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Efficacy of pendimethalin and cyhalofop-butyl + penoxsulam against major grass weeds of direct-seeded rice

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ABSTRACT

Direct-seeded rice (DSR) helps in saving water and is beneficial for soil physical health along with environmental benefits, but weeds poses a serious threat to efficient crop production. In the absence of ponded water, weeds emerge in several flushes making it difficult to manage them with a single pre- or post-emergence herbicide application. Studies were carried out under the screen house conditions at CCS Haryana Agricultural University, Hisar, where the response of four dominant grass weeds of direct-seeded rice, *viz*. *Echinochloa glabrescens*, *Leptochloa chinensis*, *Eragrostis japonica* and *Dactyloctenium aegyptium* was evaluated against pendimethalin and cyhalofop-butyl + penoxsulam mixture. The four grassy weed species were planted in pots replicated four time with 20 seed per plot. Pendimethalin was applied as pre-emergence at 0.25, 0.5, 1.0 and 2.0 kg/ha and cyhalofop-butyl + penoxsulam mixture was sprayed as post-emergence (PoE) (at 25 days after sowing) at 32.5, 65, 135 and 270 g/ha with the help of knapsack sprayer and control pots were maintained for each species and herbicides. Periodical observations on visual mortality (0-100 scale, where 0 = no effect and 100=complete mortality) and dry weight per pot was observed at harvest. Application of pendimethalin at 1.0 kg/ha resulted in excellent control of *L. chinensis* and *D. aegyptium*, whereas at 2.0 kg/ha application rate killed all the weeds. Cyhalofop-butyl + penoxsulam applied at 270 g/ha showed 100% mortality of *E. glabrescens* and *L. chinensis.* However, the highest rate (270 g/ha) of this mixture had no effect on *E. japonica*, and provided only 20% control of *D. aegyptium*. Results of this study suggest that pendimethalin can be used for managing *E. glabrescens*, *L. chinensis*, *E. japonica* and *D. aegyptium*. However, cyhalofop-butyl + penoxsulam can be used as PoE in fields dominated by *E. glabrescens* and *L. chinensis*.

INTRODUCTION

Choice of herbicide in rice crop varies according to the method of crop establishment because water regime varies with the method adapted. Different pre-emergence (pendimethalin, oxadiazon, oxadiargyl, pretilachlor, pyrazosulfuron *etc*.) and post-emergence (bispyribac-sodium, penoxsulam, fenoxaprop, azimsulfuron, 2,4-D, metsulfuron-methyl, chlorimuron + metsulfuron *etc*.) herbicides are used throughout the rice growing areas across the world (Chauhan 2012). There is a long window of emergence of weeds and also the infestation of a complex weed flora during the rainy season in direct seeded rice (DSR) fields, so one time application of herbicide may not effectively solve the weed problem (Bhullar *et al*. 2016, Singh 2016). Herbicides have to be applied in sequence or in mixtures for effective control of broad spectrum weed flora (grasses, broad-leaf weeds and sedges). Pre-emergence (PE) herbicides offer very limited window of application and they also require optimum moisture conditions at the time of sowing. PE herbicides in DSR can be applied 0-3 days after sowing (DAS) and if there is concurrence of pre monsoon showers in this short duration, farmer is left out with the only option of post-emergence (PoE) herbicides (Mahajan and Chauhan 2015). Hence, application of several herbicides in combination or in sequence is more useful than single application in DSR.

In DSR, major grass weeds being observed are *Echinochloa glabrescens*, *Leptochloa chinensis*, *Eragrostis japonica* and *Dactyloctenium aegyptium* (Mahajan and Chauhan 2013). The infestation of *L. chinensis* is increasing due to poor efficacy of many herbicides such as bispyribac-sodium and penoxsulam against this weed (Brar and Bhullar 2012), but it can be effectively managed by penoxalum + cyhalofop-methyl (Bhullar *et al.* 2016). Similarly penoxsulam is not effective for *D. aegyptium* control. Therefore, for complex weed flora control in DSR, we have to identify different herbicides, which can be applied alone or in combination as PE or PoE or sequential application of PE followed by PoE herbicides (Mahajan and Chauhan 2015). Therefore, keeping in view the present studies were conducted to determine the effectiveness of pendimethalin and cyhalofop-butyl + penoxsulam against four dominant weeds of DSR under controlled conditions which may be helpful for designing chemical weed management program for a particular DSR field.

MATERIALS AND METHODS

Experiments were conducted at CCS Haryana Agricultural University during 2012 and 2013 under the screen house conditions in the pots. The pot with a diameter of top and bottom 20.0 and 10.0 cm, respectively, and 20.0 cm height with soil carrying capacity of 4.7 kg were used in the study. Soil used for filling the pots was in the ratio of 3:1:1 with field soil, dunal sand and vermicompost. The field soil was sandy loam in texture and collected from fields where no herbicides were used for the last four years. Seeds were treated with 0.1% sodium hypochlorite immediately before each experiment for 30 minutes and washed 3-4 times with distilled water so as to ensure disease free seeds. Twenty seeds of four weed species, *viz. Echinochloa glabrescens, Leptochloa chinensis, Eragrostis japonica* and *Dactyloctenium aegyptium* were planted in each pot and watered regularly. Pendimethalin PE (0, 0.25, 0.5, 1.0, 2.0 kg/ha) was applied just after sowing of weed seeds with the help of a knapsack sprayer using water 300 L/ha with a flat fan nozzle. Herbicide dose was calculated on area basis and amount of water used in one hectare. Accordingly, concentration of herbicide was maintained in spray solution on the basis of herbicide rate. Cyhalofop-butyl + penoxsulam in ratio of 5:1 (0, 32.5, 65, 135, 270 g/ha) was applied 25 DAS similar to PE herbicide using a knapsack sprayer fitted with flat fan nozzles. Control pots were maintained for each herbicide and species for comparisons. Visual mortality (%) was recorded on a 0-100 scale, where 0 = no control and 100 = complete mortality) compared to untreated pots at 1, 2, and 4 weeks after treatment (WAT). Also, dry weight was also recorded at 4 WAT.

Due to similar trends, experimental data were pooled for both the years and analyzed using SPSS software version 7.5. The per cent data were subjected to arcsine transformation before statistically analysis. The experiment was asymmetrical factorial which was designed in CRD with four replications. The significant treatment effect was judged by using 'F' test at 5% level of significance.

RESULTS AND DISCUSSION

Pendimethalin

E. japonica proved the most robust, among all the four weed species, as it had lowest visual mortality, when averaged over different herbicide rates of pendimethalin at 4 WAT (**Table 1**). There was statistically significant difference in visual mortality by pendimethalin at all the stages. The visual mortality increased as the rates of pendimethalin increased and pendimethalin at the highest rate of 2000 g/ha provided complete kill of all the four species at all the stages of observations. At the lowest dose of pendimethalin (250 g/ha), *L. chinensis* showed maximum sensitivity among the test species.

There was statistically significant difference in visual mortality at 1 WAT, by pendimethalin when applied at 1000 and 2000 g/ha, data averaged over weed species and similar trends were recorded at 28 DAT. The results were supported by the findings of Koèárek *et al.* (2015) where it was recorded that half-life of pendimethalin ranged from 24.4 to 34.4 days, though pendimethalin can persists up to 240 days (Singh *et al.* 1994). There was complete mortality of *L. chinensis* and *D. aegyptium* at 1.0 and 2.0 kg/ha. Similar trends were recorded at 2 and 4 WAT, whereas *E. glabrescens* and *E. japonica* showed some tolerance at 1.0 kg/ha. Similar to these findings, Khaliq and Matloob (2012) also recorded the effectiveness of pendimethalin applied at 1137 g/ha in reducing the germination of *Echinochloa colona* in pot experiment. Whereas, Ahmed and Chauhan (2015) studied the effect of pendimethalin and found that increased rates of pendimethalin did not reduce total weed density; however, it reduced biomass of weeds significantly. When averaged over different weed species and herbicide rate, mortality percentage decreased from 80.1 to 76.2 as time increased from 1st to 2nd week, but this difference was narrowed as experiment advanced to 4th week. The difference in rate of growth could be due to faster metabolism of herbicide initially and later followed decreasing rate. There was no change in mortality percentage at 1.0 and 2.0 kg/ha when data averaged over different weed species. This could be attributed to the finding

Table 1. Effect of pendimethalin on periodical visual mortality (%) of rice weeds in pots

Weed Specie	Pendimethalin rate (g/ha)				Mean
	250	500	1000	2000	
1 WAT					
E. glabrescens	65.0 (53.7)	86.7 (68.7)	95.0 (77.1)	100.0 (90.0)	86.7 (72.4)
L. chinensis	73.3 (58.9)	90.0 (72.0)	100.0 (90.0)	100.0 (90.0)	90.8 (77.7)
E. japonica	30.0 (33.2)	48.3 (44.0)	93.3 (75.2)	100.0 (90.0)	67.9 (60.6)
D. aegyptium	38.3 (38.2)	61.7 (51.7)	100.0 (90.0)	100.0 (90.0)	75.0 (67.5)
Mean	51.7 (46.0)	71.7 (59.1)	97.1 (83.1)	100.0 (90.0)	80.1 (69.6)
LSD (p=0.05), weed species and pendimethalin rate = 1.9, interaction=3.9					
2 WAT					
E. glabrescens	30.0 (33.2)	65.0 (53.7)	95.0 (77.0)	100.0 (90.0)	72.5 (63.5)
L. chinensis	73.3 (59.0)	90.0 (72.0)	100.0 (90.0)	100.0 (90.0)	90.8 (77.8)
E. japonica	30.0 (33.2)	48.3 (44.0)	93.3 (75.2)	100.0 (90.0)	68.0 (60.7)
D. aegyptium	38.3 (38.2)	61.7 (51.7)	100.0 (90.0)	100.0 (90.0)	75.0 (67.5)
Mean	42.9 (40.9)	66.3 (55.4)	97.1 (83.1)	100.0 (90.0)	76.6 (67.4)
LSD (p=0.05), weed species and pendimethalin rate = 1.8, nteraction=3.8					
4 WAT					
E. glabrescens	30.0 (33.3)	45.0 (42.1)	95.0 (77.0)	100.0 (90.0)	67.5 (60.6)
L. chinensis	73.3 (59.0)	90.0 (72.0)	100.0 (90.0)	100.0 (90.0)	90.8 (77.8)
E. japonica	30.0 (33.2)	48.3 (44.0)	93.3 (75.2)	100.0 (90.0)	68.0 (60.7)
D. aegyptium	38.3 (38.2)	61.7 (51.7)	100.0 (90.0)	100.0 (90.0)	75.0 (67.5)
Mean	42.9 (40.9)	61.3 (52.5)	97.1 (83.1)	100.0 (90.0)	75.3 (66.7)
LSD (p=0.05), weed species and pendimethalin rate = 1.8, interaction=3.8					

Figures in parentheses are arcsine transformed

Table 2. Effect of pendimethalin on dry weight (g/pot) of rice weeds at 4 WAT

Weed species	Pendimethalin rate (g/ha)					Mean
	0	250	500	1000	2000	
E. glabrescens	2.90	2.50	2.10	0.20	0.00	1.54
L. chinensis	1.70	1.07	0.31	0.00	0.00	0.62
E. japonica	2.81	1.53	1.32	0.63	0.00	1.26
D. aegyptium	2.02	1.30	0.73	0.00	0.00	0.81
Mean	2.36	1.60	1.11	0.21	0.00	1.06
LSD (p=0.05), weed species=0.09, pendimethalin rate = 0.10, interaction=0.21						

of Koèárek *et al.* (2016), which concluded that double dose did not increase the pendimethalin half-life.

Pendimethalin sprayed at 2.0 kg/ha had zero dry weight for all weed species, whereas, *L. chinensis* and *D. aegyptium* even failed to emerge at pendimethalin 1.0 kg/ha and produced no biomass at these application rates (**Table 2**). When pendimethalin rate was increased from 0.25 to 0.5 kg/ha, there was 30% reduction in dry weight, but when it was increased from 0.50 to 1.0 kg/ha, it was 82% reduction in dry weight per pot. Data averaged over all weed species showed that lower rate may be metabolized fast and more than higher rate resulting in lower mortality, hence more reduction in dry matter. Averaging weed dry weight data across pendimethalin rates revealed that maximum dry weight per pot was recorded by *E. glabrescens,* which significantly differed to other weed species. There was 91% reduction in weeds dry weight per pot with pendimethalin 1.0 kg/ha application compared to control suggesting that this rate of pendimethalin can be used for managing these weeds in DSR.

Effect of cyhalofop-butyl + penoxsulam

At 1 WAT, cyhalofop-butyl+penoxsulam sprayed at 25 DAS had least control of *E. japonica* followed by *D. aegyptium* (**Table 3**). *L. chinensis* had the highest mortality percentage, when data was averaged over different rates of applications, indicating a good herbicide mixture for managing fields dominated by this weed. Earlier researchers (Jacob *et al.* 2017) have also reported that cyhalofop-butyl provided 96% control of *L. chinensis* but penoxsulam gave only 35% control. In this study, cyhalofop-butyl + penoxulam applied at 270 g/ha resulted in highest control of *L. chinensis* (88.3%) compared to other weed species as recorded after

Table 3. Effect of cyhalofop-butyl + penoxsulam (5:1) on periodical percent visual mortality of rice weeds in pots

Weed Species	Cyhalofop-butyl + penoxsulam (g/ha)				Mean
	32.5	65	135	270	
1 WAT					
E. glabrescens	20.0 (26.6)	40.0 (39.2)	41.7 (40.2)	81.7 (64.7)	45.8 (42.7)
L. chinensis	38.3 (38.2)	43.3 (41.2)	46.7 (43.1)	88.3 (70.1)	54.2 (48.1)
E. japonica	11.7 (19.9)	13.3 (21.3)	33.3 (35.2)	36.7 (37.3)	23.8 (28.4)
D. aegyptium	21.7 (27.7)	25.0 (30.0)	43.3 (41.2)	46.7 (43.1)	34.2 (35.5)
Mean	22.9 (29.3)	30.4 (32.2)	41.2 (39.4)	63.4 (53.8)	39.5 (38.7)
LSD (p=0.05), weed species and cyhalofop-butyl + penoxsulam = 1.5, interaction= 2.9					
2 WAT					
E. glabrescens	25.0 (30.0)	60.0 (50.8)	86.7 (68.7)	100.0 (90.0)	67.9 (59.9)
L. chinensis	63.3 (52.7)	78.3 (62.3)	91.7 (73.4)	100.0 (90.0)	83.3 (69.6)
E. japonica	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0(0.0)	0.0 (0.0)
D. aegyptium	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	20.0 (26.6)	5.0 (6.6)
Mean	22.0 (23.1)	34.6 (25.9)	44.6 (35.5)	55.0 (51.6)	39.1 (34.0)
LSD (p=0.05), weed species and cyhalofop-butyl + penoxsulam = 1.0, interaction=2.0					
4 WAT					
E. glabrescens	33.3 (35.2)	63.3 (52.7)	95.0 (77.1)	100.0 (90.0)	72.9 (63.8)
L. chinensis	83.3 (65.9)	90.0 (71.6)	98.3 (85.7)	100.0 (90.0)	92.9 (78.3)
E. japonica	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
D. aegyptium	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	20.0 (26.6)	5.0 (6.6)
Mean	29.2 (35.2)	38.3 (52.7)	48.3 (77.1)	55.0 (51.6)	42.7 (63.8)
LSD (p=0.05), weed species and cyhalofop-butyl + penoxsulam = 1.7, interaction=3.3					

Figures in parentheses are arcsine transformed

Table 4. Effect of cyhalofop-butyl + penoxsulam (5:1) on dry weight (g/pot) of rice weeds at 4 WAT

Weed species	cyhalofop-butyl + penoxsulam (g/ha)					Mean
	0.0	32.5	65	135	270	
E. glabrescens	4.54	2.93	1.39	0.50	0.00	1.87
L. chinensis	2.41	0.84	0.41	0.34	0.00	0.80
E. japonica	4.13	3.60	2.34	2.32	2.23	2.92
D. aegyptium	4.80	4.24	3.58	2.97	2.23	3.56
Mean	3.97	2.90	1.93	1.53	1.11	2.29
LSD (p=0.05), weed species=0.10 and cyhalofop-butyl + penoxsulam = 0.11, interaction=0.23						

one week of herbicide application. Initially, the difference in visual mortality of *L. chinensis* between 135 g/ha and 270 g/ha application rate was prominent but as time advanced it was narrowed down. At 1 WAT, *E. japonica* recorded significantly lowest visual control (11.7%), when cyhalofop + penoxulam applied at 32.5 g/ha, which was statistically at par with cyhalofop-butyl + penoxsulam at 65 g/ha. Whereas, no visual mortality of *E. japonica* was recorded at 2 and 4 WAT at any of the application rate. *D. aegyptium* was not effectively controlled by cyhalofop-butyl + penoxsulam as there was only 20% control at 4 WAT when applied at 270 g/ha. Although, at 1 WAT, there was 22-47% visual phytotoxicity at different application rates. *L. chinensis* and *E. glabrescens* had higher visual phytotoxicity and it further increased with time, when data were averaged over different rate of cyhalofop-butyl + penoxsulam. Similar to present findings, Lap *et al.* (2013) and Singh (2016) reported that cyhalofop-butyl + penoxsulam mixture is highly effective in controlling *Echinochloa* spp. based on the different trials conducted across Asia.

As there was less effect of herbicide mixture on E. *japonica* and *D. aegyptium*, higher dry weight/pot was recorded in both the species, when data were averaged over different herbicide rates (**Table 4**). There was significant decrease in dry weights with increase in herbicide rates. Dry weight reduction of 35% in *E. japonica* was recorded as cyhalofop-butyl + penoxsulam rate doubled from 32.5 to 65 g/ha, but further doubling the rate resulted in a further decrease of only 5% dry weight. At the highest application rate, no dry weight was recorded of *E. glabrescens* and *L. chinensis* as both showed 100% mortality. Yao *et al*. (2013) also found cyhalofop-butyl + penoxsulam excellent in controlling *E. glabrescens* and *L. chinensis* at different locations in China. Compared to untreated control, the highest rate of cyhalofop-butyl + penoxsulam reduced the dry weight of *E. japonica* and *D. aegyptium* by 46 and 54%, respectively. When averaged over different weed species, the mean dry weights were significantly different among various herbicide rates and 72% reduction in dry weight was recorded with the highest application rate of cyhalofop-butyl + penoxsulam when compared with untreated control.

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