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Penoxsulam influence on weed complex and productivity of transplanted rice and its residual effects in rice-wheat cropping system

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ABSTRACT

Field experiments were conducted to evaluate the bio-efficacy of penoxsulam 2.67% w/w (2.5% w/v) OD applied as post-emergence (PoE) in transplanted rice and its residual effect in succeeding wheat crop at CCS Haryana Agricultural University, Regional Research Station, Karnal. Penoxsulam 22.5 g/ha reduced the density (0.0 to 0.7/m^2) and dry weight (0.0 to 6.3 g/m^2) of grassy weeds during 2011 and 2012 and was similar to weed free check. Penoxsulam at 22.5 g/ha resulted in similar dry weight of grassy and broad-leaf weeds with all other herbicidal treatments, and was superior to bispyribac-sodium 20 g/ha in controlling grassy weeds during 2012 and bispyribac-sodium 20-25 g/ha in controlling broad-leaf weeds during both the years. It provided almost complete control of sedges. The grain yield under penoxsulam 22.5 g/ha (5.68 t/ha in 2011 and 6.89 t/ha in 2012) was at par with its higher dose (25 g/ha) and more than its lower dose (20 g/ha). It also resulted in net returns (` 31921-55372/ha) and B:C ratio (2.03-2.68) almost similar/higher to recommended post-emergence herbicides. Weeds growing throughout the crop season reduced the grain yield of rice to the tune of 37.5 and 43.4% during 2011 and 2012, respectively. Penoxsulam 22.5 g/ha also performed well against weed complex in adaptive trials at farmers' fields during *Kharif* 2017. There was no phyto-toxicity of penoxsulam even up to 50 g/ha on transplanted rice crop and also there was no residual phyto-toxicity on the succeeding wheat during 2011-12 to 2013-14. It also did not leave any detectable residual carry-over at harvest in soil, straw and rice grain when applied up to 45 g/ha.

INTRODUCTION

Rice is the staple food of more than 60% of the world population and there is urgent need to increase productivity and production to meet the food demands of the consistently growing population (Fageria 2007). It is grown in India over an area of 44 m ha with total production of 105 m tones, amounting to 40% of the total food grain (Economic Survey 2015-16). Productivity of rice is low in the country and among different constraints, weeds pose a major threat. Weed infestation in transplanted rice in India has been reported to cause yield reductions of 27-68% (Yadav *et al.* 2009, Manhas *et al.* 2012, Duary *et al.* 2015, Hossain and Malik 2017). Most of the already recommended herbicides (butaclor, pretilachlor, anilofos and oxadiargyl) are applied as pre-emergence. However, sometimes the pre-emergence (PE) herbicides do not perform well particularly under water scarce conditions immediately after transplanting. Hence, need was felt for post-emergence herbicides for control of complex weed flora in transplanted rice. Penoxsulam 24% SC has already been reported very effective for control of complex weed flora in transplanted rice (Mishra *et al.* 2007, Yadav *et al.* 2008), but with limited acceptability and use by the farmers as its recommended application window of 8-12 days after transplanting (DAT) as spray in puddle transplanted rice fields could be too early to be practically followed. Bispyribac-sodium is being most commonly used for post-emergence control of weeds in transplanted rice (Yadav *et al.* 2009). However, some of grassy and broad-leaf weeds and sedges are not controlled effectively by alone application of these herbicides. Penoxsulam 2.5% OD is a new herbicide formulation for post-emergence weed control in transplanted rice. Therefore, an investigation was conducted to optimize the dose and time of application of penoxsulam against complex weed flora in transplanted rice, along with its evaluation at farmers' fields, and residual carry over in soil, straw and grains of rice.

MATERIALS AND METHODS

Field experiments were conducted to evaluate the bio-efficacy of penoxsulam 2.67% w/w (2.5% w/v) OD in transplanted rice at CCS Haryana Agricultural University, Regional Research Station, Karnal during *Kharif* 2011 and 2012, its phyto-toxicity on rice crop and succeeding wheat crop during 2011-12 to 2013-14, residue analysis in *Kharif* 2017 and multi-locational adaptive trials at farmers' fields during *Kharif* 2017.

On-station experiments

Bio-efficacy studies: A field experiment was conducted to evaluate the bio-efficacy of penoxsulam 2.67% w/w (2.5% w/v) OD applied as post-emergence (PoE) in transplanted rice at CCS Haryana Agricultural University, Regional Research Station, Karnal during *Kharif* 2011 and 2012. The soil of the experimental field was clay loam in texture, low in available N, medium in P_2O_5 and high in available K_2O with slightly alkaline reaction (pH 8.2). The treatments included penoxsulam 2.5% OD 20, 22.5, 25 g/ha at 15-20 DAT, check herbicides penoxsulam 24% SC 22.5 g/ha at 8-12 DAT, bispyribac-sodium 10% SC 20 g/ha at 10-14 DAT, bispyribac-sodium 25 g/ha at 15-25 DAT (during 2012), butachlor 50% EC 1500 g/ha at 0-3 DAT, along with weed free and weedy checks. The experiment was laid out in randomized block design with three replications. Transplanting of rice cultivar '*HKR 47*' (40 and 36 days old nursery in 2011 and 2012, respectively) was done at spacing of 20 x 15 cm on 20 July and 12 July during 2011 and 2012, respectively. The plot size was 6.1 x 2.4 m. The post-emergence (PoE) herbicides were applied as spray using knap-sack sprayer fitted with flat fan nozzle in a spray volume of 300 litres/ha, and the pre-emergence (PE) herbicides as sand mix broadcast using 150 kg sand/ha. The soil in field was kept under saturated condition during spray application and re-irrigated after 24 hours of spray application. Crop was raised as per the recommendations of the state University and harvested on 30 October, 2011 and 22 October, 2012. Density and dry weight of weeds were recorded at 60 days after transplanting (DAT) and yield and yield attributes at maturity. Crop injury in respect of phyto-toxicity symptoms (yellowing, chlorosis, stunting or scorching) under different treatments was also recorded by visual rating (0-100%) at 15, 30 and 45 days after herbicide application (DAA). Since, there was no crop injury on rice crop and subsequent wheat data pertaining to this aspect are not included herein.

Phyto-toxicity studies: Another field experiment was conducted to study the phyto-toxicity of penoxsulam 2.5% OD on transplanted rice at CCS Haryana Agricultural University, Regional Research Station, Karnal during *Kharif* 2011 to 2013. The treatments included application of penoxsulam at 25 and 50 g/ha at 15-20 DAT along with untreated check with three replications. During *Kharif* 2011, 2012 and 2013, 40, 36 and 35 days old nursery of rice cv. '*HKR-47*' were transplanted on 20 July, 12 July and 7 July, respectively. The other agronomic practices and spray methodology were same as that adopted for bio-efficacy experiment. Transplanting was done at a spacing of 20 x 15 cm in a plot size of 6.1 x 2.4 m. Herbicides were applied by spray with knapsack sprayer fitted with flat fan nozzle using 300 liter water/ha. Crop was harvested on 30 October, 2011 and 22 October, 2012 and 21 October 2013. Observations (from 10 plants/plot) on crop phyto-toxicity in rice terms of vein clearing, epinasty, hyponasty, wilting and injury to leaf tips and leaf surface were recorded at 1, 3, 5, 7, 10, 15 and 30 days after herbicide application (DAA), on 0-10 point scale, with 0= no phyto-toxicty and 10= compete mortality.

Wheat crop was sown on the same plots after rice on 25 November 2011 (*DPW 621-50*), 20 November 2012 (*DPW 621-50*) and 17 November 2013 (*WH 711*) using seed rate of 100-112.5 kg/ha at row spacing of 20 cm. Crop was raised as per package of practices of the state university. Observations from 10 plants/plot on crop phyto-toxicity were recorded at 15 and 30 DAS on 0-10 point scale with 0= no phyto-toxicity and 10= complete mortality.

Residue studies: Residual studies in soil as well as straw and grains of rice were conducted during *Kharif* 2017 for the standard grade made available by the manufacturer company during this season. The treatments included penoxsulam 2.5% OD at 22.5 (X), 45.0 g/ha (2X) applied at 15-20 DAT and untreated check. Rice cv. '*HKR 47*' was transplanted on 13 July at a spacing of 20 x 15 cm in a plot size of 16.0 x 6.0 m. Herbicides were applied by spray with knapsack sprayer fitted with flat fan nozzle using 300 liter water/ha. Crop raised as per the recommendations of the CCS HAU was harvested on 20 October. The harvest time samples of grain, straw and soil were analysed for residue estimation of penoxsulam by using HPLC.

On-farm adaptive trials: Adaptive trials at farmers' fields were conducted at 12 locations in Karnal, Kurukshetra and Panipat districts during *Kharif* 2017

with commercial product of penoxsulam 2.5% OD made available by the manufacturing company. The fields were infested with complex weed flora comprising grassy weeds, broadleaf weeds and sedges. Penoxsulam at 22.5 g/ha at 15-20 DAT was evaluated in comparison to the check herbicide bispyribac-sodium at 25 g/ha at 15-25 DAT. Herbicides were applied as spray in 300 litres water/ha. The area under each treatment was 0.2 ha at each site.

Statistical analysis

Before statistical analysis, the data on density of weeds was subjected to square root $(\sqrt{x+1})$ transformation to improve the homogeneity of the variance. The data were subjected to the analysis of variance (ANOVA) separately for each year. The significant treatment effect was judged with the help of 'F' test at the 5% level of significance. The 'OPSTAT' software of CCS Haryana Agricultural University, Hisar, India was used for statistical analysis (Sheoran *et al.* 1998).

RESULTS AND DISCUSSION

On-Station experiments

Effect on weeds: Application of penoxsulam 2.5% OD 22.5 g/ha at 15-20 DAT significantly reduced the density (0.0-0.7/m^2) and dry weight (0.0-6.3 g/m^2) of grassy weed *Echinochloa* spp. than its lower dose (20 g/ha), but was at par with its higher dose of 25 g/ha (**Table 1 and 2**). It resulted in density of grassy weeds similar to check herbicides penoxsulam 24% SC 22.5 g/ha, butachlor 1500 g/ha and weed free check during both the years; bispyribac-sodium 20 g/ha during 2011 and bispyribac-sodium 25 g/ha during 2012. It resulted in significantly lower dry weight of grassy weeds than with bispyribac-sodium 20 g/ha during 2012, and was at par with all other herbicidal treatments. During both the years, penoxsulam 22.5 g/ha resulted in statistically similar density of broad-leaf weeds (BLW) (19.3-32.7/m^2) with all its other doses, and check herbicides penoxsulam 24% SC 22.5 g/ha and butachlor 1500 g/ha during 2011 (**Table 1**). However, this treatment was inferior to butachlor during 2012. Penoxsulam 22.5 g/ha was also superior to bispyribac-sodium 20-25 g/ha, in reducing the density as well as dry weight of broad-leaf weeds during both the years. However, it was inferior to weed free conditions during both the years.

Penoxsulam 2.5% OD 22.5 g/ha resulted in lower dry weight of broad-leaf weeds) (0.8-1.2 g/m^2) than its dose of 20 g/ha, but further reduction with its higher dose of 25 g/ha was not significant (**Table 2**). Penoxsulam 22.5 g/ha provided almost complete control of sedges, and was at par with all other weed control treatments except weedy check, which registered significantly lower density and dry weight of sedges during both the years, and bispyribac 25 g/ha for density of sedges in 2011 (**Tables 1 and 2**). Penoxsulam 24% SC 20.0-22.5 g/ha applied at 10-12 DAT was found very effective in controlling *E. crus-galli*, *E. colona*, *A. baccifera*, *Euphorbia* sp., *Fimbristylis miliaceae* and *Cyperus rotundus* in transplanted rice (Yadav *et al.* 2008). Penoxsulam 22.5 g/ha, another formulation of penoxsulam was found very effective against complex weed flora besides providing wider window of its application. Bispyribac-sodium was very effective against grasses particularly *E. crusgalli* and *E. colona*, but control of broad-leaf weeds and sedges was poor (Yadav *et al.* 2009). Therefore, penoxsulam could be suitable alternative under those situations where broad-leaf weeds and sedges dominate.

Effect on crop: There was no significant effect of different herbicidal treatments on the plant height and panicle length of rice during both the years (**Table 3**). Penoxsulam 2.5% OD 22.5 g/ha resulted in effective

Table 1. Effect of penoxsulam 2.5% OD on density of weeds (no./m^2) at 60 DAT in transplanted rice (*Kharif* 2011 and 2012)

Treatment	Dose (g/ha)	Time (DAT)	Grassy weeds		Broad-leaf weeds		Sedges	
			2011	2012	2011	2012	2011	2012
Penoxsulam	20	15-20	2.51(5.3)	2.20(4.0)	6.33(39.3)	5.50(30.0)	1.0(0)	1.0(0)
Penoxsulam	22.5	15-20	1.24(0.7)	1.0(0)	5.77(32.7)	4.33(19.3)	1.0(0)	1.0(0)
Penoxsulam	25	15-20	1.00(0.0)	1.0(0)	5.69(31.3)	4.33(18.7)	1.0(0)	1.0(0)
Penoxsulam (check)	22.5	8-12	1.55(2.0)	1.0(0)	5.79(32.7)	3.91(14.7)	1.0(0)	1.0(0)
Bispyribac-sodium	20	14	1.90(2.7)	1.96(3.3)	8.87(78.0)	7.80(60.0)	2.04(5.3)	1.0(0)
Bispyribac-sodium	25	15-25	-	1.0(0)	-	7.55(56.0)	-	1.0(0)
Butachlor	1500	0-3	1.00(0.0)	1.0(0)	4.93(23.3)	1.0(0)	1.0(0)	1.0(0)
Weed free			1.00(0.0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)
Weedy check			4.50(19.3)	6.14(36.7)	10.03(100.0)	8.91(78.7)	5.43(29.3)	1.96(3.3)
LSD (p=0.05)			0.73	0.64	0.87	1.24	1.47	0.44

*Original figures in parentheses were subjected to square root $(\sqrt{x+1})$ transformation before statistical analysis

tillers/mrl (57.5 in 2011 and 82.7 in 2012) on par with all other treatments except penoxsulam 20 g/ha in 2012 and weedy check during both the years, which registered lower number of effective tillers/mrl. The grain yield under penoxsulam 22.5 g/ha (6.58 t/ha in 2011 and 6.89 t/ha in 2012) was higher than its lower dose (20 g/ha) and at par with higher dose (25 g/ha) during both the years. Grain yield of rice with penoxsulam 2.5% OD 22.5 g/ha was similar to penoxsulam 24% SC 22.5 g/ha, bispyribac-sodium 20 g/ha and 25 g/ha, butachlor 1500 g/ha and weed free check (5.90 t/ha in 2011 and 6.98 t/ha in 2012); and higher than weedy check. Studies conducted elsewhere also revealed that penoxsulam 24% SC 20.0-22.5 g/ha improved yield attributes and yield of transplanted rice due to effective control of complex weed flora (Jason *et al.* 2007, Mishra *et al.* 2007, Yadav *et al.* 2009). Weeds allowed to grow throughout the crop season reduced the grain yield of transplanted rice to the extent of 37.5% and 43.4% during 2011 and 2012, respectively. This is in agreement with earlier findings where yield reductions of 27-68% due to weeds have been reported in transplanted rice (Yadav *et al.* 2009, Manhas *et al.* 2012, Duary *et al.* 2015, Hossain and Malik 2017)

Economics

Penoxsulam 2.5% OD 22.5 g/ha offered net returns of ` 31921-55372/ha, which was almost similar/higher to already recommended PoE herbicide penoxsulam 24% SC 22.5 g/ha (` 30700-55042/ha).

Table 2. Effect of penoxsulam 2.5% OD on dry weight of weeds (g/m^2) at 60 DAT in transplanted rice (*Kharif* 2011 and 2012)

Treatment	Dose (g/ha)	Time (DAT)	Grassy weeds		Broad-leaf weeds		Sedges	
			2011	2012	2011	2012	2011	2012
Penoxsulam	20	15-20	34.1	19.4	2.6	1.6	0.0	0.0
Penoxsulam	22.5	15-20	6.3	0.0	1.2	0.8	0.0	0.0
Penoxsulam	25	15-20	0.0	0.0	1.0	0.7	0.0	0.0
Penoxsulam (check)	22.5	8-12	9.9	0.0	1.4	0.8	0.0	0.0
Bispyribac-sodium	20	10-14	14.5	13.7	3.3	2.5	0.4	0.0
Bispyribac-sodium	25	15-25	-	0.0	-	2.1	-	0.0
Butachlor	1500	0-3	0.0	0.0	0.3	0.0	0.0	0.0
Weed free			0.0	0.0	0.0	0.0	0.0	0.0
Weedy check			223.7	232.1	5.9	3.8	17.7	1.2
LSD (p=0.05)			14.4	11.6	1.3	0.7	4.0	0.6

Table 3. Effect of penoxsulam 2.5% ODon plant height, yield attributes and grain yield of transplanted rice (*Kharif* 2011 and 2012)

Treatment	Dose (g/ha)	Time (DAT)	Plant height (cm)		No. of effective tillers/ mrl		Panicle length (cm)		Grain yield (t/ha)	
			2011	2012	2011	2012	2011	2012	2011	2012
Penoxsulam	20	15-20	92.5	121.3	53.2	76.5	20.2	22.1	5.17	6.48
Penoxsulam	22.5	15-20	92.2	120.7	57.5	82.7	20.3	22.1	5.68	6.89
Penoxsulam	25	15-20	91.7	121.1	56.5	81.2	20.0	21.5	5.59	6.77
Penoxsulam (check)	22.5	8-12	93.5	120.5	56.7	82.2	20.1	22.0	5.54	6.84
Bispyribac-sodium	20	10-14	93.1	121.0	54.2	77.2	20.2	21.8	5.39	6.56
Bispyribac-sodium	25	15-25	-	121.3	-	78.8	-	21.7	-	6.65
Butachlor	1500	0-3	90.9	122.1	58.8	85.5	20.3	22.1	5.57	7.12
Weed free			95.1	121.1	60.8	83.3	20.3	22.0	5.90	6.98
Weedy check			93.1	121.5	39.8	50.5	20.0	21.2	3.68	3.95
LSD (p=0.05)			NS	NS	5.4	5.5	NS	NS	0.44	0.40

Table 4. Effect of penoxsulam on economics of transplanted rice (*Kharif* 2011 and 2012)

Treatment	Dose (g/ha)	Time (DAT)	Variable cost (x10^3 `/ha)		Gross returns (x10^3 `/ha)		Net returns (x10^3 `/ha)		B-C ratio	
			2011	2012	2011	2012	2011	2012	2011	2012
Penoxsulam	20	15-20	30.93	32.66	57.38	82.92	26.44	50.25	1.85	2.54
Penoxsulam	22.5	15-20	31.14	32.87	63.06	88.24	31.92	55.37	2.03	2.68
Penoxsulam	25	15-20	31.34	33.08	62.05	86.66	30.70	53.58	1.98	2.62
Penoxsulam (check)	22.5	8-12	30.83	32.56	61.53	87.60	30.70	55.04	2.00	2.69
Bispyribac-sodium	20	10-14	30.52	32.25	59.88	84.03	29.37	51.78	1.96	2.61
Bispyribac-sodium	25	15-25	-	32.56	-	85.18	-	52.62	-	2.62
Butachlor	1500	0-3	29.79	31.50	61.88	91.08	32.09	59.58	2.08	2.89
Weed free			37.44	40.26	65.45	89.39	28.00	49.13	1.75	2.22
Weedy check			28.85	30.53	40.89	50.60	12.04	20.07	1.42	1.66

Table 5. Performance of penoxsulam 2.5% OD against weeds in transplanted rice in adaptive trials at farmers' fields (*Kharif* 2017)

District	Location	Variety	Weed control (%)		Grain yield (t/ha)	
			Penoxsulam (22.5 g/ha)	Bispyribac-Na (25 g/ha)	Penoxsulam (22.5 g/ha)	Bispyribac-Na (25 g/ha)
Karnal	Uchana-1	*CSR-30*	90	89	3.26	2.97
Karnal	Uchana-2	*CSR-30*	92	91	3.10	3.06
Karnal	Tikri	*HKR 47*	92	90	6.30	6.12
Karnal	Shindarpur	*PB 1121*	90	92	3.45	3.52
Karnal	Uchani-1	*PB 1121*	95	90	3.85	3.50
Karnal	Uchani-2	*CSR -30*	89	87	2.85	2.56
Karnal	Popra	*PB 1121*	92	90	3.82	3.62
Karnal	Kunjpura	*PB 1121*	95	92	3.94	3.71
Karnal	Panhari	*HKR 47*	95	93	6.64	6.30
Kuruksetra	Darala	*CSR-30*	90	88	3.02	2.94
Panipat	Ishrana	*PB 1121*	90	87	3.42	3.25
Panipat	Dhurana	*PB 1121*	88	85	3.55	3.28
Average	-	-	91.5	89.5	3.93	3.74

B-C ratio from penoxsulam 22.5 g/ha (2.03-2.68) was also almost similar to penoxsulam 24% SC 22.5 g/ha (**Table 4**).

Herbicide residues and crop phyto-toxicity: There was no phyto-toxicity of applied penoxsulam 2.5% OD even up to 50 g/ha on transplanted rice crop at 1, 3, 5, 7, 10, 15 and 30 days after application (DAA) of the herbicide during *Kharif* 2011 to 2013 (data not given). Also there was no residual phyto-toxicity of penoxsulam up to 50 g/ha on succeeding wheat crop during *Rabi* 2011-12 to 2013-14. No residues of penoxsulam applied at 22.5 g/ha and 45.0 g/ha were detected in soil, straw and grains of rice at harvest during *Kharif* 2017 (data not given), indicating its safety to the human/animal health and the environment.

On-farm adaptive trials

Penoxsulam at 22.5 g/ha applied at 15-20 DAT in transplanted rice (scented rice varieties '*CSR 30*' at four locations and PB 1121 at six locations) and coarse rice '*HKR 47*' at two locations) during *Kharif* 2017 provided 88-95% control of weeds (**Table 5**). The average grain yield obtained under penoxsulam 22.5 g/ha (3.93 t/ha) was 5.1% higher as compared to the check herbicide bispyribac-sodium 25 g/ha (3.74 t/ha).

The present investigation indicated that foliar application of penoxsulam 2.5% OD at 22.5 g/ha as PoE (15-20 DAT) could be a better alternative for satisfactory control of complex weed flora and yield improvement in transplanted rice without causing any phyto-toxicity up to 50 g/ha on rice and succeeding wheat crop. It also did not leave any detectable residual carry-over effects in soil, straw and rice grain up to 45 g/ha. Wider window of its application over penoxsulam offers more convenient option to farmers for control of broad spectrum of weeds in transplanted rice.

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