. Weed control efficiency (WCE) and weed index (WI).

Crop growth parameters namely plant height, tillers and crop biomass were recorded at 40 DAS. Plant height was recorded from 5 randomly selected plants. Tillers were counted from third row from two spots of 50 cm row length in each plot. Tillers were harvested separately from the same area for recording the crop biomass. Crop samples were oven dried before weighing at 60±2 °C till the constant weight was achieved. Effective tillers were recorded from third row from two spots of 50 cm row length in each plot at harvest. Yield attributing characters like number of grains/panicle and 1000 grain weight were recorded at harvest from 5 randomly selected plants. The grain yield (at 14% moisture) and straw yield was recorded. The cost of cultivation was worked out based on the labour and input cost incurred towards rice cultivation in different treatments. Economics of cultivation was worked out and benefit-cost ratio was calculated by dividing gross returns with variable cost of cultivation.

Statistical analysis

The pooled analysis of data of three years was done after verifying the homogeneity of variance. The years by treatment interactions were non-significant. Weed density and biomass data were subjected to square root transformation ($\sqrt{x+1}$) before performing ANOVA. The data was analyzed using Proc GLM in SAS 9.3 and differences among treatment means were determined using ANOVA. When the F-test was significant, Fisher's protected least significant difference (LSD) post hoc test was used to test significant difference between treatment means values at 5% level of significance.

RESULTS AND DISCUSSION

The major weed flora in the experimental field at Ludhiana consisted of grasses, *viz. Digitaria sanguinalis, Echinochloa colona, Dactyloctenium aegyptium*; sedges, *viz. Cyperus rotundus, Cyperus iria* and broad-leaf weeds, *viz. Phyllanthus niruri, Mollugo nudicaulis, Digera arvensis, Alternanthera philoxeroides.*

Weed density and biomass

Amongst herbicide treatments, pre-mix of pendimethalin plus pyrazosulfuron 1150 g/ha resulted in significantly lower weed population and biomass than its lower dose of 690 g and 920 g/ha. Pendimethalin plus pyrazosulfuron 1150 g/ha (pre-mix) recorded the lowest weed density of *Cyperus iria* at 30 DAS which was statistically similar to weed free (**Table 1**). However, density of *Cyperus rotundus* was the lowest in weed free treatment, and tested pre-emergence herbicides did not give efficient control of *C. rotundus*. Pre-emergence application of pendimethalin plus pyrazosulfuron 1150 g/ha was recorded as the best herbicide treatment for the control of sedges as compared to alone application of pendimethalin and pyrazosulfuron. Pendimethalin 750 g and 1125 g/ha effectively controlled grasses however, it failed to control sedges and some broad-leaf weeds. Significant reduction in population of broad-leaf weeds (*Phyllanthus niruri, Alternanthera philoxeroides, Mollugo nudicaulis, Digera arvensis*) was recorded with different herbicides application as compared to weedy check. Pyrazosulfuron 25 g/ha was more effective than its lower dose (20 g/ha) for the control of sedges, although similar control of broad-leaf weeds was observed.

Pendimethalin plus pyrazosulfuron 1150 g/ha continued to show the best results by reducing weed density and biomass of grasses, broad-leaf weeds and sedges at 60 DAS (**Table 1**). Grass weed density in pendimethalin plus pyrazosulfuron 690 g/ha were statistically like grass weeds observed in weedy plots. Standalone application of pendimethalin 750 g and 1125 g/ha was equally effective in controlling grasses (*Digitaria sanguinalis, Dactyloctenium aegyptium, Echinochloa colona*) as its pre-mix with pyrazosulfuron. The density of sedges (*Cyperus rotundus, C. iria*) and broad-leaf weeds (*Alternanthera philoxeroides, Mollugo nudicaulis, Digera arvensis*) in pendimethalin treated plots were statistically similar to that observed in weedy plot. However, grasses (*Digitaria sanguinalis, Dactyloctenium aegyptium, Echinochloa colona*) and *Phyllanthus niruri* were effectively controlled with pendimethalin.

The critical period of crop-weed competition ranges from 11.8–83.2 days after sowing (DAS) for short-duration rice varieties (Chauhan *et al.* 2012, Singh *et al.* 2014). Weeds in DSR systems are mainly managed by using herbicides and manual weeding. However, Manual weeding is becoming less popular because of the labour scarcity and high wages. In the absence of manual weeding, farmers in irrigated areas mainly rely on herbicides to control weeds in DSR systems. In DSR systems, weeds come in large numbers along with the crop due to frequent irrigations, and manual or mechanical weeding is not economical and some weeds especially mimic weeds are hard to be controlled with hand weeding, therefore, herbicide use become a necessity to keep crop weed free in critical period of crop-weed competition. Most upland and aerobic rice growers in Asia mechanically weed their crops two or three times per season, investing up to 190 person days/ha in hand weeding which is very easy and environment-friendly but it is tedious, time consuming, highly labour intensive and expensive. In addition, during peak period, the availability of labour is becoming a serious problem by time. So, herbicides are used successfully for weed control in rice fields for their rapid effect, easier application and low-cost involvement in comparison to the traditional methods of hand weeding. Herbicides having narrow spectrum of weed control are used for the control of grasses and broad-leaf weeds in DSR. In the present study, it was observed that the highest weed control efficiency among the herbicidal treatments was recorded with pendimethalin plus pyrazosulfuron at 1150 g/ha. Singh *et al.* (2005, 2008) also observed that pre-mix of pendimethalin plus pyrazosulfuron resulted in effective control of mixed weed flora in rice field due to pendimethalin which was effective in controlling annual grasses and broad-leaved weeds and pyrazosulfuron gave effective control against broad-leaved weeds and sedges, hence provided over all control of weed flora. These results were in confirmation with the findings of Kaur and Singh (2015), which showed that pendimethalin resulted in effective control of grasses and broad-leaved weeds, and sedges was controlled with pyrazosulfuron. Pendimethalin plus pyrazosulfuron 1150 g/ha as pre-emergence application helped in managing mixed weed flora at critical crop-weed competition period of rice and showed no phytotoxic effect on rice. Uncontrolled growth of grasses, sedges and broad-leaf weeds for whole crop season in direct seeded rice resulted in 68.7% reduction in rice grain yield.

Crop growth, yield attributes and grain yield of rice

Herbicide application resulted in more plant height as compared to weedy (**Table 2**). Pre-emergence application of pendimethalin plus pyrazosulfuron 1150 g/ha resulted in significantly a greater number of tillers and crop biomass as compared to other herbicide treatments. The largest number of effective tillers and grains per panicle was observed in weed free which was statistically similar to pendimethalin plus pyrazosulfuron 1150 g/ha, but

Table 1. Effect of weed control treatments on weed density at 20 and 60 days after sowing (DAS)

Treatment	Weed density [a,b,c] (no./m^2)																	
	Digitaria sanguinalis		*Dactyloctenium aegyptium*		*Echinochloa colona*		*Cyperus rotundus*		*Cyperus iria*		*Phyllanthus niruri*		*Alternanthera philoxeroides*		*Mollugo nudicaulis*		*Digera arvensis*	
	20 DAS	60 DAS	20 DAS	60 DAS	20 DAS	60 DAS	20 DAS	60 DAS	20 DAS	60 DAS	20 DAS	60 DAS	20 DAS	60 DAS	20 DAS	60 DAS	20 DAS	60 DAS
Pendimethalin plus pyrazosulfuron 690 g/ha	14 c	57 d	9 c	50 bc	17 c	55 c	47 c	58 c	26 c	56 c	11 b	12 b	11 b	41 b	8 ab	20 b	10 ab	15 c
Pendimethalin plus pyrazosulfuron 920 g/ha	6 b	39 bc	5 b	55 bc	7 b	39 b	19 b	45 bc	6 b	39 b	2 a	3 a	1 a	39 b	0 a	17 b	0 a	10 bc
Pendimethalin plus pyrazosulfuron 1150 g/ha	2 a	33 b	1 a	45 b	1 a	28 b	4 a	34 b	1 a	29 b	0 a	0 a	0 a	19 b	0 a	10 b	0 a	8 b
Pyrazosulfuron 20 g/ha	16 c	52 cd	8 c	68 c	19 c	61 c	30 bc	69 c	18 c	46 bc	5 a	9 b	6 a	36 b	5 a	15 b	4 a	26 c
Pyrazosulfuron 25 g/ha	14 c	44 c	11 c	65 c	17 c	57 c	16 b	56 c	7 b	38 b	4 a	8 b	4 a	28 b	4 a	14 b	2 a	16 bc
Pendimethalin 750 g/ha	1 a	34 b	0 a	44 b	1 a	31 b	88 d	109 d	71 d	123 d	6 a	11 b	7 ab	39 b	7 ab	17 b	6 a	23 c
Pendimethalin 1125 g/ha	0 a	27 b	0 a	47 b	0 a	26 b	89 d	119 d	70 d	113 d	5 a	9 b	8 ab	34 b	6 ab	11 b	6 a	19 c
Weedy	18 c	58 d	10 c	60 c	21 c	48 c	91 d	101 d	83 d	108 d	14 b	20 c	13 b	33 b	13 b	15 b	18 b	22 c
Weed free	0 a	0 a	0 a	0 a	0 a	0 a	0 a	0 a	0 a	0 a	0 a	0 a	0 a	0 a	0 a	0 a	0 a	0 a

Table 2. Effect of weed control treatments on crop growth and weed biomass at 40 days after sowing (DAS)

Treatment	Plant height at 40 DAS[a] (cm)	Tiller density at 40 DAS[a] (no./m^2)	Crop biomass at 40 DAS[a] (g/m^2)	Weed biomass at 40 DAS[a,b,c] (g/m^2)				Weed control efficiency (%) at 40 DAS[a]			
				Grasses	Broad-leaf weeds	Sedges	Total	Grasses	Broad-leaf weeds	Sedges	Total
Pendimethalin plus pyrazosulfuron 690 g/ha	9.8 a	226.8 bc	30.4 c	30.1 bc	5.8 b	43.4 c	78.9 b	24.8	76.9	64.3	56.8
Pendimethalin plus pyrazosulfuron 920 g/ha	10.3 a	264.8 b	43.6 b	22.5 b	1.5 a	40.8 c	64.8 b	5.2	93.6	66.1	65.9
Pendimethalin plus pyrazosulfuron 1150 g/ha	11.0 a	298.6 a	56.8 a	8.6 a	0 a	18.8 b	26.1 a	81.3	100.0	84.2	85.3
Pyrazosulfuron 20 g/ha	10.2 a	210.3 c	40.9 b	38.8 c	6.8 b	49.2 c	93.8 b	4.8	73.1	59.4	49.2
Pyrazosulfuron 25 g/ha	10.4 a	221.3 c	46.6 b	34.4 c	2.3 a	28.1 b	69.0 b	2.5	90.9	76.8	62.9
Pendimethalin 750 g/ha	9.9 a	216.4 c	32.7 c	25.6 b	6.4 b	98.8 d	130.6 c	36.8	74.7	18.4	30.6
Pendimethalin 1125 g/ha	10.1 a	222.3 c	39.7 bc	15.1 ab	5.8 b	103.4 d	124.4 bc	63.0	77.0	14.6	33.8
Weedy	6.5 b	131.2 d	28.1 c	40.3 c	25.3 c	121.1 d	186.1 d	-	-	-	-
Weed free	10.9 a	302.1 a	58.6 a	0 a	0 a	0 a	0 a	100	100	100	100

[a] DAS, days after sowing.

[b] The data were square root transformed for homogenous variance prior to analysis; however, data presented are the means of actual values for comparison.

[c] Least square means within columns with no common letters are significantly different according to Fisher's protected least significant difference (LSD) test where $P < 0.05$.

Table 3. Effect of weed control treatments on yield attributes and yield at harvest

Treatment	Effective tiller[a] (no./m^2)	Grains/ panicle[a] (no.)	1000 grain weight[a] (g)	Weed index (%)	Grain yield[a] (t/ha) 2016	2017	2018	Pooled	Straw yield[a] (t/ha)	Benefit: Cost ratio
Pendimethalin plus pyrazosulfuron 690 g/ha	256.8 c	119.8 b	22.6 a	30.7	3.982 bc	4.098 bc	4.021 bc	4.034 bc	5.547 b	1:2.05
Pendimethalin plus pyrazosulfuron 920 g/ha	312.1 b	121.6 b	22.7 a	28.9	4.321 b	4.151 bc	4.236 bc	4.236 bc	6.025 ab	1:2.45
Pendimethalin plus pyrazosulfuron 1150 g/ha	354.6 a	135.9 a	23.0 a	18.6	5.587 a	4.648 b	4.388 b	4.874 b	6.246 a	1:2.87
Pyrazosulfuron 20 g/ha	248.4 c	117.5 b	22.5 a	45.9	3.103 c	3.323 c	3.244 c	3.223 c	5.467 b	1:2.12
Pyrazosulfuron 25 g/ha	259.6 c	120.8 b	22.8 a	45.3	3.112 c	3.389 c	3.293 c	3.265 c	5.624 b	1:2.28
Pendimethalin 750 g/ha	258.9 c	121.4 b	21.9 a	48.8	2.533 cd	3.452 c	3.221 c	3.069 c	5.501 b	1:2.17
Pendimethalin 1125 g/ha	265.8 c	127.6 b	22.7 a	48.1	3.069 c	3.148 c	3.108 c	3.108 c	5.613 b	1:2.20
Weedy	168.9 d	65.8 c	21.6 a	68.7	1.689 d	1.899 d	2.013 d	1.867 d	3.014 c	1:1.49
Weed free	360.2 a	138.1 a	23.3 a	-	5.897 a	6.041 a	6.021 a	5.987 a	6.987 a	1:2.33

[a] Least square means within columns with no common letters are significantly different according to Fisher's protected least significant difference (LSD) test where $P < 0.05$.

was significantly more as compared to standalone application of pendimethalin and pyrazosulfuron (**Table 3**). No significant difference in thousand grain weight was recorded. Different weed control treatments had significant effect on the grain yield of rice. The highest grain and straw yield of rice was obtained with weed free and it was followed by pre-mix application of pendimethalin + pyrazosulfuron. This indicated that sequential application of some post-emergence herbicide (depending upon weed flora) is also required to achieve the potential yield. Pendimethalin + pyrazosulfuron at 1150 g/ha resulted in significantly more grain yield than standalone application of pendimethalin and pyrazosulfuron herbicides. The highest returns were obtained with pre-emergence application of pendimethalin plus pyrazosulfuron 1150 g/ha and it was followed by pendimethalin + pyrazosulfuron at 920 g/ha.

Conclusion

With change in rice production system from puddled transplanted to DSR, weed flora changes dramatically. Pre-emergence application of pyrazosulfuron plus pendimethalin 1150 g/ha provided effective control of grasses, sedges and broad-leaf weeds in dry seeded rice during early period of crop-weed competition. At later stages, a suitable post-emergence herbicide for control of emerged weeds may be advised to realize the potential grain yield.

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