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Weed dynamics and production potential of direct-seeded rice cultivars as influenced by weed management

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ABSTRACT

The field study was undertaken during rainy season of 2012 and 2013 to evaluate the rice cultivars and weed management effects on weeds growth and yield of direct-seeded rice (DSR) cultivars. The associated weed flora include *Echinochloa colona*, *Echinocloa crus-galli*, *Cynodon dactylon* as grasses; *Cyperus rotundus*, *Cyperus iria* as sedges; *Caesulia auxillaries* and *Eclipta alba* as broad-leaved weeds. Bispyribac-sodium + azimsulfuron (25 + 35 g/ha) + 0.25% NIS as post-emergence at 15-20 DAS was found to be most effective in minimizing weed density, biomass and in enhancing the weed control efficiency 40.9% and 38.0% during 2012 and 2013 at 60 DAS, respectively. The maximum rice grain, straw and biological yield was found with application of bispyribac + azimsulfuron (25 g + 35 g/ha) + 0.25% NIS as post-emergence at 15-20 DAS and was significantly superior over rest of the treatments during both the years of study.

Key words: Direct-seeded rice, Rice cultivars, Weed control, Zero-tillage

Dry direct-seeding (DSR) is probably the oldest method of crop establishment. Historical accounts of rice cultivation in Asia indicate that, during its early period of domestication, rice used to be dry sown in a mixture with other crops that were established under the shifting cultivation system (Grigg 1974). In 21th century, scarcity of agricultural land and water and continuing shortage of labour would encourage a shift towards direct-seeding method of rice production system (Mortimer *et al*. 2005). Despite several advantages (Balasubranmanian and Hill 2002) of DSR, various production obstacles are also encountered in direct-seeded rice, of which heavy weed infestation is the major one. Weeds cause heavy damage to DSR crop, which can be to the tune of 5-100% (Rao *et al*. 2007). Manual removal of weeds is labour intensive, tedious, back breaking and does not ensure weed removal at critical stage of crop-weed competition due to non-availability of labours and sometimes bad weather condition, which does not allow labours to move in the field. Thus, herbicides are considered to be an alternatives to hand weeding (Singh *et al*. 2007). Herbicides are more effective in controlling the weeds besides reducing the total energy requirement for rice cultivation. Besides chemicals and manual weeding, agronomic practices like crop establishment by zero tillage or reduced tillage with residue retention play an important role in weed suppression and improving the yield. The present study was undertaken to study the effect of different rice cultivars and weed management practices on weeds, rice growth and yield in direct dry-seeded rice.

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MATERIALS AND METHODS

The field experiment was undertaken for two years during *Kharif* (rainy season) 2012 and 2013 at Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh, India (25°18' N latitude, 83°03' E longitude and at an altitude of 75.7 m above mean sea level) in the Northern-Gangetic alluvial plains having characteristics of sub-tropical climate. The soil of the experimental site was sandy clay loam in texture with pH 7.2. It was moderately fertile, being low in organic carbon (0.43%), available nitrogen (198 kg/ha) and medium in available phosphorus (24.6 kg/ha) and potassium (210 kg/ha). The crops received 622.2 mm of rainfall during 2012 and 818.3 mm in 2013. The rainfall observed to be higher in initial stage but later it was uniformly distributed throughout the crop period during the second year. The weekly mean maximum temperature varied from 28.4 to 40.8 °C (average 32.36 °C) and 26.7 to 35.5 °C (average 31.41 °C) along with minimum temperature ranged from 15.3 to 29.5 °C (average 24.42 °C) and 17.3 to 28.3 °C (average of 25.03 °C) during 2012 and 2013, respectively. The weekly mean sun-shine hours in 2012 was low (5.43 h) as compared to 2013 (5.72 h). The weekly mean rate of evaporation was less in second year (3.51 mm) over first year (3.72 mm), respectively.

The experiment was laid out in split-plot design replicated thrice. The treatments comprised four rice cultivars, *viz*. '*Sarjoo-52', 'HUR-105', 'PAU-201'* and '*Arize- 6129'* were assigned to main plots and each main plot were further divided into six sub-plots to accommodate weed management treatments *i.e*. weedy check, weed free, pendimethalin 1.0 kg/ha as pre-emergence (PE), pendimethalin 1.0 kg/ha *fb* bispyribac-sodium 25 g/ha + 0.25% NIS as post emergence (PoE), oxadiargyl 90 g/ha *fb* bispyribac-sodium 25 g/ha + 0.25% NIS (PoE), bispyribac-sodium + azimsulfuron (25 + 35 g/ha) + 0.25% NIS (PoE). Seeding of all the cultivars were done with pre-sowing irrigation by zero-till drill machines. An uniform dose of 120 kg N + 60 kg P_2O_5 + 60 kg K_2O + 25 kg $ZnSO_4$/ha was applied in all the treatments in the form of urea, DAP, MOP and $ZnSO_4$, respectively. Half dose of total N and full dose of P_2O_5, K_2O and $ZnSO_4$ was applied as basal and remaining half dose of N was top dressed in two equal instalments at active tillering and panicle initiation stage. Seed rate of 30 kg/ha was used for seeding by zero-till drill machine. Pre-emergence (just after sowing) and post-emergence (as per treatments) herbicides were applied with the help of a hand-operated knapsack sprayer fitted with flat-fan nozzle using water 600 L/ha.

Data on weed density were subjected to square root transformation ($\sqrt{x+0.5}$) before statistical analysis to normalize their distribution. The data were analyzed statistically using method described by Panse and Sukhatme (1978). Data on weeds biomass was recorded by cutting weeds at ground level, washing with tap water, sun followed by oven drying at 70±2 °C for 48 hours and then weighing. To determine the effect of crop growth, data on initial plant population/m row at 20 DAS, plant height (cm), tillers (m/row), plant dry matter (g/m row) were recorded at harvest and leaf area index was recorded at 90 days after sowing. Weed control efficiency was calculated using following formula.

$$WCE = \frac{WDc - WDt}{WDc} \times 100$$

Where, WD_C is the weed density (number/m^2) in control plot; WD_T is the weed density (number/m^2) in treated plot; in both WD_C and WD_T; the unit should be same or uniform.

RESULTS AND DISCUSSION

Experimental field was infested with grasses (*Echinocloa colonum, E. Crusgalli*, and *Cynodon dactylon*), sedges (*Cyperus rotundus* and C*yperus iria*) and broad-leaf weeds (*Caexulia auxillaries* and *Eclipta alba*). Among the weed flora, averaged over two years, the maximum relative percentage of weed was grasses, sedges and broad-leaved weeds in all the cultivars.

Effect on weed density

The rice cultivar "*Arize-6129*" had minimum density of weeds among all the cultivars at 60 DAS. Maximum weed density was recorded under '*PAU-201'* (**Table 1**). All weed management practices resulted in significant reduction in total weed density as compared to weedy check. Application of bispyribac-sodium + azimsulfuron (25 + 35 g/ha) + 0.25% NIS PoE at 15-20 DAS showed maximum efficacy in minimizing all kinds of weed flora and proved significantly superior over all the weed management treatments. The next best treatment in this respect was pendimethalin at 1.0 kg/ha (PE) *fb* bispyribac-sodium at 25 g/ha + 0.25% NIS (PoE) at 15-20 DAS. Applications of pendimethalin at 1.0 kg/ha (PE) was less effective as compared to other weed control treatments in minimizing the density of weeds as the field was infected with complex weed flora and this herbicide could not control the flush of weeds of all three types of weeds like, grasses, sedges and broad-leaved weeds at later stage. Singh *et al*. (1999) and Yaduraju and Mishra (2004) also reported that control of initial weed emergence facilitates better environment for direct-seeded rice crop.

Effect on weed biomass and weed control efficiency

Significant variation in total weed biomass under different weed management and crop cultivars was observed. '*Arize-6129*' had minimum weed biomass and the maximum weed biomass was recorded '*PAU-201'* (**Table 1**) due to smothering effect of '*Arize-6129*'. Hussain and Gogoi (1997) also observed significantly lower weed biomass in association with the traditional variety (*Kalaguni*) than in '*IR–36'* variety due to the higher smothering effect of the traditional variety. Among weed management treatments, bispyribac-sodium + azimsulfuron (25 + 35 g/ha) + 0.25% NIS (PoE) recorded the minimum weed dry matter followed by pendimethalin at 1.0 kg/ha (PE) *fb* bispyribac-sodium at 25 g/ha + 0.25% NIS (PoE). This integration of pre- and post-emergence herbicides minimized the weed biomass. Wallia *et al*. (2008) reported effective weed control with integration of pre-emergence application of pendimethalin with post-emergence application of azimsulfuron. The maximum weed biomass was recorded in weedy plots. Among herbicidal treatments, pendimethalin at 1.0 kg/ha (PE) recorded maximum weed biomass.

Weed control efficiency (WCE) of different weed control treatments varied significantly during both the *Kharif* seasons of 2012 and 2013 at 60 days after sowing (**Table 1**). Minimum WCE was recorded in '*PAU-201*' cultivar while maximum in '*Arize-6129*'. Maximum weed control efficiency (100 %) was found with weed free at 60 days after sowing and with bispyribac-sodium + azimsulfuron (25 + 35 g/ha) + 0.25% NIS. The sequential and post-emergence application of herbicide controlled all grassy, sedges and broad-leaved weeds more efficiently and minimized the weed problem. Application of pendimethalin alone was not that effective. The integrated weed control appeared essential for successful direct-seeded rice (Gill 2008).

Effect on crop growth and yield

Application of pre- and post-emergence herbicides did not cause any phytotoxic symptoms on rice plant. Initial plant population was maximum in '*Arize-6129'*, which was significantly superior over rest of the crop cultivars (**Table 2**). This was due to cultivar initial weed suppress efficiency of '*Arize-6129'*. Among the weed management methods, maximum initial plant population was recorded with bispyribac-sodium + azimsulfuron + NIS. '*Arize-6129'* plant height at harvest was maximum and was at par with '*Sarjoo-52'*. Among the weed management methods, bispyribac-sodium + azimsulfuron + NIS recorded maximum plant height while at par with pendimethalin *fb* bispyribac-sodium + NIS treatments in both the year. During first and second year, effective tillers were higher in '*Arize-6129'* and were significantly superior over rest of the cultivars. '*Arize-6129'* had recorded maximum plant biomass at harvest (g/m row) and was at par with '*Sarjoo-52*'. '*HUR-105*' was significantly superior over '*PAU-201'*. Similar results were reported earlier (Hussain and Gogoi 1997).

Leaf area index of direct-seeded rice increased with crop age and recorded at 60 days after sowing (**Table 2**). Among the crop cultivars, '*Arize-6129'* had maximum leaf area index than other three cultivars during both the year. In weed management methods, maximum LAI were recorded under weed free treatment and next best treatment recorded with the application of bispyribac-sodium + azimsulfuron

Table 1. Effect of rice cultivars and weed management on weed density, weed biomass and WCE at 60 DAS

Treatment	Weed density (no./m^2)						Weed biomass (g/m^2)		Weed control efficiency (%)	
	Grasses		Sedges		Broad-leaf weeds					
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
Rice cultivars										
Sarjoo-52	16.4* (322.0)	17.3 (357.9)	9.2 (99.6)	9.7 (110.7)	7.4 (64.7)	7.8 (71.9)	8.6 (87.5)	9.1 (97.3)	43.2	41.4
HUR-105	17.4 (359.5)	18.2 (395.4)	9.7 (111.2)	10.2 (122.3)	7.9 (72.2)	8.2 (79.4)	9.1 (97.7)	9.6 (107.5)	36.6	35.2
PAU-201	18.6 (410.8)	19.4 (446.7)	10.4 (127.1)	10.8 (138.2)	8.4 (82.5)	8.8 (89.8)	9.7 (111.7)	10.2 (121.4)	27.6	26.8
Arize-6129	15.3 (282.0)	16.3 (317.8)	8.6 (87.2)	9.1 (98.3)	7.0 (56.7)	7.4 (63.9)	8.1 (76.7)	8.6 (86.4)	50.3	47.9
LSD (p=0.05)	0.22	0.24	0.12	0.13	0.10	0.11	0.12	0.12	-	-
Weed management										
Pendimethalin 1.0 kg/ha (PE)	20.1 (404.6)	21.1 (447.7)	11.2 (125.2)	11.8 (138.5)	9.0 (81.3)	9.5 (90.0)	10.5 (110.0)	11.0 (121.7)	28.7	26.6
Pendimethalin 1.0 kg/ha (PE) *fb* bispyribac-Na 25 g/ha + 0.25% NIS (PoE)	19.2 (369.6)	20.3 (412.6)	10.7 (114.4)	11.3 (127.7)	8.6 (74.3)	9.1 (82.9)	10.0 (100.5)	10.6 (112.2)	34.8	32.4
Oxadiargyl 90 g/ha (PE) *fb* bispyribac-Na 25 g/ha + 0.25% NIS (PoE)	19.6 (384.6)	20.6 (427.6)	10.9 (119.0)	11.5 (132.3)	8.8 (77.3)	9.3 (85.9)	10.2 (104.6)	10.8 (116.3)	32.2	29.9
Bispyribac-Na + azimsulfuron (25 + 35 g/ha) + 0.25% NIS (PoE) 15-20 DAS	18.3 (335.4)	19.4 (378.5)	10.2 (103.8)	10.8 (117.1)	8.2 (67.4)	8.7 (76.0)	9.5 (91.2)	10.1 (102.9)	40.9	38.0
Weedy check	23.8 (567.2)	24.7 (610.2)	13.2 (175.5)	13.7 (188.8)	10.7 (114.0)	11.1 (122.6)	12.4 (154.2)	12.9 (165.9)	0.0	0.0
Weed free	0.7 (0.00)	0.7 (0.00)	0.7 (0.00)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	100.0	100.0
LSD (p=0.05)	0.34	0.36	0.19	0.20	0.15	0.16	0.18	0.19	-	-

*Data were subjected to square root transformation ($\sqrt{x+0.5}$). Data given in parentheses are original value. DAS- Days after sowing, *fb*- Followed by, PE-Pre-emergence, PoE- Post emergence

Table 2. Effect of rice cultivars and weed management on growth attributes of direct-seeded rice

Treatment	Initial plant population (m/row at 20 DAS)		Plant height (cm)		Tillers (m/row)		Plant biomass (g/m row)		Leaf area index (at 90 DAS)	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
Rice cultivars										
Sarjoo-52	26.8	23.2	96.1	93.0	60.0	59.0	98.9	97.6	3.94	3.57
HUR-105	24.6	21.8	93.4	90.6	57.3	56.2	98.1	96.8	3.84	3.49
PAU-201	23.8	21.1	89.3	86.5	53.2	52.1	93.4	92.2	3.57	3.26
Arize-6129	28.0	24.8	102.7	99.8	65.3	64.2	100.1	99.1	4.05	3.66
LSD (p=0.05)	2.37	2.16	4.04	4.50	6.12	5.8	3.84	3.44	0.19	0.16
Weed management										
Pendimethalin 1.0 kg/ha (PE)	26.4	23.3	93.7	90.9	57.6	56.5	92.6	91.4	3.75	3.41
Pendimethalin 1.0 kg/ha (PE) *fb* bispyribac-Na 25 g/ha + 0.25% NIS (PoE)	27.5	24.6	97.2	94.4	61.0	59.9	107.4	105.9	3.95	3.58
Oxadiargyl at 90 g/ha (PE) *fb* bispyribac-Na 25 g/ha + 0.25% NIS (PoE)	25.0	22.3	94.2	91.4	58.1	57.0	93.8	92.5	3.84	3.48
Bispyribac-Na + azimsulfuron (25 +35 g/ha) + 0.25% NIS (PoE) 15-20 DAS	28.3	25.0	99.9	97.1	63.7	62.6	113.5	111.9	4.07	3.68
Weedy check	18.2	15.6	83.2	80.1	46.1	45.1	60.4	60.5	2.82	2.64
Weed free	29.4	25.8	104.0	101.1	67.1	66.0	118.1	116.3	4.68	4.18
LSD (p=0.05)	1.09	0.90	3.03	2.98	2.93	2.68	2.34	2.19	0.14	0.12

DAS- Days after sowing, *fb*- Followed by, PE-Pre-emergence, PoE- Post-emergence

Table 3. Effect of rice cultivars and weed management on rice grain, straw and biological yield

Treatment	Grain yield (t/ha)		Straw yield (t/ha)		Biological yield (t/ha)	
	2012	2013	2012	2013	2012	2013
Rice cultivars						
Sarjoo-52	4.10	3.92	6.32	6.16	10.42	10.09
HUR-105	3.91	3.76	6.01	5.86	9.92	9.62
PAU-201	3.42	3.27	5.24	5.11	8.66	8.39
Arize-6129	4.29	4.12	6.56	6.40	10.85	10.52
LSD (p=0.05)	0.35	0.30	0.73	0.65	1.06	0.63
Weed management						
Pendimethalin 1.0 kg/ha (PE)	3.74	3.59	5.93	5.78	9.67	9.37
Pendimethalin 1.0 kg/ha (PE) *fb* bispyribac-Na at 25 g/ha + 0.25% NIS (PoE)	4.11	3.94	6.57	6.40	10.68	10.35
Oxadiargyl 90 g/ha (PE) *fb* bispyribac-Na 25 g/ha + 0.25% NIS (PoE)	3.91	3.74	6.21	6.05	10.12	9.79
Bispyribac-Na + azimsulfuron (25 +35 g/ha) + 0.25% NIS (PoE) 15-20 DAS	4.33	4.16	6.95	6.77	11.28	10.93
Weedy check	2.05	1.96	3.03	2.96	5.08	4.92
Weed free	5.44	5.23	7.52	7.33	12.96	12.56
LSD (p=0.05)	0.25	0.23	0.52	0.50	0.70	0.53

DAS - Days after sowing, *fb* - Followed by

+ NIS during both the years. These results were in agreement with Gill (2008).

The maximum rice grain yield was recorded in '*Arize-6129*' (4.29 t/ha and 4.12 t/ha in 2012 and 2013, respectively) during both the years (**Table 3**). All the herbicidal treatments either applied in sequential combination with herbicides or as sole application, significantly increased yield of rice as compared to weedy check during both the years of study. Among weed management methods, bispyribac-Na + azimsulfuron + NIS (4.33 t/ha and 4.16 t/ha) produced significantly maximum rice grain yield than rest of the treatments during both the years. Kamboj *et al.* (2012) also reported significantly higher grain yield and straw yield with sequential herbicide application as it reduced the weed competition and enabled the direct-seeded rice to better utilize nutrient and growth factors. This can be further explained in terms of negative correlation between total weed biomass and rice grain yield (r^2 = 0.834 and r^2 = 0.809 during 2012 and 2013, respectively) (**Figure 1**). Same trends were also observed in respect of straw and biological yield during both the year of studies.

It was concluded that post-emergence application of herbicides mixture is better than pre- or post-emergence application of single herbicide. Application of bispyribac-sodium + azimsulfuron (25

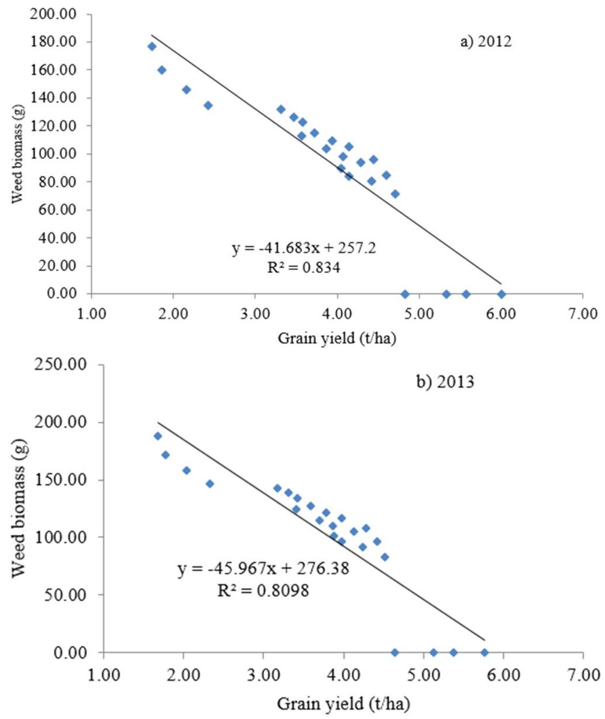

Figure 1. Relationship between weed biomass and rice yield in 2012 (a) and in 2013 (b)

+ 35 g/ha) + 0.25% NIS as PoE at 15-20 DAS was most effective for suppressing weed and improving growth and yield of direct-seeded rice hybrid Arize-6129.

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Weed management in irrigated dry-seeded rice

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ABSTRACT

A field experiment was conducted during *Kharif* 2015 and *Summer* 2016, at Agricultural Research Station, Dhadesugur, University of Agricultural Sciences, Raichur, Karnataka, India, to study the effect of different herbicides for control of weeds in irrigated dry-seeded rice. The dominant weeds in fields were *Echinochloa* sp. *Panicum repens, Cynodon dactylon, Bracharia mutica, Digitarias anguinalis* and *Leptochloa chinensis* among grasses, *Eclipta alba,Commelina communis* and *Ludwigia parviflora* as among broad-leaf weeds and *Cyperus* sp. as sedge. Among herbicidal treatments, post-emergece application of BAS 9548 H (penoxsulam 10 g/l + bentazone 360 g/l SC) 3000 ml/ha recorded significantly higher rice grain yield followed by the application of BAS 9548 (penoxsulam 10 g/l + bentazone 360 g/l SC) 2500 ml/ha and twice hand weeding at 15 and 30 days after sowing (DAS). The maximum B:C ratio was observed in plots treated with BAS 9548 H (penoxsulam 10 g/l + bentazone 360 g/l SC) and twice hand weeded check.

Key words: Weeds biomass, Weed control efficiency, Direct-seeded rice, BAS 9548 H, Weed managment

Rice (*Oryza sativa* L.) is the staple food for more than 60% of the world population, providing energy for about 40% of the world population where every third person on earth consumes rice every day in one form or other (Datta and Khushi 2002). Among several reasons for low rice productivity, the losses due to weeds are one of the most important. Weeds are most severe and widespread biological constrains to crop production in India and weeds alone cause 33% of losses out of total losses due to pests (Verma *et al.* 2015). Irrespective of the method of rice establishment, weeds are a major impediment to rice production due to their ability to compete for resources. In general, weeds problem in transplanted paddy is lower than that of direct-seeded rice (Rao *et al.* 2007). But in situations where continuous standing water cannot be maintained particularly during the first 45 days, weed infestation in transplanted rice also may be as high as direct-seeded rice. According to Singh *et al.* (2004), weeds can reduce the grain yield of dry-seeded rice (DSR) by 75.8%, wet-seeded rice (WSR) by 70.6% and transplanted rice (TPR) by 62.6%. Weeds by virtue of their high adaptability and faster growth dominate the crop habitat and reduce the yield potential. Therefore, the present investigation was undertaken to study the effect of early post-emergent herbicide for control of major weeds in irrigated dry-seeded rice.

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MATERIALS AND METHODS

A field study was taken during *Kharif*-2015 and *Summer*-2016 on effect of different herbicides against weeds in irrigated dry-seeded rice at Agricultural Research Station, Dhadesugur, Raichur, Karnataka. The soil of the experimental site was medium deep black and neutral in pH (8.04), EC (0.47 ds/m), medium in organic carbon content (0.41%), low in nitrogen (189 kg/ha), medium in phosphorus (58.5 kg/ha) and potassium (287.5 kg/ha). There were eight treatments, *viz.* BAS 9548 H (penoxsulam 10 g/l + bentazone 360 g/l SC) 840 g/ha (2270 ml/ha), BAS 9548 H (penoxsulam 10 g/l + bentazone 360 g/l SC) 925 g/ha (2500 ml/ha), BAS 9548 H (penoxsulam 10 g/l + bentazone 360 g/l SC) 1110 g/ha (3000 ml/ha), bentazone 480 g/l SL 960 g/ha (2000 ml/ha), penoxsulam 21.7% SC 18 g/ha (83.3 ml/ha), cyhalofop-butyl 10% EC 150 g/ha (1500 ml/ha), hand weeding and weedy check and replicated thrice. Herbicides were sprayed using a Knapsack sprayer fitted with a flat-fan nozzle at a spray volume of 500 l/ha.

Rice was sown by tractor drawn seed drill at spacing of 20 x 10 cm in both the years. Recommended dose of fertilizer (150:75:75 kg NPK/ha) was applied uniformly in three equal splits. Irrigation comprised of alternate drying and wetting followed by intermittent irrigation at seven days interval up to 15 days before harvest. Other agronomic and plant protection measures were adopted as recommended during the crop growth. The efficacy of different treatments on weeds was evaluated at crop maturity. Quadrates (0.25 m^2) were placed in each plot at random to determine the weed density. Weed seedlings within these quadrates were counted and the efficacy of weed control treatments was evaluated by comparing the density with the untreated control. Weeds were cut at ground level, washed with tap water, oven dried at 70 ^{0}C for 48 hours and then weighed for biomass. The weed control efficiency was calculated using the formula given by Tawaha *et al.* (2002).

After harvest and threshing of crop, grain yield was recorded in net plot wise and converted to grain yield per hectare. The cost of inputs that were prevailing at the time of their use was considered for working out the economics of various treatments. Net return was calculated by deducting the cost of cultivation from gross returns and gross returns was calculated by using the total income obtained from grain and straw yield of rice and the benefit: cost ratio was worked out.

To see the impact of this herbicide on succeeding crop, the blackgram crops was sown after harvesting of the paddy crop from the herbicide treated plots and the data recorded on germination of seed and impact on crop growth and development *viz.* leaf injury on tips and leaf surface, wilting, vein clearing, necrosis, epinasty, hyponasty, stunted growth *etc.* after 7, 15 and 21 days after germination (DAG). The data of each year was analysed separately. MSTAT was used for statistical analysis of data and means were separated using critical difference (LSD) at p=0.05. The data on weeds were transformed by square root transformation before being subjected to ANOVA (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Effect on weed density

Grassy weeds: The grassy weeds, which were predominant in trials field were *Echinochloa* sp. *Panicum repens, Cynodon dactylon, Bracharia mutica, Digitarias anguinalis* and *Leptochloa chinensis* (**Table 1)**. Post-emergence application of BAS 9548 H 3000 ml/ha recorded significantly lower grassy weeds followed by the application of BAS 9548 H 2500 ml/ha and twice hand weeded check as compared to application of bentazone 480 g/l SL 960 g/ha (2000 ml/ha), penoxsulam 21.7% SC 18 g/ha (83.3 ml/ha), cyhalofop-butyl 10% EC 150 g/ha (1500 ml/ha) and weedy check in *Kharif* 2015 and summer 2016 when observed at 60 DAS. Singh *et al.* (2007) reported that post-emergence application of penoxsulam recorded significantly lower grassy weed population in rice. Similarly, Yadav *et al.* (2007) have also reported penoxsulam as an effective post-emergence herbicide against mixed weed flora in rice.

Broad-leaf weeds: The predominant broad-leaf weeds in the trials field were *Eclipta alba, Commelina communis* and *Ludwigia parviflora*. Post-emergence application of BAS 9548 H 2500 ml/ha was at par with the application of BAS 9548 H 3000 ml/ha and twice hand weeded check found to be significantly superior treatment with recorded lowest population of broad-leaf weeds over rest of the treatments (**Table 1)**. Further, weedy check recorded significantly higher weed population of broad-leaf weeds. These results were in conformity with the findings of Yadhav *et al.* (2008).

Sedges: Post-emergence application of BAS 9548 H 2500 ml/ha, 3000 ml/ha and twice hand weeded check were found equally effective in controlling sedges in direct-seeded rice. Post emergence application of bentazone 480 g/l SL 960 g/ha (2000 ml/ha), penoxsulam 21.7% SC 18 g/ha (83.3 ml/ha), cyhalofop-butyl 10% EC 150 g/ha (1500 ml/ha) were at par with each other in controlling sedges in direct-seeded rice. Weedy check recorded significantly higher sedges density compared to other weed controlling treatments. These results were in conformity with the findings of Jabusch *et al.* (2005) and Jason *et al.* (2007).

Effect on weeds biomass

Post-emergence application of BAS 9548 H 2500 ml/ha, 3000 ml/ha and twice hand weeded check found to be significantly superior to the rest of the treatments in controlling the weeds and recorded least weeds biomass. Post-emergence application of bentazone 480 g/l SL 960 g/ha (2000 ml/ha), penoxsulam 21.7% SC 18 g/ha (83.3 ml/ha), cyhalofop-butyl 10% EC 150 g/ha (1500 ml/ha) were at par with each other in recording lower weeds biomass by controlling weeds in direct-seeded rice. Further, weedy check recorded significantly higher dry weight of weeds compared to other weed controlling treatments. These results were in conformity with the findings of Mishra *et al.* (2007) and Nandal *et al.* (1999).

Effect on weed control efficiency (WCE)

Post-emergence application of BAS 9548 H 3000 ml/ha recorded significantly higher weed control efficiency (92.4 and 92.2% in *Kharif* 2015 and summer 2016, respectively) and which was at par with the post-emergent application of 2500 ml/ha and twice hand weeded check (**Table 1)**. However, post-emergence application of bentazone 480 g/l SL 960 g/ha (2000 ml/ha), penoxsulam 21.7% SC 18 g/ ha (83.3 ml/ha), cyhalofop-butyl 10% EC 150 g/ha (1500 ml/ha) were at par with each other in recording weed control efficiency. These results were in conformity with the findings of Jabusch *et al.* (2005) and Jason *et al.* (2007).

Effect on yield and economics

During both the seasons studies, twice hand weeding at 15 and 30 days after sowing recorded significantly higher rice grain yield (6.05 and 5.80 t/ha in *Kharif* 2015 and summer 2016, respectively) and which was at par with post-emergent application of BAS 9548 H 2500 ml/ha (5.37 and 5.17 t/ha in *Kharif* 2015 and summer 2016, respectively) and application of BAS 9548 2500 ml/ha (5.62 and 5.42 t/ha in *Kharif* 2015 and summer 2016, respectively). Post-emergence application of bentazone 480 g/l SL 960 g/ ha (2000 ml/ha), penoxsulam 21.7% SC 18 g/ha (83.3 ml/ha), cyhalofop-butyl 10% EC 150 g/ha (1500 ml/ha) were at par with each other in recording grain and straw yield. Maximum B:C ratio was also observed in plots treated with BAS 9548 H along with twice hand weeded check (**Table 2**). Efficacy of penoxsulam in controlling weeds and increasing rice grain yield was also reported by Yadhav *et al.* (2008).

Table 1. Effect of weed control treatments on weed density (no./m^2), total weed biomass and weed control efficiency in direct-seeded rice at 60 days after sowing (1st season- *Kharif* 2015 and 2nd season- summer 2016)

Treatment		Grasses				Broad-leaf weeds				Sedges	Total weed dry weight (g/m^2)	Weed control efficiency (%)
	Echino-chloa sp.	*Panicum repens*	*Cynodon doctylon*	*Leptochloa chinensis*	*Brachiaria mutica*	*Digitaria sanguinalis*	*Eclipta alba*	*Ludwigia parviflora*	*Commelina communis*	*Cyperus* sp.		
1st season- Kharif 2015												
BAS 9548 H 840 g/ha (2270 ml/ha)	1.40 (0.96)	1.40 (0.96)	1.49 (1.21)	1.47 (1.15)	1.49 (1.21)	1.49 (1.21)	1.47 (1.16)	1.49 (1.21)	1.46 (1.12)	1.46 (1.13)	4.03 (15.3)	89.8
BAS 9548 H 925 g/ha (2500 ml/ha)	1.36 (0.86)	1.36 (0.86)	1.41 (0.98)	1.41 (0.98)	1.41 (0.98)	1.41 (0.98)	1.41 (0.98)	1.41 (0.98)	1.40 (0.95)	1.40 (0.95)	3.80 (13.5)	91.0
BAS 9548 H 1110 g/ha (3000 ml/ha)	1.35 (0.82)	1.31 (0.71)	1.40 (0.95)	1.31 (0.71)	1.31 (0.71)	1.39 (0.92)	1.39 (0.92)	1.36 (0.85)	1.36 (0.86)	1.36 (0.86)	3. 50 (11.3)	92.4
Bentazone 480 g/l SL 960 g/ha (2000 ml/ha)	1.65 (1.72)	1.60 (1.56)	1.66 (1.74)	1.66 (1.74)	1.66 (1.74)	1.66 (1.74)	1.93 (2.74)	1.90 (2.61)	1.91 (2.65)	1.67 (1.78)	6.40 (40.0)	73.3
Penoxsulam 21.7% SC 18 g/ha (83.3 ml/ha)	1.53 (1.35)	1.51 (1.28)	1.50 (1.25)	1.50 (1.26)	1.50 (1.26)	1.52 (1.32)	1.52 (1.31)	1.82 (2.31)	1.81 (2.28)	1.52 (1.32)	5.99 (34.9)	76.7
Cyhalofop butyl 10% EC 150 g/ha (1500 ml/ha)	1.59 (1.52)	1.55 (1.39)	1.54 (1.36)	1.54 (1.37)	1.54 (1.37)	1.54 (1.37)	1.83 (2.35)	1.84 (2.38)	1.83 (2.35)	1.57 (1.45)	6.15 (36.9)	75.4
Hand weeding	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	100
Weedy check	3.20 (9.21)	3.20 (9.25)	3.52 (11.4)	3.50 (11.2)	3.52 (11.4)	3.62 (12.1)	3.67 (12.5)	3.33 (10.1)	3.35 (10.2)	3.75 (13.1)	12.2 (150)	-
LSD (P=0.05)	0.31	0.32	0.33	0.31	0.28	0.31	0.28	0.29	0.31	0.31	3.05	10.5
2nd season- summer 2016												
BAS 9548 H 840 g/ha (2270 ml/ha)	1.40 (0.98)	1.40 (0.96)	1.49 (1.24)	1.46 (1.15)	1.49 (1.23)	1.48 (1.21)	1.46 (1.15)	1.48 (1.21)	1.46 (1.15)	1.45 (1.13)	4.09 (15.8)	89.6
BAS 9548 H 925 g/ha (2500 ml/ha)	1.35 (0.84)	1.36 (0.86)	1.41 (0.98)	1.41 (0.98)	1.41 (0.98)	1.41 (0.98)	1.41 (0.98)	1.41 (0.98)	1.40 (0.95)	1.40 (0.95)	3.80 (12.5)	91.7
BAS 9548 H 1110 g/ha (3000 ml/ha)	1.36 (0.87)	1.31 (0.71)	1.40 (0.95)	1.31 (0.71)	1.31 (0.71)	1.39 (0.92)	1.39 (0.92)	1.36 (0.85)	1.36 (0.86)	1.36 (0.86)	3. 50 (11.8)	92.2
Bentazone 480 g/l SL 960 g/ha (2000 ml/ha)	1.64 (1.72)	1.60 (1.56)	1.66 (1.74)	1.66 (1.74)	1.66 (1.74)	1.66 (1.74)	1.93 (2.74)	1.90 (2.61)	1.91 (2.65)	1.67 (1.78)	6.40 (40.2)	73.5
Penoxsulam 21.7% SC 18 g/ha (83.3 ml/ha)	1.51 (1.31)	1.51 (1.28)	1.50 (1.25)	1.50 (1.26)	1.50 (1.26)	1.52 (1.32)	1.52 (1.31)	1.82 (2.31)	1.81 (2.28)	1.52 (1.32)	5.99 (35.9)	76.3
Cyhalofop-butyl 10% EC 150 g/ha (1500 ml/ha)	1.58 (1.52)	1.55 (1.39)	1.54 (1.36)	1.54 (1.37)	1.54 (1.37)	1.54 (1.37)	1.83 (2.35)	1.84 (2.38)	1.83 (2.35)	1.57 (1.45)	6.15 (37.9)	75.0
Hand weeding	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	100
Weedy check	3.20 (9.25)	3.21 (9.35)	3.53 (11.5)	3.49 (11.2)	3.54 (11.6)	3.61 (12.1)	3.61 (12.1)	3.33 (10.1)	3.43 (10.8)	3.75 (13.1)	12.3 (152)	-
LSD (p=0.05)	0.35	0.32	0.33	0.31	0.28	0.31	0.28	0.29	0.31	0.31	3.05	10.8

Figures in the parentheses are square root transformed values $(\sqrt{x+1})$

Table 2. Effect of weed control treatments on yield and economics of direct seeded rice (1st season- *Kharif* 2015 and 2nd season- summer 2016)

Treatment	1st season- *Kharif* 2015					2nd season- summer 2016				
	Grain yield (t/ha)	Straw yield (t/ha)	Cost of cultivation (x10^3 `/ha)	Gross returns (x10^3 `/ha)	B:C ratio	Grain yield (t/ha)	Straw yield (t/ha)	Cost of cultivation (x10^3 `/ha)	Gross returns (x10^3 `/ha)	B:C ratio
BAS 9548 H 840 g/ha (2270 ml/ha)	5.08	5.24	31.75	106.94	3.36	4.96	5.14	31.75	104.44	3.28
BAS 9548 H 925 g/ha (2500 ml/ha)	5.37	5.84	32.50	113.25	3.48	5.17	5.54	32.50	108.94	3.35
BAS 9548 H 1110 g/ha (3000 ml/ha)	5.62	6.05	34.00	118.39	3.48	5.42	5.95	34.00	114.29	3.36
Bentazone 960 g/ha (2000 ml/ha)	4.41	4.85	33.25	93.05	2.80	4.21	4.75	33.25	88.95	2.68
Penoxsulam 18 g/ha (83.3 ml/ha)	4.80	5.16	33.00	101.26	3.07	4.50	5.06	33.00	95.16	2.88
Cyhalofop-butyl 150 g/ha (1500 ml/ha)	4.74	5.12	33.25	99.89	3.00	4.44	4.92	33.25	93.68	2.82
Hand weeding	6.05	6.56	38.00	127.55	3.36	5.80	6.16	38.00	122.24	3.22
Weedy check	3.46	3.72	31.00	72.85	2.35	3.15	3.42	31.00	66.46	2.14
LSD (p=0.05)	0.68	1.11	6.17	19.50	0.15	0.67	1.01	6.17	17.62	0.13

Materials	Urea	DAP	MOP	Bentazone	Combi product	Clincher	Penoxsulam	Grain	Straw
Prices (`/kg/litre)	5.0	20.0	15.0	1500	1500	1500	1500	20.0	1.0

Table 3. Phytotoxicity of herbicides applied in rice on the germination and growth of succeeding blackgram crop (mean data)

Treatment	Phytotoxic effect (%)			Germi-nation per cent
	7 DAG	15 DAG	21 DAG	
BAS 9548 H 840 g/ha (2270 ml/ha)	0.0	0.0	0.0	94.5
BAS 9548 H 925 g/ha (2500 ml/ha)	0.0	0.0	0.0	93.3
BAS 9548 H 1110 g/ha (3000 ml/ha)	0.0	0.0	0.0	93.1
Bentazone 960 g/ha (2000 ml/ha)	0.0	0.0	0.0	92.0
Penoxsulam 18 g/ha (83.3 ml/ha)	0.0	0.0	0.0	94.5
Cyhalofop-butyl 150 g/ha (1500 ml/ha)	0.0	0.0	0.0	93.5
Hand weeding	0.0	0.0	0.0	96.1

Effect on succeeding blackgram crop

Phytotoxicity effect (rating 0) was not noticed both on germination and growth of succeeding mungbean crop in all the plots (**Table 3**) during both the season.

BAS 9548 H (penoxsulam 10 g/l + bentazone 360 g/l SC) 2500 to 3000 ml/ha could be recommended for post-emergence application at 20-25 DAS to achieve effective control of weeds and toget higher grain yield in irrigated dry-seeded rice.

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Effect of different levels of irrigation and integrated weed management practices on weeds and yield of aerobic rice

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ABSTRACT

The experiment was conducted on irrigation levels and integrated weed management practices during 2013 and 2014 at College of Agriculture, Hyderabad. Results revealed that higher grain yield was recorded with scheduling of irrigations at IW/CPE ratio of 2.0 (2.55 and 2.42 t/ha) due to accumulation of higher chlorophyll content and dry matter production of crop. Net returns (` 20656 and 18347/ha) and benefit cost ratio (1.7 and 1.6) was also higher with the same irrigation level. Scheduling of irrigations at IW/CPE ratio of 1.5 was the next best treatment in aerobic rice. Out of weed management practices tested, application of pendimethalin/butachlor as pre-emergence *fb* chlorimuron-ethyl + metsulfuron-methyl post-emergence *fb* MW + HW at 45 DAS recorded lower weed population, weed dry matter and higher in weed control efficiency, which resulted higher chlorophyll and dry matter accumulation in crop and finally produced higher grain yield in pendimethalin 1.0 kg/ha as PE *fb* MSM + CME 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS (2.15 and 2.05 t/ha) and butachlor 1.0 kg/ha as PE *fb* MSM + CME 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS (2.08 and 1.98 t/ha). The same treatments recorded higher net returns and benefit cost ratio in pendimethalin 1.0 kg/ha as PE *fb* MSM + CME 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS (1.6 and 1.5) and butachlor 1.0 kg/ha as PE *fb* MSM + CME 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS (1.6 and 1.5). Over the pooled years, significant interaction effect of irrigation scheduling at IW/CPE ratio of 2.0 along with application of pendimethalin/butachlor as pre emergence *fb* chlorimuron-ethyl + metsulfuron-methyl as post-emergence *fb* MW + HW at 45 DAS recorded lower weed dry matter (35.1/36.4) and higher grain yield (2.85/2.80 t/ha).

Key words: Aerobic rice, Irrigation regimes, Weed management practices, Weed control efficiency, Weed index, Yield

India is the second largest producer of rice (103.5 mt) after China (145.7 mt) (USDA, 2015). In Telangana, rice is cultivated in 13.67 lakh ha with production of 43.2 lakh tones and productivity of 3.16 kg/ha (Department of Agriculture 2015). Rice consumes fresh water about 90% and it requires 3,000-5,000 litres of water to produce 1.0 kg of grain (IRRI 2001). High water requirement encourages in shifting from traditional transplanting to aerobic rice cultivation.

Unpuddled and aerated tillage is highly vulnerable to weeds which emerge early than the crop when adequate moisture and nutrients available by frequent irrigations scheduled, hence the later stage of crop growth was slow down and finally decreased the yields by 50-91%. Manual, mechanical and chemical control measures were effective against weeds but shortage of labour during peak period and escalating of labour wages are making delayed and expensive weed control practices. So, the integration of herbicides like application as pre- and post-emergence and also including of mechanical and manual weeding practices results in timely weed control and more productive (Hussain *et al.* 2008). Therefore, experiment was done to see the effect of irrigation levels and integrated weed management practices on weed and crop growth and yield of aerobic rice.

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MATERIALS AND METHODS

The field experiment was conducted during *Kharif*, 2013 and 2014 at College of Agriculture, Rajendranagar (latitude 17.2, longitude 78.4), Hyderabad, India. The soil was clay loam, neutral in reaction, low soil organic carbon (0.45%), low in available N 150.5 kg/ha, P_2O_5 18.7 kg/ha and medium in K_2O 227.2 kg/ha, respectively. The Moisture retention at field capacity (-0.03 M Pa) and at permanent wilting point (-1.5 M Pa) was estimated by using pressure membrane apparatus. At the soil depth of 45 to 60 cm, the bulk density was 1.39 g/cc (Dastane 1972). The total available soil moisture amounted to 124.1 mm. Irrigation water was neutral in pH 7.89 and safe to use.

During the crop growth period, weekly mean maximum temperature was 26.3 °C to 31.8 °C and 27.2 °C to 36.2 °C; mean minimum temperatures were 11.4 °C to 22.2 °C and 22.1 °C to 24.9 °C during 2013 and 2014, respectively. The pan evaporation was 403.1 mm in 2013 and 423 mm in 2014. The total rainfall was 468 mm in 24 rainy days in 2013 and 358.2 mm in 23 rainy days in 2014. The experiment was replicated thrice with 24 treatment combinations comprising four irrigation levels (IW/CPE ratios of 0.5, 1.0, 1.5 and 2.0) and six weed management practices *i.e.*, pendimethalin 1.0 kg/ha as pre-emergence (PE) followed by (*fb*) fenoxaprop-p-ethyl 60 g/ha at 15 DAS *fb* mechanical weeding (MW) *fb* hand weeding (HW) at 45 DAS, pendimethalin 1.0 kg/ha as PE *fb* metsulfuron-methyl (MSM) + chlorimuron-ethyl (CME) 4.0 g/ha at 25 DAS *fb* MW *fb* HW at 45 DAS, butachlor 1.0 kg/ha as PE *fb* fenoxaprop-p-ethyl 60 g/ha at 15 DAS *fb* MW *fb* HW at 45 DAS, butachlor 1.0 kg/ha as PE *fb* metsulfuron-methyl + chlorimuron-ethyl 4.0 g/ha at 25 DAS *fb* MW *fb* HW at 45 DAS, weed free check (HW at 25 DAS and MW *fb* HW at 45 DAS) and unweeded control as sub-plots in split plot design.

Rice '*JGL-17004*' was sown in 25 cm x solid rows spacing using seed rate 40 kg/ha and fertilized with 140 N, 60 P_2O_5 and 50 K_2O kg/ha. Nitrogen was applied in four equal splits at basal, tillering, panicle initiation and heading stages. The entire dose of phosphorus, 2/3[rd] of potassium at basal and 1/3[rd] potassium applied at panicle initiation stage. Later, foliar spray of 2% $FeSO_4$ was given at tillering and panicle initiation stages as the crop showed iron deficiency symptom. For every irrigation, 40 mm depth of irrigation water (IW) was given when the cumulative pan evaporation (CPE) readings reached the level of 80, 40, 26.6 and 20 mm in order to get IW/CPE ratio of 0.5, 1.0, 1.5 and 2.0, respectively. Soil samples were drawn before irrigation and moisture content was estimated gravimetrically. Volume of water measured through water meter. Observations on weed growth, crop growth and yield were recorded and presented.

RESULTS AND DISCUSSION

Effect on weeds

In aerobic rice at 40 DAS and harvest during two years of study (**Table 1**), high frequency of irrigations at IW/CPE ratio of 2.0 recorded higher weed density (7.4 and 8.1) and (4.7 and 5.6) followed by IW/CPE ratio of 1.5 (7.2 and 7.9) and (4.4 and 5.3) during 2013 and 2014, respectively. Early emergence of weeds due to higher availability of moisture and nutrients might be reason for higher weed population (Banerjee *et al.* 2008).

Integrated weed management practices, recorded lower density of weeds in weed free check (3.9 and 4.3 in 2013) and (2.9 4.0 no./m^2 in 2014) followed by pendimethalin/butachlor 1.0 kg/ha *fb* metsulfuron-methyl + chlorimuron-ethyl 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS in pendimethalin 1.0 kg/ha as PE *fb* MSM + CME 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS (5.2 and 4.1no./m^2 in 2013)

Table 1. Influence of irrigation levels and integrated weed management practices on weed population, weed dry matter at 40 DAS and harvest in aerobic rice

Treatment	Weed population (no./m^2)				Weed dry matter (g/m^2)			
	45 DAS		At harvest		45 DAS		At harvest	
	2013	2014	2013	2014	2013	2014	2013	2014
Irrigation levels (IW/CPE ratios)								
IW/CPE =0.5	6.3 (44.9)	6.9 (52.7)	3.8 (24.0)	4.9 (32.8)	53.8	60.5	34.4	33.7
IW/CPE =1.0	6.5 (47.5)	7.2 (56.4)	4.1 (25.4)	5.0 (34.2)	57.2	63.7	37.7	37.0
IW/CPE =1.5	7.2 (57.6)	7.9 (66.4)	4.4 (28.8)	5.3 (37.7)	67.3	74.1	41.3	39.5
IW/CPE =2.0	7.4 (60.5)	8.1 (69.8)	4.7 (31.0)	5.6 (39.9)	71.5	78.5	43.7	41.5
LSD (p=0.05)	0.1	0.2	0.2	0.2	1.8	2.0	1.3	NS
Integrated weed management								
T_1- Pendimethalin 1.0 kg/ha as PE *fb* fenoxaprop-p-ethyl 60 g/ha at 15 DAS + MW *fb* HW at 45 DAS	7.5 (56.3)	7.9 (64.1)	3.0 (8.5)	3.9 (14.7)	71.3	75.2	7.2	11.1
T_2- Pendimethalin 1.0 kg/ha as PE *fb* MSM + CME 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS	5.2 (26.6)	4.1 (36.3)	2.7 (7.1)	3.7 (13.2)	26.9	32.0	6.1	9.4
T_3- Butachlor 1.0 kg/ha as PE *fb* fenoxaprop-p-ethyl 60 g/ha at 15 DAS + MW *fb* HW at 45 DAS	7.7 (58.7)	8.0 (66.0)	3.1 (9.1)	3.8 (14.4)	73.8	78.2	8.4	11.7
T_4- Butachlor 1.0 kg/ha as PE *fb* MSM + CME 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS	5.4 (28.8)	4.3 (39.3)	2.8 (7.4)	3.9 (14.8)	27.7	33.8	6.8	10.0
T5- Weed free check (HW at 25 DAS and MW *fb* HW at 45 DAS	3.9 (15.4)	4.3 (22.2)	2.9 (8.3)	4.0 (15.3)	11.8	18.9	6.7	9.8
T_6- Weedy check (unweeded control)	11.4 (130)	11.1 (140)	11.1 (123)	12.0 (144)	163.2	177.2	200.4	175.7
LSD (p=0.05)	0.2	0.2	0.3	0.3	2.3	4.5	4.3	4.7

Original data in parentheses was subjected to squar root transformation

Table 2. Interaction effect of irrigation levels and integrated weed management practices on weed dry matter (g/m^2) in aerobic rice at 40 DAS (pooled)

Treatment	T_1	T_2	T_3	T_4	T_5	T_6	Mean
IW/CPE =0.5	59.2	24.3	62.1	25.2	13.3	158.6	57.1
IW/CPE =1.0	64.3	26.2	66.8	27.2	14.0	164.3	60.5
IW/CPE =1.5	80.9	32.2	84.0	34.0	16.6	176.6	70.7
IW/CPE =2.0	88.6	35.1	91.0	36.4	17.4	181.3	75.0
Mean	73.2	29.5	76.0	30.7	15.4	170.2	
Interaction		I x T	T x I				
LSD (p=0.05)		6.4	6.2				

and (2.7 and 3.7 no./m^2 in 2014) and butachlor 1.0 kg/ha as PE *fb* MSM + CME 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS (5.4 and 4.3no./m^2 in 2013) and (2.8 and 3.9no./m^2 in 2014), which were at par with each other (Sunil *et al.* 2010 and Jayadeva *et al.* 2011).

Higher weed dry matter production (**Table 1**) recorded in irrigation scheduled at IW/CPE ratio of 2.0 (71.5 and 78.5 g/m^2 in 2013) and (43.7 and 41.5 g/m^2 in 2014) followed by IW/CPE ratio of 1.5 (67.3 and 74.1) and (41.3 and 39.5) at 40 DAS and harvest, but it was not significant at harvest in 2014. Application of metsulfuron-methyl + chlorimuron-ethyl 4.0 g/ha applied at 25 DAS recorded the lower weed dry matter production in pendimethalin 1.0 kg/ha as PE *fb* MSM + CME 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS (26.9 and 32.0 g/m^2 in 2013) and (6.1 and 9.4 g/m^2 in 2014) and butachlor 1.0 kg/ha as PE *fb* MSM + CME 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS (27.7 and 33.8) and (6.8 and 10.0) and they were followed with weed free check (11.8 and 18.9) and (6.7 and 9.8) at 45 DAS and harvest during both the years (Narolia *et al.* 2014).

There was significant interaction effect (**Table 2**) of on drymatter production of weeds pooled over both the years. It was higher with irrigation regime at IW/CPE ratio of 2.0 along with application of pendimethalin/butachlor 1.0 kg/ha as PE *fb* metsulfuron-methyl + chlorimuron-ethyl 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS in IW/CPE =2.0 pendimethalin 1.0 kg/ha as PE *fb* MSM + CME 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS (35.1 g/m^2) and IW/CPE =2.0 butachlor 1.0 kg/ha as PE *fb* MSM + CME 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS (36.4 g/m^2) and which followed by same weed treatments within the IW/CPE ratio of 1.5 as IW/CPE =1.5 pendimethalin 1.0 kg/ha as PE *fb* MSM + CME 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS (32.2 g/m^2) and IW/CPE =1.5 butachlor 1.0 kg/ha as PE *fb* MSM + CME 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS (34.0 g/m^2). This might be due to effective control of sedges and broad-leaved weeds (BLW).

Significantly lower weed control efficiency (**Table 3**) was recorded with irrigation scheduled at IW/CPE ratio of 2.0 at 40 DAS (59.0 and 58.3%) and harvest (79.3 and 77.7) during both the years except in 2014 when it was non-significant. This might be due to adequate availability of moisture, early emergence of weeds and accumulation of drymatter which caused lower weed control efficiency (Saha *et al.* 2005). Among the weed management practices, higher weed control efficiency was recorded with application of metsulfuron methyl + chlorimuron-ethyl 4.0 g/ha at 25 DAS in pendimethalin 1.0 kg/ha as PE *fb* MSM + CME 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS and butachlor 1.0 kg/ha as PE *fb* MSM + CME 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS (83.6 and 82.0%) and (83.2 and 81.0%) and at harvest (97.0 and 95.0%) and (96.7 and 94.6%) during both the years respectively. Application of fenoxaprop-p-ethyl 60 g/ha at 15 DAS was effective only on grasses and resulted in lower weed control efficiency (**Table 2**).

Table 3. Influence of irrigation levels and integrated weed management practices on weed control efficiency (%) at 40 DAS and harvest and weed index (%) in aerobic rice

Treatment	Weed control efficiency (%)				Weed index (%)	
	45 DAS		At harvest			
	2013	2014	2013	2014	2013	2014
Irrigation levels (IW/CPE ratios)						
IW/CPE =0.5	64.5	63.4	81.4	79.0	28.4	27.5
IW/CPE =1.0	63.6	62.7	81.0	78.7	20.4	21.8
IW/CPE =1.5	60.3	59.6	80.1	78.2	18.8	19.7
IW/CPE =2.0	59.0	58.3	79.3	77.7	18.3	19.0
LSD (p=0.05)	1.1	1.2	0.8	NS	-	-
Integrated weed management						
Pendimethalin 1.0 kg/ha as PE *fb* fenoxaprop-p-ethyl 60 g/ha at 15 DAS + MW *fb* HW at 45 DAS	56.5	57.7	96.5	94.1	20.8	21.8
Pendimethalin 1.0 kg/ha as PE *fb* MSM + CME 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS	83.6	82.0	97.0	95.0	6.9	6.6
Butachlor 1.0 kg/ha as PE *fb* fenoxaprop-p-ethyl 60 g/ha at 15 DAS + MW *fb* HW at 45 DAS	55.1	56.0	95.9	93.7	23.8	24.7
Butachlor 1.0 kg/ha as PE *fb* MSM + CME 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS	83.2	81.0	96.7	94.6	9.7	9.7
Weed free check (HW at 25 DAS and MW *fb* HW at 45 DAS	92.8	89.2	96.7	94.7	0.0	0.0
Weedy check (unweeded control)	0.0	0.0	0.0	0.0	67.5	69.2
LSD (p=0.05)	1.1	1.5	0.6	0.9	-	-

Effect on crop

In aerobic rice (**Table 4**), irrigation regime at IW/CPE ratio of 2.0 recorded higher SPAD chlorophyll reading (SCMR) values at 40 DAS (35.11 and 34.72%) and harvest (32.93 and 32.44%) and it followed by IW/CPE ratio of 1.5 during both years, respectively. These findings were supported by Geethalakshmi *et al.* (2008). Control of broad spectrum weeds resulted higher SCMR values were with application of pendimethalin/butachlor as PE *fb* post-emergence application of metsulfuron-methyl + chlorimuron-ethyl *fb* MW + HW at 45 DAS. At harvest, SCMR value was recorded at par with all other treatments ranged from 31.23 to 32.04 except unweeded control recorded lower during both years (**Table 4**).

Dry matter production of crop (**Table 4**) at 40 DAS was higher with IW/CPE 2.0 (142.1 and 138.1 g/m^2) followed by IW/CPE ratio of 1.5 (133.9 and 129.8 g/m^2) whereas at harvest IW/CPE ratios of 2.0 (995.0 and 921.8 g/m^2) and 1.5 (924.6 and 832.0 g/m^2) both were at par each other during both the years. This was supported by Narolia *et al.* (2014). Over the weed management practices, weed free check (135.4 and 131.0 g/m^2) and application of pendimethalin 1.0 kg/ha as PE *fb* metsulfuron-methyl + chlorimuron-ethyl 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS (133.5 and 130.1 g/m^2) recorded at par higher drymatter production and it followed by butachlor 1.0 kg/ha as PE *fb* metsulfuron-methyl + chlorimuron-ethyl 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS (128.8 and 125.5). Weed free check (1044.8 and 920.1 g/m^2) recorded higher dry matter production followed by application of pendimethalin 1.0 kg/ha as PE *fb* metsulfuron-methyl + chlorimuron-ethyl 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS (1009.5 and 883.4 g/m^2) and butachlor 1.0 kg/ha as PE *fb* metsulfuron-methyl + chlorimuron-ethyl 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS (948.4 and 868.7 g/m^2) at harvest during 2013 and 2014, respectively. This might be caused by reduction in crop weed competition for resources at critical stage of the crop (Jadhav *et al.* 2014).

Slightly higher grain yield was recorded (**Table 5**) in 2013 and 2014 with irrigations given at IW/CPE ratio of 2.0 (2.55 and 2.42 t/ha) followed by 1.5 (2.16 and 2.04 t/ha) over other irrigation levels. This might be due to increased number of irrigations which favoured in more availability of resources and efficient translocation of photosynthates from source to sink in turn recorded better crop growth and yields (Pandey *et al.* 2010). Higher grain yields recorded with weed free check (2.29 and 2.19 t/ha) followed by application of pendimethalin/butachlor 1.0 kg/ha as PE *fb* metsulfuron-methyl + chlorimuron-ethyl 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS in pendimethalin 1.0 kg/ha as PE *fb* MSM + CME 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS (2.15 and 2.05 t/ha) and butachlor 1.0 kg/ha as PE *fb* MSM + CME 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS (2.08 and 1.98 t/ha) both were statistically at par with each other. Similar findings were made by Singh *et al.* (2008) and Walia *et al.* (2012). Comparatively lower yields were recorded with fenoxaprop-p-ethyl 60 g/

Table 4. Influence of irrigation levels and integrated weed management practices on SPAD chlorophyll content and dry matter production of crop (g/m^2) at 40 DAS and harvest in aerobic rice

Treatment	SPAD chlorophyll content				Dry matter production of crop (g/m^2)			
	45 DAS		At harvest		45 DAS		At harvest	
	2013	2014	2013	2014	2013	2014	2013	2014
Irrigation levels (IW/CPE ratios)								
IW/CPE =0.5	31.23	30.57	30.80	30.04	108.3	104.3	641.2	588.6
IW/CPE =1.0	32.95	32.27	31.52	30.76	111.0	107.0	763.4	689.8
IW/CPE =1.5	34.28	33.77	31.89	31.29	133.9	129.8	924.6	832.0
IW/CPE =2.0	35.11	34.72	32.93	32.44	142.1	138.1	995.0	921.8
LSD (p=0.05)	0.50	0.04	0.49	0.11	7.0	8.0	172.3	94.1
Integrated weed management								
Pendimethalin 1.0 kg/ha as PE *fb* fenoxaprop-p-ethyl 60 g/ha at 15 DAS + MW *fb* HW at 45 DAS	33.66	32.49	32.02	30.80	121.9	116.9	880.5	806.2
Pendimethalin 1.0 kg/ha as PE *fb* MSM + CME 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS	34.13	33.61	32.03	31.41	133.5	130.1	1009.5	883.4
Butachlor 1.0 kg/ha as PE *fb* fenoxaprop-p-ethyl 60 g/ha at 15 DAS + MW *fb* HW at 45 DAS	33.64	32.56	32.01	31.23	121.7	116.7	855.4	810.1
Butachlor 1.0 kg/ha as PE *fb* MSM + CME 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS	34.02	33.74	31.71	31.35	128.8	125.5	948.4	868.7
Weed free check (HW at 25 DAS and MW *fb* HW at 45 DAS	33.56	32.99	32.04	31.45	135.4	131.0	1044.8	920.1
Weedy check (unweeded control)	31.75	31.20	30.83	30.22	101.7	98.4	247.9	260.0
LSD (p=0.05)	0.33	0.66	0.34	0.66	3.4	3.8	33.4	27.4

Table 5. Influence of irrigation levels and integrated weed management practices on grain and straw yield and harvest index (%) in aerobic rice

Treatment	Grain yield (t/ha)		Straw yield (t/ha)		Harvest index (%)	
	2013	2014	2013	2014	2013	2014
Irrigation levels (IW/CPE ratios)						
IW/CPE =0.5	1.05	1.03	2.53	2.40	28.3	29.2
IW/CPE =1.0	1.52	1.40	2.84	2.70	34.6	33.5
IW/CPE =1.5	2.16	2.04	3.89	3.74	35.5	35.0
IW/CPE =2.0	2.55	2.42	4.60	4.41	35.9	35.7
LSD (p=0.05)	0.22	0.24	0.33	0.28	1.4	2.3
Integrated weed management						
Pendimethalin 1.0 kg/ha as PE *fb* fenoxaprop-p-ethyl 60 g/ha at 15 DAS + MW *fb* HW at 45 DAS	1.85	1.74	3.29	3.15	35.4	34.7
Pendimethalin 1.0 kg/ha as PE *fb* MSM + CME 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS	2.15	2.05	4.24	4.00	33.1	33.7
Butachlor 1.0 kg/ha as PE *fb* fenoxaprop-p-ethyl 60 g/ha at 15 DAS + MW *fb* HW at 45 DAS	1.77	1.67	3.17	3.01	35.1	35.2
Butachlor 1.0 kg/ha as PE *fb* MSM + CME 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS	2.08	1.98	3.92	3.83	34.4	33.9
Weed free check (HW at 25 DAS and MW *fb* HW at 45 DAS	2.29	2.19	4.44	4.32	33.7	33.3
Weedy check (unweeded control)	0.79	0.71	1.71	1.59	29.8	29.4
LSD (p=0.05)	0.09	0.10	0.13	0.15	1.1	1.4

ha applied treatments. This might be due to fenoxaprop-p-ethyl controlled only grassy weeds (Kumar *et al.* 2010**)**.

The interaction effect was significant when irrigation applied at IW/CPE ratio of 2.0 along with it weed free check (3.06 t/ha) and followed by application of pendimethalin/butachlor 1.0 kg/ha applied as PE *fb* metsulfuron-methyl + chlorimuron-ethyl 4.0 g/ha at 25 DAS (**Table 6**).

Higher straw yield (**Table 5**) was recorded with irrigations given at IW/CPE ratio of 2.0 (4.60 and 4.41 t/ha) followed by 1.5 (3.89 and 3.74 t/ha). Weed free check (4.44 and 4.32 t/ha) resulted higher straw yield and followed by pendimethalin/butachlor 1.0 kg/ha applied as PE *fb* metsulfuron methyl + chlorimuron-ethyl 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS in pendimethalin 1.0 kg/ha as PE *fb* MSM + CME 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS (4.24 and 4.0 t/ha) and butachlor 1.0 kg/ha as PE *fb* MSM + CME 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS (3.92 and 3.83 t/ha) during two years. Similar results were obtained by Prameela *et al.* (2014). Harvest index (**Table 5**) was higher with IW/CPE ratio of 2.0 (35.9 and 35.7%) and 1.5 (35.5 and 35.0% in 2013 and 2014, respectively) both were at par with ach other.

Table 6. Interaction effect of irrigation levels and integrated weed management practices on grain yield (t/ha) of aerobic rice (pooled)

Treatment	T_1	T_2	T_3	T_4	T_5	T_6	Mean
I_1 (IW/CPE =0.5)	1.01	1.29	0.93	1.24	1.45	0.31	1.04
I_2 (IW/CPE =1.0)	1.45	1.75	1.44	1.67	1.86	0.60	1.46
I_3 (IW/CPE =1.5)	2.12	2.49	2.09	2.42	2.60	0.89	2.10
I_4 (IW/CPE =2.0)	2.60	2.85	2.42	2.80	3.06	1.19	2.49
Mean	1.79	2.10	1.72	2.03	2.24	0.75	
Interaction		I x T	T x I				
LSD (p=0.05)		0.18	0.28				

*I x T: IWM practices within the irrigation levels (at 5% level of significance); T x I: Irrigation levels across the IWM practices (at 5% level of significance)

Economics

During two years of study (**Table 7**), net returns of aerobic rice was higher with IW/CPE ratio of 2.0 (` 20656 and 18347) and was followed by 1.5 (` 15098 and 12908). Similar findings were observed with Murthy and Reddy (2013) and Narolia *et al.* (2014). Among the integrated weed management practices, higher net returns were observed with weed free check (` 19562 and 17726 in 2013 and 2014, respectively) and was followed by pre-emergence application of pendimethalin/butachlor 1.0 kg/ha *fb* (metsulfuron-methyl + chlorimuron ethyl) 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS as in pendimethalin 1.0 kg/ha as PE *fb* MSM + CME 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS (` 16683 and 14590) and butachlor 1.0 kg/ha as PE *fb* MSM + CME 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS (` 15270 and 13541 in 2013 and 2014, respectively) both these treatments were on par each other. Higher net returns might be attributed to higher grain and straw yield. Prameela *et al.* (2014) also found similar results. Heavy weed infestation resulted lower yields and in turn lower net returns by unweeded control in aerobic rice.

Significantly higher benefit cost ratio was noticed with IW/CPE ratio of 2.0 (1.7 and 1.6) and was at par with IW/CPE ratio of 1.5 (1.5 and 1.5). It may be due to higher yields and returns. These findings were in accordance with the results of Murthy and Reddy (2013) and Narolia *et al.* (2014). Wherein integrated weed management practices the benefit cost ratio was higher in weed free check (` 1.7 and 1.7) and was at par with application of pendimethalin/butachlor 1.0 kg/ha as PE *fb* (metsulfuron-methyl + chlorimuron-ethyl) 4.0 g/ha at

Table 7. Net returns and benefit cost ratio of aerobic rice as influenced by irrigation levels and integrated weed management practices

Treatment	Net returns (x10^3 `/ha)		Benefit cost ratio	
	2013	2014	2013	2014
Irrigation levels (IW/CPE ratios)				
IW/CPE =0.5	4.22	3.82	1.3	1.2
IW/CPE =1.0	8.68	6.33	1.5	1.3
IW/CPE =1.5	15.10	12.91	1.5	1.5
IW/CPE =2.0	20.66	18.35	1.7	1.6
LSD (p=0.05)	4.60	4.29	0.2	0.2
Integrated weed management				
Pendimethalin 1.0 kg/ha as PE *fb* fenoxaprop-p-ethyl 60 g/ha at 15 DAS + MW *fb* HW at 45 DAS	9.74	7.63	1.4	1.3
Pendimethalin 1.0 kg/ha as PE *fb* MSM + CME 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS	16.68	14.59	1.6	1.5
Butachlor 1.0 kg/ha as PE *fb* fenoxaprop-p-ethyl 60 g/ha at 15 DAS + MW *fb* HW at 45 DAS	8.66	7.08	1.3	1.2
Butachlor 1.0 kg/ha as PE *fb* MSM + CME 4.0 g/ha at 25 DAS + MW *fb* HW at 45 DAS	15.27	13.54	1.6	1.5
Weed free check (HW at 25 DAS and MW *fb* HW at 45 DAS	19.56	17.73	1.7	1.7
Weedy check (unweeded control)	3.07	1.54	1.3	1.2
LSD (p=0.05)	1.78	1.78	0.1	0.1

25 DAS + MW *fb* HW at 45 DAS. These findings were supported by Prameela *et al.* (2014) (**Table 7**).

The study revealed that successful growing of aerobic rice in Telangana with scheduling of irrigations at IW/CPE ratio of 2.0 and 1.5 and pendimethalin/butachlor 1.0 kg/ha applied as PE *fb* chlorimuron-ethyl + metsulfuron-methyl 4.0 g/ha applied as POE *fb* MW + HW at 45 DAS provided higher yields.

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Integrated weed management in direct-seeded upland rice under Tripura condition

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ABSTRACT

A field experiment was conducted at KVK, South Tripura during the *Kharif* season of 2013 and 2014 to study the integrated weed management in direct-seeded upland rice. The predominant weed flora in the experimental field were *Amaranthus viridis, Oldenlendia corymbosa, Spilanthes acmella, Ludwigia parviflora, Cleome rutidosperma, Malvestrum coromondalianeum* among the broad-leaf weeds, *Digitaria sanguinalis* among grasses and *Cyperus iria* among sedges. The results revealed that though the hand weeding thrice at 15, 30 and 45 DAS recorded lowest weed dry weight and the highest grain yield, it was not economically viable. The pre-emergence application of pendimethalin at 1.0 kg/ha at 2 DAS + bispyribac-sodium at 25 g/ha at 20 DAS recorded the highest net returns and return per rupee invested and appeared to be the most promising and remunerative weed management practices for direct-seeded rice under Tripura condition followed by pendimethalin at 1.0 kg/ha at 2 DAS + one hand weeding at 30 DAS.

Key words: Bispyribac-sodium, Integrated weed managment, Herbicide, Pendimethalin, Weed managment

Rice is the fundamental principal food crop for about half of the world's population supplying 20% of the calories consumed worldwide. India is the second largest rice producing country in the world. The method of direct-seeding escapes the transplanting and puddling operations, which is an attractive alternative to traditional transplanting of rice. A major impediment in the successful cultivation of direct-seeded rice (DSR) in tropical countries is heavy infestation of weeds, which often range from 50-91% (Paradkar *et al.* 1997). No single method like manual, mechanical, biological or chemical, could reach to the desired level of weed control because of the vast diversity of weeds in crop fields. Hence the present study was carried out to find effective integrated weed management practices to control the weeds in direct-seeded upland rice under Tripura condition.

MATERIALS AND METHODS

A field experiment was conducted at Krishi Vigyan Kendra, South Tripura during the *Kharif* (rainy) season of 2013 and 2014 to evaluate the effective integrated weed management practices for direct-seeded upland rice under Tripura conditions. Twelve treatments *viz.* pendimethalin at 1.0 kg/ha at 2 DAS, bispyribac-sodium at 25 g/ha at 25 DAS, pendimethalin at 1.0 kg/ha at 2 DAS + one hand weeding at 30 DAS, pendimethalin at 1.0 kg/ha at 2 DAS + bispyribac-sodium at 25 g/ha at 20 DAS, metsulfuron-methyl + chlorimuron-ethyl (Almix) at 4 g at 10 DAS followed by bispyribac-sodium at 25 g at 20 DAS, pyrazosulfuron-ethyl at 25 g/ ha at 3 DAS followed by bispyribac-sodium at 25 g at 20 DAS, fenoxaprop-p-ethyl at 60 g/ha + metsulfuron-methyl + chlorimuron-ethyl (Almix) at 4 g/ha at 15 DAS, stale seed bed + smother crop (cowpea) in between two rows of rice, stale seed bed + one hand weeding at 30 DAS, *Sesbania* (broadcast) 25 kg/ha during sowing of rice + 2,4-D at 500 g/ha at 25 DAS, hand weeding at 15, 30 and 45 DAS, weedy check were assigned in a randomized block design replicated thrice. Rice variety '*NDR-97*' was used for the experimental purpose with recommended package of practices. Five tonnes of farm yard manure per hectare were applied at the time of field preparation for the rice crop. Chemical fertilizers were applied to meet 60 kg nitrogen in the form of urea, 40 kg phosphorus in the form of single superphosphate and 40 kg potassium in the form of muriate of potash.

Weed counts at different stages (15, 30, 60 and at harvest stage) was taken by placing quadrat at random at three sites in each plot and calculating the average. Weed sample from any of the quadrat was taken, grouped into grasses, broad-leaved weed and sedges, dried and weighed. Weed dry matter was expressed category wise in g/m^2. Weed control

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efficiency was calculated during different stages, *viz.* 30, 60 and harvest stage. Yield and yield attributing characters were also studied. Economics was also calculated for each treatment separately. The data generated from the experiment were subject to analysis of variance (ANOVA) as applied to randomized block design describe by Cochran and Cox (1965).

RESULTS AND DISCUSSION

Effect on weeds

The upland direct-seeded rice of Tripura was infested by different grassy, broad-leaved weeds and sedges. *Amaranthus viridis, Oldenlendia corymbosa, Spilanthes acmella, Ludwigia parviflora, Cleome rutidosperma, Malvestrum coromondalianeum* among the broad-leaf weeds (37.89%); *Digitaria sanguinalis* among grasses (37.89%) and *Cyperus iria* among sedges (31.96%) were predominant in the experimental field. The effect of various weed management practices on dry weight of grasses, broad-leaved, sedges and all weeds showed highly significant differences at 60 DAS (**Table 1**). There was no remarkable changes in dry weight of grasses, broad-leaved, sedges and total weeds between the two years. It is evident from the data that in both the years weed dry weight of grassy (141.09 g/m^2 in 2013 and 136.27 g/m^2 in 2014), broad-leaved (67.67 g/m^2 in 2013 and 64.66 g/m^2 in 2014), sedges (42.81 g/m^2 in 2013 and 40.51 g/m^2 in 2014) and total weed (251.57 g/m^2 in 2013 and 241.44 g/m^2) was the highest in weedy check. Unchecked weed growth exploited the available nutrients and water resulting in better growth and dry matter production. Similar observations have been made by Singh *et al.* (2014) and Kashid *et al.* (2015). The lowest dry weight for grasses (24.89 g/m^2 in 2013 and 20.12 g/m^2 in 2014), broad-leaved (18.99 g/m^2 in 2013 and 15.63 g/m^2 in 2014), sedges (5.14 g/m^2 in 2013 and 2.84 g/m^2 in 2014) and total weed (49.02 g/m^{2}in 2013 and 38.59 g/m^2 in 2014) was recorded with hand weeding thrice at 15, 30 and 45 DAS, closely followed by pendimethalin + one hand weeding and pendimethalin + bispyribac-sodium. This is in conformity with the findings of Valverde *et al.* (2005), and Singh *et al.* (2005b).

Weed control efficiency

Weed control efficiency for grassy (82.4% in 2013 and 85.7% in 2014), broad-leaved weeds (71.9% in 2013 and 76.7% in 2014), sedges (88.0% in 2013 and 93.3% in 2014) and total weeds (80.5% in 2013 and 84.6% in 2014) was the highest with hand weeding thrice at 15, 30 and 45 DAS and this treatment was followed by pendimethalin + one hand weeding and pendimethalin + bispyribac sodium in case of grassy, broad-leaved weeds and total weeds for both the years (**Table 2**). This was in conformity with the report of Jhon *et al.* (2012). It was also evident that the weed control efficiency was improved when the chemical was integrated with one manual weeding, which implied that the persistence of the herbicide was short and for season long weed control, it has to be integrated with other control methods. This is in conformity with the report of Pannu *et al.* (1991).

Table 1. Dry weight (g/m^2) of grassy, broad-leaved, sedges and all weed at 60 days after sowing

Treatment	Grassy weed		Broad-leaved weed		Sedges		Total weed	
	2013	2014	2013	2014	2013	2014	2013	2014
Pendimethalin at 1.0 kg/ha at 2 DAS	76.91	72.02	39.49	36.45	29.17	26.15	145.57	134.61
Bispyribac -sodium at 25 g/ha at 25 DAS	95.69	91.08	43.90	40.72	9.09	8.49	148.67	140.28
Pendimethalin at 1.0 kg/ha at 2 DAS+ one hand weeding at 30 DAS	28.39	23.21	23.55	20.40	9.39	6.49	61.33	50.10
Pendimethalin at 1.0 kg/ha at 2 DAS + bispyribac -sodium at 25 g/ha at 20 DAS	29.85	23.84	26.01	20.50	9.58	7.48	65.44	51.82
Metsulfuron-methyl+ chlorimuron-ethyl (Almix) at 4 g at 10 DAS followed by bispyribac -sodium at 25 g at 20 DAS	88.81	84.29	43.33	40.55	8.89	7.71	141.03	132.55
Pyrazosulfuron-ethyl at 25 g/ha at 3 DAS followed by bispyribac - sodium at 25 g at 20 DAS	78.70	73.94	37.39	34.65	16.77	14.08	132.87	122.67
Fenoxaprop-p-ethyl at 60 g/ha + metsulfuron-methyl+ chlorimuron-ethyl (Almix) at 4 g/ha at 15 DAS	82.44	77.88	40.74	37.34	15.90	12.85	139.08	128.07
Stale seed bed + smother crop (cowpea) in between two rows of rice	117.16	111.51	40.44	36.94	30.40	27.72	188.00	176.17
Stale seed bed + one hand weeding at 30 DAS	92.95	88.03	41.89	38.38	23.76	21.19	158.60	147.60
Sesbania (broadcast) 25 kg/ha during sowing of rice + 2,4-D at 500 g/ha at 25 DAS	113.14	108.87	37.18	33.88	29.76	27.30	180.08	170.05
Hand weeding at 15, 30 and 45 DAS	24.89	20.12	18.99	15.63	5.14	2.84	49.02	38.59
Weedy check	141.09	136.27	67.67	64.66	42.81	40.51	251.57	241.44
LSD (p=0.05)	7.76	7.66	4.16	4.05	3.37	3.35	8.26	8.96

In case of sedges, metsulfuron-methyl+ chlorimuron-ethyl (Almix) at 4 g at 10 DAS followed by bispyribac -sodium at 25 g at 20 DAS recorded the highest weed control efficiency (79.2% in 2013 and 84.9% in 2014) of sedges, better than pendimethalin treated plot (78.1% and 81.7% in 2013 and 2014 respectively) and after the hand weeding thrice at 15, 30 and 45 DAS (88.0% in 2013 and 93.3% in 2014) for both the years. The practical implication of the above response is that, though pendimethalin is a safe and effective herbicide for the rice, it is not recommendable in areas where sedge predominates or the herbicide must be integrated with any other herbicide which can control sedges. This was in conformity with the findings of Yaduraju and Mishra (2004) who reported that pre-emergence application of pendimethalin controlled only grasses, few broad-leaved weeds but not the sedges.

Effect on yield parameters and yield

It was clear from the data presented in **Table 3** that different weed management practices did have a positive role in determining the yield and other yield attributing characters of upland rice. Among different treatments, hand weeding thrice at 15, 30 and 45 DAS recorded highest number of panicles/m^2 (339.4 in 2013 and 322.2 in 2014), number of grains/panicle (67.67 in 2013 and 71.28 in 2014), grain yield/ha

Table 2. Effect of treatments on weed control efficiency (%) at 60 DAS

Treatment	Grassy weed		Broad-leaved weed		Sedges		Total weed	
	2013	2014	2013	2014	2013	2014	2013	2014
Pendimethalin at 1.0 kg/ha at 2 DAS	45.49	48.66	41.65	45.73	31.85	38.5	42.14	46.14
Bispyribac -sodium at 25 g/ha at 25 DAS	32.18	35.07	35.13	39.37	78.77	80.0	40.90	43.87
Pendimethalin at 1.0 kg/ha at 2 DAS+ one hand weeding at 30 DAS	79.88	83.45	65.20	69.62	78.07	81.7	75.62	79.95
Pendimethalin at 1.0 kg/ha at 2 DAS + bispyribac -sodium at 25 g/ha at 20 DAS	78.84	83.00	61.56	69.48	77.63	82.4	73.99	79.27
Metsulfuron-methyl+ chlorimuron-ethyl (Almix) at 4 g at 10 DAS followed by bispyribac -sodium at 25 g at 20 DAS	37.05	39.91	35.97	39.62	79.24	84.9	43.94	46.97
Pyrazosulfuron-ethyl at 25 g/ha at 3 DAS followed by bispyribac -sodium at 25 g at 20 DAS	44.22	47.29	44.74	48.40	60.82	66.9	47.18	50.92
Fenoxaprop-p-ethyl at 60 g/ha + metsulfuron-methyl+ chlorimuron-ethyl (Almix) at 4 g/ha at 15 DAS	41.57	44.48	39.80	44.40	62.85	69.8	44.71	48.76
Stale seed bed + smother crop (cowpea) in between two rows of rice	16.96	20.50	40.23	45.00	28.99	34.8	25.27	29.51
Stale seed bed + one hand weeding at 30 DAS	34.12	37.24	38.10	42.86	44.49	50.1	36.95	40.94
Sesbania (broadcast) 25 kg/ha during sowing of rice + 2,4-D at 500 g/ha at 25 DAS	19.81	22.39	45.05	49.55	30.49	35.8	28.42	31.96
Hand weeding at 15, 30 and 45 DAS	82.36	85.66	71.94	76.72	88.00	93.3	80.52	84.56
Weedy check	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 3. Yield attributing characters and yield of upland rice as effected by different weed management practices

Treatment	No. of panicles/m^2		No. of filled grains/panicle		Grain yield (t/ha)		Harvest index (%)	
	2013	2014	2013	2014	2013	2014	2013	2014
Pendimethalin at 1.0 kg/ha at 2 DAS	240.54	198.16	52.95	50.66	2.15	2.36	35.60	35.82
Bispyribac -sodium at 25 g/ha at 25 DAS	232.90	235.13	44.03	54.68	2.21	2.26	37.69	34.77
Pendimethalin at 1.0 kg/ha at 2 DAS+ one hand weeding at 30 DAS	324.17	335.10	65.23	69.66	3.30	3.59	39.62	39.82
Pendimethalin at 1.0 kg/ha at 2 DAS + bispyribac-sodium at 25 g/ha at 20 DAS	317.24	336.27	66.67	68.01	3.26	3.41	40.14	39.73
Metsulfuron-methyl+ chlorimuron-ethyl (Almix) at 4 g at 10 DAS followed by bispyribac -sodium at 25 g at 20 DAS	216.54	253.73	45.45	56.19	2.49	2.65	40.14	36.29
Pyrazosulfuron-ethyl at 25 g/ha at 3 DAS followed by bispyribac -sodium at 25 g at 20 DAS	249.42	291.24	60.35	61.14	2.71	2.80	40.15	36.68
Fenoxaprop-p-ethyl at 60 g/ha + metsulfuron-methyl+ chlorimuron-ethyl (Almix) at 4 g/ha at 15 DAS	182.93	168.85	49.15	51.81	1.89	1.98	32.97	33.18
Stale seed bed + smother crop (cowpea) in between two rows of rice	188.75	173.30	52.18	52.82	1.86	2.01	32.92	33.27
Stale seed bed + one hand weeding at 30 DAS	228.11	259.80	57.31	54.80	1.86	2.10	33.42	35.10
Sesbania (broadcast) 25 kg/ha during sowing of rice + 2,4-D at 500 g/ha at 25 DAS	198.00	218.61	53.07	53.81	1.81	1.93	32.79	34.13
Hand weeding at 15, 30 and 45 DAS	339.36	322.18	67.67	71.28	3.45	3.60	40.33	40.57
Weedy check	119.55	101.86	32.65	33.18	0.58	0.74	16.85	20.76
LSD (p=0.05)	61.76	45.51	10.03	7.97	0.34	0.37	3.88	2.35

(3.45 t/ha in 2013 and 3.60 45 t/ha in 2014) and harvest index (40.33 in 2013 and 40.57 in 2014) during both the years. This treatment was at par with pendimethalin + one hand weeding and pendimethalin + bispyribac-sodium.

The efficacy of pendimethalin in combination with hand weeding was reported effective in controlling weed in dry direct seeded rice by Ramamoorthy *et al*. (1998) . Effective and timely weed management under these treatments reduced the density as well as dry weight of weeds which facilitated the crop to have sufficient space, light, nutrient and moisture and thus the number of panicles/m^2, number of grains/panicle and finally the grain yield/ha and harvest index was increased.

Economics

Among the various treatment, highest cost of cultivation was recorded with treatment hand weeding thrice at 15, 30, 45 DAS followed by pendimethalin + one hand weeding (**Table 4**). The highest net return and return per rupee invested was recorded with pendimethalin + bispyribac-sodium. Though the treatment hand weeding thrice at 15, 30, 45 DAS recorded highest gross return but the high cost involvement showed that the treatment was uneconomic.

The results revealed that the remuneration from the rice crop was highly dependent on weed management practices adopted. Pendimethalin at 1.0 kg/ha at 2 DAS + bispyribac-sodium at 25 g/ha at 20 DAS recorded the highest net return (` 23847/- in the first year and ` 26010/- in the second year) and return per rupee invested (2.02 and 2.11) in both the years and was found to be the most remunerative weed management practices (**Table 4**). The herbicide pendimethalin at 1.0 kg/ha + one hand weeding at 30 DAS registered net return of ` 21427/- and 25573/- in the first year and second year respectively and was the next best treatment. This is simply due to higher grain and straw yield of the crop obtained from these treatments and comparatively lower cost involved in the cultivation of crop under these treatments. Similar result was reported by Yakadri *et al.* (2016). Though the rice yield and gross return were the highest under hand weeding at 15, 30 and 45 DAS, the data on net income and return per rupee invested showed that it was less remunerative than pendimethalin at 1.0 kg/ha at 2 DAS + bispyribac-sodium at 25 g/ha at 20 DAS and pendimethalin at 1.0 kg/ha + one manual weeding at 30 DAS, which implied that it was uneconomic and unnecessary to give three hand weeding during the entire crop growth.

The net income was found negative under weedy check due to greater competition between rice and weed which led to poor growth of the crop, lower grain and straw yield. This again emphasized the importance of weed management in profitable rice production. This is in conformity with the study conducted by Prashanth *et al.* (2016) who reported that the lowest net returns and B:C ratio was obtained in unweeded check in transplanted rice. Kashid *et al.*

Table 4. Economics of rice cultivation under different weed management practices

Treatment	Cost of cultivation (x10^3 `/ha)	Gross Returns x10^3 `/ha)		Net Returns (x10^3 `/ha)		Return/ Rupee invested	
		2013	2014	2013	2014	2013	2014
Pendimethalin at 1.0 kg/ha at 2 DAS	20.55	31.89	34.85	11.34	14.30	1.55	1.70
Bispyribac -sodium at 25 g/ha at 25 DAS	21.73	32.38	33.56	10.65	11.83	1.49	1.54
Pendimethalin at 1.0 kg/ha at 2 DAS+ one hand weeding at 30 DAS	26.55	47.98	52.12	21.43	25.57	1.81	1.96
Pendimethalin at 1.0 kg/ha at 2 DAS + bispyribac -sodium at 25 g/ha at 20 DAS	23.45	47.30	49.46	23.85	26.01	2.02	2.11
Metsulfuron-methyl+ chlorimuron-ethyl (Almix) at 4 g at 10 DAS followed by bispyribac -sodium at 25 g at 20 DAS	22.60	36.09	39.15	13.49	16.54	1.60	1.73
Pyrazosulfuron-ethyl at 25 g/ha at 3 DAS followed by bispyribac -sodium at 25 g at 20 DAS	22.68	39.32	41.17	16.64	18.49	1.73	1.82
Fenoxaprop-p-ethyl at 60 g/ha + metsulfuron-methyl+ chlorimuron-ethyl (Almix) at 4 g/ha at 15 DAS	20.48	28.39	29.67	7.91	9.19	1.39	1.45
Stale seed bed + smother crop (cowpea) in between two rows of rice	23.48	27.97	30.09	4.49	6.61	1.19	1.28
Stale seed bed + one hand weeding at 30 DAS	26.03	27.89	31.23	1.86	5.20	1.07	1.20
Sesbania (broadcast) 25 kg/ha during sowing of rice + 2,4-D at 500 g/ha at 25 DAS	19.79	27.28	28.87	7.49	9.08	1.38	1.46
Hand weeding at 15, 30 and 45 DAS	32.43	50.05	52.14	17.62	19.71	1.54	1.61
Weedy check	15.83	10.48	12.38	-5.35	-3.45	0.66	0.78
LSD (p=0.05)	-	4.72	5.23	4.72	5.23	0.22	0.23

(2015) reported that significantly the highest net return and return per rupee invested was obtained with the pre-emergence application of herbicide integrating with one hand weeding or one post emergence herbicide. Sharma *et al.* (2004) reported that pendimethalin + one hand weeding and pendimethalin + criss cross sowing + one hand weeding were better than the other treatments in terms of increasing grain, biomass yields and net returns.

Acceptability of any farming practices essentially depends upon its economic viability. The result of the present study revealed that the economics favoured the pre-emergence use of pendimethalin at 1.0 kg/ha at 2 DAS followed by bispyribac-sodium at 25 g/ha at 20 DAS in direct seeded upland rice. Hence the integration of pendimethalin and bispyribac-sodium is the best integrated weed management practices for direct seeded upland rice under Tripura condition.

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Productivity of transplanted rice as influenced by herbicide combinations

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ABSTRACT

A field experiment was conducted during *Kharif*, 2013 and 2014, Collage of Agriculture, Rajendranagar, Hyderabad in Telangana state. Fourteen weed management practices were evaluated in a randomized complete block design, replicated thrice. Significantly higher grain yield (6.9 t/ha) was obtained with either hand weeding twice at 25 and 45 DAT or pyrazosulfuron-ethyl 20 g/ha at 3 DAT followed by manual weeding at 25 DAT (6.8 t/ha) or pretilachlor 750 g/ha as pre-emergence (PE) at 3 DAT followed by metsulfuron-methyl + chlorimuron-ethyl 4 g/ha as post-emergence (PoE) at 25 DAT (6.6 t/ha) or bispyribac-sodium 20 g/ha + metsulfuron-methyl + chlorimuron-ethyl 4 g/ha as PoE at 25 DAT (6.3 t/ha). However, significantly higher net returns (`/ha) and B:C ratio were recorded with pyrazosulfuron-ethyl 20 g/ha at 3 DAT followed by manual weeding at 25 DAT of (` 69788, B:C 2.79), pretilachlor 750 g/ha as PE at 3 DAT followed by metsulfuron-methyl + chlorimuron-ethyl 4 g/ha as PoE at 25 DAT (` 67646, B:C 2.77), hand weeding twice at 25 and 45 DAT (` 68720, B:C 2.68), and bispyribac-sodium 20 g/ha + metsulfuron-methyl + chlorimuron-ethyl 4 g/ha as PoE at 25 DAT (` 62299, B:C 2.58).

Key words: Grain yield, Herbicide combinations, Productivity, Transplanted rice, Weed dry matter

Rice (*Oryza sativa* L.) is one of the most important food grains produced and consumed worldwide. In India, rice is grown in an area of 44.1 million ha, with a production of 106.64 million tonnes, and productivity of 2416 kg/ha (Ministry of Agriculture 2016-17). In Telangana state, area under rice crop is 2.0 million ha with a production of 6.62 million tonnes and productivity of 3.30 t/ha (DES, Hyderabad, 2016-17). Rice crop suffers from various biotic and abiotic production constraints. Weed competition is one of the major yield limiting factors among biotic constraints in rice. The reduction in paddy yield due to weed competition ranged from 9-51 per cent (Mani *et al.* 1986). With the advent of capital intensive technology like dwarf high yielding varieties tailored to respond to external inputs like fertilizers, irrigation and new intensive cropping systems also aggregated the problem of weeds (Yaduraj and Mishra 2002). The direct and most important effect of weeds is the reduction in crop yields resulting from competition for water nutrients and sunlight, but also quality of grains is impaired besides causing some nuisance at the time of harvest (Rao *et al.* 2007).

Herbicide technology offers an alternative method of selective and economical control of weeds right from the beginning, giving crop an advantage of good start and competitive superiority. However, no single herbicide is effective for broad-spectrum weed control in transplanted rice. Combination products consisting of two or more herbicides have greater activity on diverse weed flora due to differential mode of action and have become popular in recent years. With this background, the present investigation was undertaken.

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MATERIALS AND METHODS

An investigation was carried out during *Kharif* 2013 and 2014 at College of Agriculture, Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad. The soil of the experimental site was sandy clay loam in texture, neutral in reaction (7.9), low in available nitrogen (225.6 kg N/ha), high in available phosphorus (27.14 kg P/ha) and available potassium (169.7 Kg K/ha)

The experiment was laid out in a randomized block design with fourteen weed management practices, *viz.* pretilachlor 625 g/ha as pre-emergence (PE) or 6% + bensulfuron-methyl 0.6% 10 kg granules/ha as pre-emergence (PE) at 3 DAT, pyrazosulfuron-ethyl 20 g/ha at 3 DAT followed by manual weeding at 25 DAT, penoxsulam 22.5 g/ha as post-emergence (PoE) at 12 DAT, cyhalofop-p-butyl 100 g/ha as PoE 15 DAT, bispyribac-sodium 25 g/ha as PoE 25 DAT, azimsulfuron 35 g/ha as PoE at 25 DAT, bispyribac-sodium 25 g/ha + ethoxysulfuron 18.75 g/ha as PoE at 25 DAT, bispyribac-sodium 20 g/ha + metsulfuron-methyl + chlorimuron-ethyl 4 g/ha as PoE at 25 DAT, pretilachlor 750 g/ha as PE at 3 DAT *fb* ethoxysulfuron 18.75 g/ha as PoE at 25 DAT, pretilachlor 750 g/ha as PE at 3 DAT *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha as PoE at 25 DAT, hand weeding twice at 25 and 45 DAT and weedy check. The herbicides were applied using knap-sack sprayer fitted with flat fan nozzle by mixing in 500 L of water/ha as per treatments. Twenty five days old seedlings of rice variety '*MTU-1010*' were transplanted at a spacing of 15 x 15 cm. Recommended dose of 120: 60: 40 kg/ha of NPK was applied uniformly. Half of the nitrogen and whole of phosphate and potash were applied at the time of final puddling and the remaining quantity of nitrogen was applied at panicle initiation stage. Weed dry weight were sampled randomly at two places with the help of a 0.25 m^2 sized quadrate at 60 day growth stage. Weed control efficiency was also calculated on the basis of dry matter production by weeds.

RESULTS AND DISCUSSION

Weed flora

General weed flora of the experimental field during *Kharif* 2013 and 2014 were *Echinochloa crus-galli*, *Echinochloa colona*, *Paspalum distichum* among grasses, *Cyperus difformis*, *Cyperus rotundus* and *Fimbristylis dichotoma* among sedges and *Eclipta alba*, *Bacopa monnieri* and *Ammannia baccifera* among broad-leaved weeds, comprising 44% sedges, 30% grasses and 26% broad-leaved weeds.

Effect on weed dry matter

At 30 DAT, hand weeding twice at 25 and 45 DAT registered the lower total weed dry weight which was at par with pyrazosulfuron-ethyl 20 g/ha as PE at 3 DAT followed by manual weeding at 25 DAT, pretilachlor 750 g/ha as PE at 3 DAT followed by metsulfuron-methyl + chlorimuron-ethyl 4 g/ha as PoE at 25 DAT, pretilachlor 750 g /ha as PE at 3 DAT followed by ethoxysulfuron 18.75 g/ha as PoE at 25 DAT, which were significantly superior over other treatments. These were followed by pretilachlor 6% + bensulfuron methyl 0.6% 10 kg granules/ha as PE at 3 DAT and was statistically comparable with pyrazosulfuron-ethyl 20 g /ha 3 DAT, pretilachlor 625 g/ha as PE at 3 DAT and penoxsulam 22.5 g/ha as PoE at 12 DAT. Maximum total weed dry weight was registered in weedy check during both the years.

At 60 DAT, pre-emergence application of pyrazosulfuron-ethyl 20 g/ha at 3 DAT followed by manual weeding at 25 DAT registered the lower total weed dry weight (13.0 and 14.5 g/m^2), whereas at 90 DAT and at harvest, significantly the lower total weed dry weight (32.69 and 39.85 g/m^2) was recorded with hand weeding twice at 25 and 45 DAT and was statistically comparable with pyrazosulfuron-ethyl 20 g/ha followed by manual weeding at 25 DAT, pretilachlor 750 g/ha as PE at 3 DAT followed by metsulfuron-methyl + chlorimuron-ethyl 4 g/ha as PoE at 25 DAT and bispyribac-sodium 20 g /ha + metsulfuron-methyl + chlorimuron-ethyl 4 g/ha as PoE at 25 DAT. In turn, all these treatments were followed by pretilachlor 750 g/ha as PE at 3 DAT followed by ethoxysulfuron 18.75 g/ha as PoE at 25 DAT and was statistically on par with azimsulfuron 35 g/ha as PoE at 25 DAT, bispyribac-sodium 25 g/ha + ethoxysulfuron 18.75 g/ha as PoE at 25 DAT and pretilachlor 6% + bensulfuron-methyl 0.6% 10 kg granules/ha as PE at 3 DAT. The higher total weed dry weight was recorded under weedy check however, it was at par with penoxsulam 22.5 g/ha as PoE at 12 DAT, pyrazosulfuron-ethyl 20 g/ha 3 DAT, bispyribac-sodium 25 g/ha as PoE 25 DAT, pretilachlor 625 g/ha as pre-emergence (PE) or 6% + bensulfuron-methyl 0.6% 10 kg granules/ha as PE at 3 DAT and cyhalofop-p-butyl 100 g /ha as PoE 15 DAT under the study. Among the herbicide treated plots, pyrazosulfuron-ethyl 20 g/ha as PE at 3 DAT followed by manual weeding at 25 DAT was statistically comparable with hand weeding twice at 25 and 45 DAT. This was mainly due to killing of germinating weed seeds as well as removal of established weeds. Sulfonylurea herbicides inhibit the aceto lactate synthase enzyme which involved in the synthesis of the branched chain amino acids (leucine, isoleucine, and valine) which are required for DNA synthesis and cell growth. During the critical period of crop weed competition, weed dry weight continuously remained increasing and crop growth affected due to competition from weeds for the natural resources (Parthipan and Ravi 2014).

Weed control efficiency (WCE) ranged from 73.3-76.8% and 75.2-80.6% in respective years with various herbicide combinations. Weed control efficiency was high between 0-30 DAT then decreased sharply between 30 - 60 DAT, thereafter, it decreased linearly toward harvest in both years owing to increase in weed density. High weed control efficiency in the initial growth stages appeared to be mainly due to higher herbicide efficacy.

During both years, higher WCE at all the stages was noticed in pyrazosulfuron-ethyl 20 g/ha as PE at 3 DAT followed by manual weeding at 25 DAT, hand weeding twice at 25 and 45 DAT and pretilachlor 750 g /ha as PE at 3 DAT followed by metsulfuron-methyl + chlorimuron-ethyl 4 g/ha as PoE at 25 DAT due to higher suppression of weeds with sequential application of PE herbicide/PoE herbicides or manual weeding and broad spectrum weed control. The treatment bispyribac-sodium 20 g/ha + metsulfuron-methyl + chlorimuron-ethyl 4 g/ha as PoE at 25 DAT showed less WCE at 30 DAT and then from 60 DAT, it showed comparatively higher WCE owing to PoE application of herbicide. It was clearly evident that combination of two chemicals gave higher weed control efficacy than sole application. The treatment pretilachlor 625 g/ha as pre-emergence (PE) or 6% + bensulfuron-methyl 0.6% 10 kg granules/ha as PE at 3 DAT, pyrazosulfuron-ethyl 20 g/ha 3 DAT, pretilachlor 6% + bensulfuron-methyl 0.6% 10 kg granules/ha as PE at 3 DAT, penoxsulam 22.5 g/ha as PoE at 12 DAT, cyhalofop-p-butyl 100 g /ha as PoE 15 DAT, bispyribac-sodium 25 g/ha as PoE 25 DAT, azimsulfuron 35 g/ha as PoE at 25 DAT, bispyribac-sodium 25 g/ha + ethoxysulfuron 18.75 g/ha as PoE at 25 DAT, and pretilachlor 750 g/ha as PE at 3 DAT *fb* ethoxysulfuron 18.75 g/ha as PoE at 25 DAT showed good WCE up to 30 DAT due to single application of PE herbicide alone as the herbicide controlled a portion of weed population. Poor weed control efficiency was noticed in azimsulfuron because it controlled only sedges, bispyribac-sodium controlled only grasses and cyhalofop-p-butyl controlled only barnyard grass at all crop growth stages in 2013 and 2014 (Parthipan and Ravi 2014).

Effect on crop

Rice grain yield was significantly higher with hand weeding twice at 25 and 45 DAT treatment to the tune of 6.4 t/ha and 6.9 t/ha during 2013 and 2014, respectively. However, comparable grain yields were recorded with pyrazosulfuron-ethyl 20 g/ha as PE at 3 DAT followed by manual weeding at 25 DAT, pretilachlor 750 g/ha as PE at 3 DAT followed by metsulfuron-methyl + chlorimuron-ethyl 4 g/ha as PoE at 25 DAT and bispyribac-sodium 20 g/ha + metsulfuron-methyl + chlorimuron-ethyl 4 g/ha as PoE at 25 DAT. There was no significant difference in grain yield among the treatments pretilachlor 750 g/ha as PE at 3 DAT *fb* ethoxysulfuron 18.75 g/ha as PoE at 25 DAT, azimsulfuron 35 g/ha as PoE at 25 DAT, bispyribac-sodium 25 g/ha + ethoxysulfuron 18.75 g/ha as PoE at 25 DAT and pretilachlor 6% + bensulfuron-methyl 0.6% 10 kg granules/ha as PE at 3 DAT. On an average 28.96, 33.19, 36.24 and 36.80%

Table 1. Effect of different pre- and post-emergence herbicides on weed dry matter (WDM) in transplanted rice

Treatment	30 DAT		60 DAT		90 DAT		Harvest	
	2013	2014	2013	2014	2013	2014	2013	2014
Pretilachlor 625 g/ha as PE at 3 DAT	4.76 (21.7)	4.44 (18.8)	10.93 (119.0)	10.68 (113.6)	12.37 (151.9)	12.99 (167.9)	12.99 (172.6)	13.32 (183.7)
Pyrazosulfuron-ethyl 20 g/ha 3 DAT	4.40 (18.4)	4.30 (17.5)	10.73 (114.3)	10.53 (110.0)	12.11 (145.6)	12.65 (159.1)	12.72 (163.8)	13.17 (176.1)
Pretilachlor 6% + bensulfuron-methyl 0.6% 10 kg granules/ha as PE at 3 DAT	4.29 (17.5)	4.22 (16.8)	9.21 (85.5)	8.51 (71.9)	10.07 (100.4)	10.81 (115.8)	10.88 (117.3)	11.42 (129.5)
Pyrazosulfuron-ethyl 20 g/ha at 3 DAT followed by manual weeding at 25 DAT	2.02 (3.1)	2.06 (3.3)	3.36 (13.0)	3.93 (14.5)	5.91 (30.8)	5.52 (29.6)	6.76 (44.7)	6.42 (40.3)
Penoxsulam 22.5 g/ha as PoE at 12 DAT	4.31 (18.2)	4.35 (18.4)	10.45 (108.2)	10.77 (115.0)	12.43 (154.0)	12.47 (154.7)	12.70 (169.3)	12.98 (175.0)
Cyhalofop-p-butyl 100 g/ha as PoE 12 DAT	5.86 (32.5)	5.52 (29.6)	11.02 (120.7)	10.91 (118.0)	12.58 (157.2)	13.00 (168.1)	13.10 (176.5)	13.41 (187.7)
bispyribac-sodium 25 g/ha as PoE 25 DAT	5.54 (30.7)	5.49 (29.2)	10.54 (110.0)	10.39 (107.0)	12.20 (147.9)	12.66 (159.6)	12.87 (167.5)	13.19 (174.8)
Azimsulfuron 35 g/ha as PoE at 25 DAT	5.62 (30.6)	5.33 (27.9)	8.61 (73.2)	8.12 (65.0)	10.69 (113.2)	11.11 (122.0)	11.40 (129.0)	11.72 (136.5)
Bispyribac-sodium 25 g/ha + ethoxysulfuron 18.75 g/ha as PoE at 25 DAT	5.62 (30.5)	5.46 (28.5)	8.65 (73.9)	8.43 (70.2)	10.38 (106.8)	11.12 (122.4)	11.07 (121.5)	11.66 (134.9)
Bispyribac-sodium 20 g/ha + metsulfuron-methyl + chlorimuron-ethyl 4 g/ha as PoE at 25 DAT	5.62 (30.6)	5.41 (28.3)	4.50 (19.76)	4.66 (21.1)	6.25 (38.37)	6.30 (39.0)	7.10 (49.4)	7.17 (50.6)
Pretilachlor 750 g/ha as PE at 3 DAT followed by ethoxysulfuron 18.75 g/ha as PoE at 25 DAT	2.50 (5.6)	2.38 (4.7)	8.07 (66.1)	8.08 (64.3)	9.88 (96.6)	10.35 (106.2)	10.59 (111.1)	10.91 (118.4)
Pretilachlor 750 g/ha as PE at 3 DAT followed by metsulfuron-methyl + chlorimuron-ethyl 4 g /ha as PoE at 25 DAT	2.43 (4.4)	2.28 (3.7)	4.47 (19.1)	4.61 (20.4)	6.20 (37.8)	6.15 (37.0)	7.07 (49.1)	6.84 (46.4)
Hand weeding twice at 25 and 45 DAT	1.93 (2.9)	2.05 (3.2)	3.61 (14.6)	4.26 (17.2)	5.52 (32.7)	5.49 (29.1)	6.39 (39.8)	6.34 (39.4)
Weedy check	5.96 (34.2)	5.62 (30.8)	11.13 (127.4)	11.07 (122.0)	12.74 (161.4)	13.15 (175.4)	13.50 (181.3)	13.87 (193.0)
LSD (p=0.05)	0.58	0.37	1.15	0.79	0.87	0.85	0.89	0.91

Original data in parentheses was subjected to squar root transformation; PE: Pre-emrgence; PoE: Post-emegence

Table 2. Yield and economics as influenced by different weed control treatments in transplanted rice

Treatment	Grain yield (t/ha)		Gross returns (x10^3 `ha)		Net returns (x10^3 `ha)		BC ratio	
	2013	2014	2013	2014	2013	2014	2013	2014
Pretilachlor 625 g/ha as PE at 3 DAT	2.96	2.84	47.81	46.35	11.21	8.75	1.31	1.23
Pyrazosulfuron-ethyl 20 g/ha 3 DAT	3.20	3.05	51.39	49.73	14.59	11.93	1.40	1.32
Pretilachlor 6% + bensulfuron methyl 0.6% 10 kg granules /ha as PE at 3 DAT	4.25	4.23	68.65	67.64	30.33	28.32	1.79	1.72
Pyrazosulfuron-ethyl 20 g/ha at 3 DAT followed by manual weeding at 25 DAT	6.39	6.87	101.54	108.79	63.54	69.79	2.67	2.79
Penoxsulam 22.5 g/ha as early PoE at 12 DAT	3.24	3.37	52.20	54.44	13.91	15.15	1.36	1.39
Cyhalofop-p-butyl 100 g/ha as early PoE 12 DAT	2.77	2.89	45.27	47.06	8.29	7.76	1.22	1.20
bispyribac-sodium 25 g/ha as PoE 25 DAT	3.03	3.16	49.04	50.90	11.01	11.87	1.29	1.30
Azimsulfuron 35 g/ha as PoE at 25 DAT	4.54	4.39	73.06	70.44	34.73	31.12	1.91	1.79
bispyribac-sodium 25 g/ha + ethoxysulfuron 18.75 g/ha as PoE at 25 DAT	4.32	4.20	69.90	67.65	31.16	27.91	1.80	1.70
bispyribac-sodium 20 g/ha + metsulfuron-methyl + chlorimuron-ethyl 4 g/ha as PoE at 25 DAT	5.97	6.38	95.60	101.80	57.10	62.30	2.48	2.58
Pretilachlor 750 g/ha as PE at 3 DAT followed by ethoxysulfuron 18.75 g/ha as PoE at 25 DAT	4.66	4.84	75.31	77.34	37.88	38.91	2.01	2.01
Pretilachlor 750 g/ha as PE at 3 DAT followed by metsulfuron-methyl + chlorimuron-ethyl 4 g/ha as PoE at 25 DAT	6.17	6.68	98.32	105.83	60.83	67.65	2.62	2.77
Hand weeding twice at 25 and 45 DAT	6.44	6.93	102.27	109.72	62.27	68.72	2.56	2.68
Weedy check	2.77	2.78	45.00	45.17	9.00	8.17	1.25	1.22
LSD (p=0.05)	0.48	0.61	6.68	9.70	6.68	9.70	-	-

increase in grain yield was noticed in hand weeding twice at 25 and 45 DAT over pretilachlor 750 g/ha as PE at 3 DAT *fb* ethoxysulfuron 18.75 g/ha as PoE at 25 DAT, azimsulfuron 35 g/ha as PoE at 25 DAT, bispyribac-sodium 25 g/ha + ethoxysulfuron 18.75 g/ha as PoE at 25 DAT and pretilachlor 6% + bensulfuron-methyl 0.6% 10 kg granules/ha as PE at 3 DAT, respectively. The lower grain yield was registered with weedy check and was statistically comparable with penoxsulam 22.5 g/ha as early PoE at 12 DAT, pyrazosulfuron-ethyl 20 g/ha 3 DAT, bispyribac-sodium 25 g/ha as PoE 25 DAT, pretilachlor 625 g/ha as PE at 3 DAT and cyhalofop-p-butyl 100 g/ha as PoE 12 DAT during both the years.

Economics

Significantly the higher gross returns during 2013 and 2014 were achieved in hand weeding twice at 25 and 45 DAT (` 102273 and 109720), which was at par with pyrazosulfuron-ethyl 20 g/ha at 3 DAT followed by manual weeding at 25 DAT (` 101541 and 108788), pretilachlor 750 g/ha as PE at 3 DAT followed by metsulfuron-methyl + chlorimuron-ethyl 4 g/ha as PoE at 25 DAT (` 98319 and 105833) and bispyribac-sodium 20 g/ha + metsulfuron-methyl + chlorimuron-ethyl 4 g/ha as post-emergence at 25 DAT (` 95598 and 101798). However, significantly higher net returns was noticed in pyrazosulfuron-ethyl 20 g/ha at 3 DAT followed by manual weeding at 25 DAT (` 63541 and 69788) and it was at par with hand weeding twice at 25 and 45 DAT (` 62273 and 68720), pretilachlor 750 g/ha as PE at 3 DAT followed by metsulfuron-methyl + chlorimuron-ethyl 4 g/ha as PoE at 25 DAT (` 60832 and 67646) and bispyribac-sodium 20 g/ha + metsulfuron-methyl + chlorimuron-ethyl 4 g/ha as post emergence at 25 DAT (` 57099 and 62299). The higher benefit: cost ratio was recorded in pyrazosulfuron-ethyl 20 g/ha at 3 DAT followed by manual weeding at 25 DAT.

It was concluded that pre-emergence application of pyrazosulfuron-ethyl 20 g/ha at 3 DAT followed by manual weeding at 25 DAT was better options for efficient weed control, higher grain yield and profit in transplanted rice.

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Changes in microbiological characteristics of rice soil by post-emergence herbicides

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ABSTRACT

A field study was conducted in an Inceptisol with summer season rice to evaluate the degradability of different post-emergence herbicides applied alone or in combinations in terms of microbiological characteristics of rhizosphere soil. Five different herbicides (bispyribac-sodium, metamifop, chlorimurone-ethyl, metsulfuron-methyl and cyhalofop-butyl) were applied as an individual or in combination at post-emergence stage (15 DAS). A wetting agent (agrisol) was also used with some herbicides to increase the effectivity of applied herbicides. Application of different herbicides had inhibitory effect on microbial population and their activities in soil after application, but their effects were not pronounced and the soil properties were restored. Although herbicides applied at different rates but their degradability was almost equal and they took only 30 days or less period for complete degradation except cyhalofop-butyl and bispyribac-sodium + metamifop, which ware applied 80 g and 140 g/ha, respectively and found completely degraded before harvest.

Key words: Degradability, Herbicides, Microbes, Rice, Soil, Wetting agent

In general weeds reduce the crop yield by 31.5% (22.7% in winter and 36.5% in summer and *Kharif* seasons) (Vivek Mishra *et al.* 2015). The use of chemical herbicides is probably the most important component of weed management system. Generally herbicides are not harmful when the one applied in recommended levels in soil. Application of pre-emergence and post-emergence herbicide reduced the microbial population and their activities in soil from its application from 3 to 22 days after sowing, to 35 days after sowing of the crop, thereafter it became normalize due to degradation of applied herbicides (Mishra *et al.* 2015). According to Radivojevic *et al.* (2004), even though the herbicidal treatments brought higher weed control efficiency, it could not increase the microflora population due to the strong chemicals, which decreae the bacterial population to a great extent. Different micro-organisms are efficient decomposers of herbicides which are generally aliphatic, hydroxyl and aromatic compounds. They easily decompose the aliphatic and hydroxyl group but they decompose aromatic substances at a slower rate. The fate and persistence of newly introduced herbicides in soil are almost unknown. In this experiment, a new combination of post-emergence herbicides was tested comparing with existing herbicides with and without wetting agent with respect to their ultimate effect on soil microflora.

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MATERIALS AND METHODS

A field study was conducted during summer 2013 at Instructional cum Research farm, IGKV, Raipur in an Inceptisol with summer season rice to evaluate the effect of different post-emergence herbicides applied alone or in combinations in terms of microbiological and biochemical characteristics of rhizosphere soil. Five different herbicides (bispyribac-sodium, metamifop, chlorimurone-ethyl, metsulfuron-methyl and cyhalofop-butyl) were applied as an individual or in combination at post-emergence stage (15 DAS). A wetting agent (Agrisol) was also used with some herbicides to increase the effectivity of applied herbicides. The experiment included 13 treatments, *viz*. bispyribac-sodium + metamifop 42, 56, 70 and 140 g/ha ha, chlorimuran-ethyl + metsulfuron-methyl 20% WP 4 g/ha, cyhalofop-butyl 10% EC 80 g/ha, bispyribac-sodium 10% SC 20 g/ha + wetter (Agrisol), metamifop 10% SE 50 g/ha + wetter (Agrisol), bispyribac-sodium 4% + metamifop 10% SE (alone) 70 g/ha , bispyribac-sodium 10% SC 20 g/ha, metamifop 10% SE 50 g/ha, wetter (Agrisol), unsprayed control. The experiment was conducted on summer rice (*Oryza stativa* L.) with test variety '*MTU-1010*'. All the above herbicides were applied at post-emergence stage of crop *i.e.* 15 DAS of the crop. The soil was Inceptisol (pH: 6.29, EC: 0.20 dS/m, organic carbon: 22.33%, available N: 238.34 kg ha, available P: 9.24 kg ha, and available K: 252.71 kg ha). The treatments were replicated thrice under randomized block design. Rhizosphere soil was collected at a depth of 7.5-15 cm from 12 locations at different stages of crop growth from the same plot and pooled together for the purpose of analysis. Soil sampling was done at 0, 7, 15, 30, 50 days after sowing of crop and harvest stage of crop. The soil samples were subjected to analysis for microbial biomass carbon, basal soil respiration rate, population of total bacteria, actinomycetes and fungi.

In this experiment different post-emergence herbicides were tested as and individual or in combination of two herbicides to evaluate their toxicity level with respect to microbial properties of rhizosphere soil of rice.

RESULTS AND DISCUSSION

Basal soil respiration

All the herbicides including wetting agent significantly inhibited the basal soil respiration (BSR) soon after their application. The degree of inhibition was carried as per the toxicity of the herbicides. Combined application of bispyribac-sodium + metamifop at different concentration reduced the BSR with their increasing levels (**Table 1**). Among different herbicides, cyhalofop-butyl 10% EC exhibited maximum inhibition of BSR and minimum by metamifop 10% EC. Cyhalofop-butyl inhibited the BSR value from 0.339 (7 DAS) to 0.297 mg (15 DAS) whereas metamifop was found rather safe and reduced the value from 0.367 to 0.345 mg within the same period. Wetting agent Agrisol also reduced the above activity significantly at 15 DAS. The above observations were in close agreement with De Lonezo *et al.* (2001).

At 30 DAS, all the herbicides treatment significantly reduced basal soil respiration over control, except the wetting agent which was found at par with unsprayed control. At 50 DAS, all the herbicides treatments found at par with unsprayed control except cyhalofop-butyl and bispyribac-sodium + metamifop applied (140 g/ha). These herbicides started to degrade at 30 DAS but not degraded completely up to 50 DAS. The results are in conformity with the findings of Mishra *et al.* (2015) who stated that the amount of released CO_2 (as a measure of the intensity of soil microbiological activity) was reduced from 0 DAS to 35 DAS after the application of butachlor in pre-emergence and fenoxapropp-ethyl and ethoxysulfuron in post-emergence stages, respectively. The values then gradually increased upto 50 DAS. In case of hand weeding and weedy check, the BSR rate continuously increased from 0 to 50 DAS and there after narrowed down.

Mcrobial biomass carbon

Content microbial biomass carbon (MBC) reduced significantly due to application of bispyribac-sodium, metamifop, cyhalofop, chlorimuron, + metsulfuron alone or in different combinations and doses but their degree of reduction varied. Cyhalofop reduced the MBC severly *i.e.* from 90.28 µg (7 DAS) to 75.22 µg (15 DAS), whereas singal application of

Table 1. Effect of post-emergence herbicides on basal soil respiration rate (mg CO_2/h/100 g) and microbial biomass carbon content (µg/g) of rhizosphere soil at different growth stages of rice

Treatment	Days after sowing											
	0		7		15		30		50		At harvest	
	BSR	MBC	BSR	MBC	BSR	MBC	BSR	MBC	BSR	MBC	BSR	MBC
Bispyribac-sodium + metamifop 42 g/ha + wetter (Agrisol)	0.332	82.46	0.361	94.16	0.335	81.04	0.317	71.10	0.427	179.01	0.322	82.56
Bispyribac-sodium + metamifop 56 g/ha + wetter (Agrisol)	0.327	81.78	0.354	92.99	0.325	79.46	0.305	69.09	0.423	174.24	0.309	81.76
Bispyribac-sodium + metamifop 70 g/ha + wetter (Agrisol)	0.321	80.34	0.347	91.07	0.315	77.02	0.292	66.17	0.419	170.10	0.305	80.56
Bispyribac-sodium + metamifop 140 g/ha + wetter (Agrisol)	0.319	79.87	0.345	90.33	0.307	76.16	0.282	65.10	0.417	169.34	0.304	80.24
Cholrimuron-ethyl + metasufuron-methyl 20% WP 4 g/ha	0.331	82.06	0.359	93.52	0.331	80.28	0.312	70.19	0.426	176.75	0.318	82.34
Cyhalofop-butyl 80 g/ha	0.315	79.34	0.339	90.28	0.297	75.22	0.269	64.98	0.415	169.02	0.301	80.21
Bispyribac-sodium 20 g/ha + wetter (Agrisol)	0.334	82.89	0.362	94.83	0.337	82.08	0.320	72.32	0.430	180.66	0.324	83.42
Metamifop 50 g/ha + wetter (Agrisol)	0.336	83.24	0.364	95.51	0.341	83.01	0.326	73.48	0.432	181.13	0.328	83.84
Bispyribac-sodium + metamifop 70 g/ha	0.326	81.56	0.354	92.48	0.325	78.62	0.304	68.02	0.420	172.15	0.307	81.32
Bispyribac-sodium 20 g/ha	0.339	83.68	0.366	96.24	0.343	84.00	0.329	74.60	0.435	182.47	0.329	84.12
Metamifop 50 g/ha	0.339	84.21	0.367	97.04	0.345	85.01	0.333	75.77	0.438	183.85	0.330	84.78
Wetter (agrisol): A-150K 500 ml/ ha	0.342	85.53	0.370	99.76	0.350	91.41	0.375	143.87	0.456	186.62	0.334	89.12
Unsprayed control	0.343	86.64	0.371	100.37	0.382	126.51	0.406	154.34	0.461	189.30	0.336	89.36
LSD (p=0.05)	NS	NS	NS	NS	0.031	8.66	0.034	10.49	0.043	19.76	NS	NS

BSR – Basial soil respiration, MBC – Microbial biomass carbon metamifop reduced the MBC content least (**Table 1**). The reduction due to metamifop can be estimated as from 97.04 µg (7 DAS) to 85.01µg (15 DAS) .Other herbicides reduced the MBC values intermediately between the peak values. Agrisol wetter also imparted effect on MBC by reducing the content significantly at 15 DAS. However, it degraded at a faster rate and found ineffective at 30 DAS. This observation was in close agreement with Baboo *et al.* (2013). At 50 DAS, all the applied herbicides found to be degraded completely except cyhalofop and bispyribac-sodium + metamifop mixture (140 g/ha), which were still showed their presence in the rhizosphere by narrowing the MBC content significantly over control. Result of the investigation is in confirmation with the findings of Bolter *et al*. (2006). The decrease in MBC may be due to the adsorption of small amount of pesticides on organic matter that mask the effects of these agrochemicals on soil microbial biomass, and subsequently led to lysis of microbial cells (Jayamadhuri and Rangaswamy 2005). Herbicides affect various soil microbial processes, inhibit decomposition, which depends upon the type and rate of application that can alter the microbial biomass quantitatively and qualitatively (Mishra *et al*. 2013).

Bacterial population

Soil bacteria significantly affected by all the organo chemicals used in the experiment (**Table 2**). The bacterial population ranged between 45.50 to 52.90 $\times10^5$ due to application of different herbicides. Highest reduction in population was noticed due to cyhalofop-butyl where population got reduced from 57.7 $\times10^5$ (7 DAS) to 45.5 $\times10^5$ (15 DAS), wheres minimum inhibition of population was observed in plots where metamifop was applied. In these plots, population decrement was found from 57.4 $\times10^5$ to 53.3 $\times10^5$ within the same period. At 30 DAS, except wetting agent, all the treatments have shown the inhibition of bacterial population in comparison to 15 DAS. At 50 DAS, the population of bacteria increased in comparison to 30 DAS and most of the herbicides treated plots have shown at par values of bacterial population to that of unsprayed control except cyhalofop and bispyribac + metamifop (140 g/ha). These findings were in accordance with that of Chowdhury *et al.* (2008) and Baboo *et al*. (2013).

The fate of the herbicide residues in soil is a matter of great concern since they would persist on top soil (Ayansina *et al.* 2003). At harvest population of bacteria in all the treatments found slightly lower than 50 DAS but all were found at par with unsprayed control, which seems that all the herbicides degraded completely before harvesting of the crop. Unsprayed conditions facilitated the growth of bacteria as indicated by the population recorded during the experimentation. Under this treatment, the bacterial

Table 2. Effect of post-emergence herbicides on soil bacterial (x10^5/g), actinomycetes (x10^4/g) and fungal count (x10^3/g) in rhizosphere soil at different growth stages of rice

Treatment	Days after sowing																	
	0			7			15			30			50			At harvest		
	TB	Act	Fun	TB	Act	Fun	TB	Act	Fun	TB	Act	Fun	TB	Act	Fun	TB	Act	Fun
Bispyribac-sodium + metamifop 42 g/ha + wetter (Agrisol)	52.6	74.5	35.2	57.4	81.6	39.2	50.3	74.7	34.5	47.5	69.2	31.2	98.0	110.9	73.0	52.2	74.3	32.7
Bispyribac-sodium + metamifop 56 g/ha + wetter (Agrisol)	52.9	75.3	35.7	57.6	82.4	39.5	49.2	72.5	33.2	45.3	64.5	29.5	97.4	109.8	72.3	51.6	73.7	31.9
Bispyribac-sodium + metamifop 70 g/ha + wetter (Agrisol)	52.5	75.1	34.9	57.4	82.3	38.7	48.2	71.7	31.4	43.1	63.3	26.5	96.3	109.0	70.8	50.8	72.7	31.5
Bispyribac-sodium + metamifop 140 g/ha + wetter (Agrisol)	52.5	75.2	35.1	57.5	82.5	39.2	46.3	70.5	31.2	40.5	61.2	25.3	95.4	108.5	70.1	50.6	72.4	31.3
Cholrimuron-ethyl + metasufuron-methyl 20% WP 4 g/ha	52.6	74.4	34.3	57.7	81.7	38.2	49.7	73.5	32.3	45.8	66.5	29.7	97.8	110.3	72.7	51.8	73.9	32.3
Cyhalofop-butyl 80 g/ha	52.7	74.3	34.5	57.7	81.6	38.6	45.5	68.3	30.4	38.6	58.5	24.5	94.7	108.2	69.7	49.9	71.5	31.2
Bispyribac-sodium 20 g/ha + wetter (Agrisol)	52.7	74.5	34.7	57.6	81.6	38.8	51.7	75.2	34.7	49.1	71.5	31.6	98.3	111.2	73.8	52.6	74.6	33.4
Metamifop 50 g/ha + wetter (Agrisol)	52.6	74.4	34.6	57.5	81.7	38.7	52.2	75.4	35.7	50.3	71.7	31.9	98.6	111.7	74.2	52.7	74.9	33.7
Bispyribac-sodium + metamifop 70 g/ha	52.8	74.7	34.7	57.8	81.9	38.9	48.6	71.7	31.7	43.4	63.7	26.7	96.9	109.3	71.4	51.3	73.2	31.7
Bispyribac-sodium 20 g/ha	52.7	74.7	34.9	57.7	81.8	39.2	52.9	75.7	35.9	51.4	71.7	32.4	99.0	112.5	74.9	52.9	75.0	34.2
Metamifop 50 g/ha	52.5	75.5	34.5	57.4	81.5	38.6	53.3	75.9	36.2	53.1	72.0	33.7	99.5	113.7	75.2	53.2	75.7	34.6
Wetter (Agrisol): A-150K 500 ml/ ha	52.8	75.2	35.1	57.7	82.4	39.3	63.2	76.4	36.7	77.8	98.9	63.6	103.4	118.3	75.4	53.4	75.9	34.4
Unsprayed control	52.7	75.3	35.3	57.6	82.5	39.6	68.9	89.3	49.4	83.4	104.3	67.2	106.7	121.5	78.6	54.8	77.2	35.3
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	5.1	7.2	3.6	5.7	6.3	3.6	10.70	12.7	8.1	NS	NS	NS

TB – Total bacteria, Act – Actinomycetes,Fun - Fungi population gradually increased from 0 DAS to 50 DAS followed by a slight declination at harvest.

Actinomycetes population

Actinomycetes population severely affected by singal and dual application of herbicides soon after their application *i.e.* 15 DAS (**Table 2**). The actinomycetes population severely affected by cyhalofop-butyl and least affected by metamifop. The wetting agent also imparted inhibitory effect on actinomycetes population. Cyhalofop reduced the population from 68.3 $\times 10^4$ (15 DAS) to 58.5 $\times 10^4$ (30 DAS) where as metamifop reduced the population from 75.9 $\times 10^4$ (15 DAS) to 72.0 $\times 10^4$ (30 DAS). At 30 DAS the wetting agent found at par with unsprayed control treatment.

At 50 DAS, comparatively higher population of actinomycetes was noticed in comparison to 30 DAS. In this stages all the treatments showed at par values to that of control, which indicated the non existence of respective applied chemicals, except cyhalofop and higher dose of bispyribac-sodium and metamifop which were shown their existence in rhizosphere. This is in agreement with works of Baboo *et al.* (2013) who reported the actinomycetes count (ACT) at different days after herbicide application showed significant differences, with the highest on 28th day and lowest on 7th day after herbicide treatment.

Fungal population

Fungal population is reduced at 15 DAS after application of different post emergence herbicides, which were applied as single or in combination (**Table 2**). Among different herbicides treatment, cyhalofop-butyl inhibit the fungal growth at maximum level. It reduced the population from 38.6 $\times 10^3$ (7 DAS) to 30.4$\times 10^3$ (15 DAS) per gram of soil. Contrary to this, metamifop as an individual reduced the fungal growth a minimum. It narrowed the population from 38.6$\times 10^3$ (7 DAS) to 36.2$\times 10^3$ (15 DAS) per g of soil. Other herbicides used in the experiment exhibited intermediate effect on fungus, between two extremes mentioned above. Wetting agent Agrisol also showed anti-fungal activity as it also significantly reduced the fungal population in soil soon after its application at 15 DAS. At 30 DAS, all the herbicides exhibited their anti-fungal effect and significantly reduced the fungal population, hence showed their presence in rhizosphere. Only wetting agent was completely degraded and found ineffective at this stage. At 50 DAS, effect of all the herbicides found in effective to narrowed down the population comparison to unsprayed control except cyhalofop and bispyribac + metamifop which were applied 80 g and 140 g/ha. This indicated their incomplete degradation and presence in the rhizosphere soil of rice. Result of the investigation is in confirmation with the findings of Dsehmukh *et al.* (2013) who also observed lowest fungal count in all the treatments of herbicide application over initial values. At harvest, all the applied herbicides did not show their existence. This proved at par values of fungal population in all the herbicides treated plots in comparison to the value of control plot. In control plots, the fungal population gradually built-up in soil from 0 to 50 DAS and then slightly reduced at harvest. Tu *et al.* (2001) also mentioned herbicides have varying effect on soil microbial populations depending on herbicide concentrations and the microbial species present. Low residue levels can enhance population while higher levels can cause population declines.

It was concluded that application of different herbicides had inhibitory effect on microbial and biochemical activities of soil but their effects were not pronounced and the soil properties were restored.

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Optimization rate of pinoxaden + clodinafop-propargyl for weed control in wheat

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ABSTRACT

A field experiment was conducted during 2011-12 and 2012-13 at G.B. Pant University of Agriculture &Technology, Pantnagar to study the effect of different rates of pre-mix of pinoxaden 2.53% + clodinafop-propargyl 2.53% on population and growth of weeds and grain yield of wheat. Major weed species identified in the experiment were *Phalaris minor, Avena* spp., *Chenopodium album, Anagallis arvensis, Polygonum plebeium, Melilotus indica, Coronopus didymus* during both the years. The lowest density and biomass of grassy weeds were recorded with pinoxaden 2.53% + clodinafop-propargyl 2.53% at 60 g/ha. However, it was ineffective against broad-leaf weeds. Maximum grassy weed control efficiency (100%) was observed with pinoxaden + clodinafop-propargyl at 60 g/ha closely followed by its lower dose applied at 50 g/ha and pinoxaden at 50 g/ha. Pre-mix of pinoxaden 2.53% + clodinafop-propargyl 2.53% at 60 g/ha produced highest grain yield (4.5-4.6 t/ha). Uncontrolled weeds caused 55.7 and 52.2% reduction in grain yield of wheat when compared with weed free conditions during 2011-12 and 2012-13.

Key words: Clodinafop-propargyl, Optimization rate, Pinoxaden, Weed managment, Wheat

Wheat (*Triticum aestivum* L.) is the second most important food grains next to rice in India in terms of area and production. It occupies an area of 29.6 mha with annual production of 88.94 mt and productivity of 2.87 t/ha (Anonymous 2015). As a result of ever increasing population, demand for wheat will also be increased. Therefore, it is necessary to increase the wheat production and productivity to provide food to the increasing population. Weeds cause substantial losses in yield and quality of wheat crop. In wheat, weeds alone account for 10 to 82% yield losses depending upon weed species, severity and duration of weed infestation and climatic conditions (Jat *et al.* 2003). Earlier in India, isoproturon was the most effective and economical for controlling grassy weeds in wheat but its continuous and sub optimum use led to development of herbicidal resistance particularly in *Phalaris minor* in some parts of Punjab and Haryana. In order to tackle the resistance problem, some alternative herbicides like fenoxaprop-p-ethyl, clodinafop propargyl, pinoxaden and sulfosulfuron, have been recommended for weed control in irrigated wheat (Dhaliwal *et al.* 2003). Recently many new molecules have been developed by different agro-chemical industries. However, their efficacy needs to be tested. A readymade mixture of pinoxaden and clodinafop-propargyl has been developed to provide speedy and effective control of *Phalaris minor* and *Avena ludoviciana* when applied as post-emergence in wheat crop. Every herbicide has an optimum dose, under a set of environment, for effective control of weeds. Under or over dose of herbicide is not desirable as under dose may be less effective and may facilitate development of resistance in weeds, while over dose may result into phytotoxicity. Keeping the above points in view, the present study was carried out to study the combined use of two chemicals.

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MATERIALS AND METHODS

An experiment was conducted during *Rabi* seasons 2011-12 and 2012-13 at Pantnagar to see the effect of pre-mix of pinoxaden 2.53% + clodinafop propargyl 2.53% against weed flora in wheat. The soil of the experimental field was clay loam in texture, medium in organic carbon (0.67%), available phosphorus (29.6 kg/ha) and potassium (176.4 kg/ha) with pH 7.2. Eight treatments consisted of readymade mixture of pinoxaden 2.53% + clodinafop propargyl 2.53% in three different rates *i.e.* 40, 50 and 60 g/ha, pinoxaden 50 g/ha, clodinafop propargyl 60 g/ha and fenoxaprop-p-ethyl 120 g/ha along with weed free and untreated check. Experiment was laid out in randomized block design with three replications. Wheat cultivar *"UP2565'* was sown on 9 Dec, 2011 and 22th Nov, 2012 using seed rate of 100 kg/ha and fertilized with 120 kg N, 60 kg P_2O_5 and 40 kg K_2O. Herbicides were applied by using a knapsack sprayer fitted with flat-fan nozzle with water volume of 500 l/ha. Observations on weed density, dry weight of weeds were taken at 90 days after sowing. A quadrate of 0.25 m^2 was placed randomly and weed species within the quadrate were identified and their number was counted species wise. The collected weeds were first dried in the sun and then in an electric oven for at 70±2 °C till constant dry weight. Dry matter of weeds was recorded and expressed in g/m^2.The data on weed density and weed biomass were analyzed after subjecting to square root transformation for comparison. Weed control efficiency was calculated based on control of grassy weeds only.

RESULTS AND DISCUSSION

Effect on weeds

Wheat field was infested with both grassy and broad-leaved weeds during both the years. However, the flora was dominated by grassy weeds *Phalaris minor* and *Avena ludoviciana. Chenopodium album, Rumex spinosus, Coronopus didymus, Melilotus alba* and *Polygonum plebeium* were among broad-leaf weeds. Among the herbicidal treatments, post-emergence application of pre-mix of pinoxaden 2.53% + clodinafop propargyl 2.53% 60 g/ha resulted in excellent control of *Phalaris minor* and *Avena ludoviciana* (**Table 1**). This treatment was found at par with pre-mix of pinoxaden 2.53% + clodinafop propargyl 2.53% at 50 g/ ha and pinoxaden at 50 g/ha. The effective control of *Phalaris minor* with clodinafop and pinoxaden has also been reported earlier (Chhokar *et al.* 2007). . Pre-mix of pinoxaden 2.53% + clodinafop propargyl 2.53% at all tested doses found to be ineffective against broad-leaf weeds.

Biomass and weed control efficiency (WCE %)

Among the treatments, significantly less dry weight of grassy weeds was observed in pre-mix of pinoxaden 2.53% + clodinafop propargyl 2.53% at 60 g/ha at 90 DAS which was at par with its lower dose at 50 g/ha and weed free treatment. Maximum weed control efficiency (100 & 100 %), calculated on the basis of control of grassy weeds only was also recorded with pre-mix of pinoxaden 2.53% + clodinafop propargyl 2.53% at 60 g/ha at 90 DAS followed by its lower dose applied at 50 g/ha and pinoxaden at 50 g/ha (**Table 2**) .

Effect on yield

There were 49.5 and 45.6% yield reduction under unweeded plot over pre-mix of pinoxaden + clodinafop propargyl at 60 g/ha during 2011-12 and 2012-13 respectively (**Table 3**). Losses in grain yield of wheat due to uncontrolled weeds have also been reported to the extent of 10 to 50% by Mukhopadhyay and Brar (1980), 31.8 to 54.2% by Kumar (1993) and Meena (1996) at Pantnagar and 23.9 to 32.6% by Duary and Yaduraju (2005) from New Delhi. The maximum grain yield was recorded from the weed free plot (5.2 and 5.2 t/ha). Among the herbicidal treatments, pre-mix of pinoxaden+ clodinafop propargyl at 60 g/ha produced the highest yield which was closely followed by pre-mix of pinoxaden 2.53% + clodinafop propargyl 2.53% at 50 g/ha, clodinafop-propargyl at 60 g/ha and pinoxaden at 50 g/ha. Yield attributes, *viz.* number of grains/spike, spike length and 1000-grain weight in plots treated with this pre-mix at 60 g/ha was also at par with weed free condition. The highest number of spikes/m^2 (372 and 366), number of grains/spike (42.7 and 42.3), spike length (12.4 and 12.1 cm) and

Table 1. Effect of pre-mix of pinoxaden + clodinafop propargyl on density of weeds at 90 days after sowing during 2011-12 and 2012-13

Treatment	Dose (g/ha)	Weed density (no./m^2) *P.minor*		*Avena* spp.		BLWs		Total	
		2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Pinoxaden 2.53% + clodinafop propargyl 2.53%	40	2.82(7)	2.49(5)	2.43(5)	2.75(7)	9.22(84)	9.93(98)	9.83(96)	10.51(110)
Pinoxaden 2.53% + clodinafop propargyl 2.53% EC	50	1.90(3)	1.00(0)	1.00(0)	1.41(1)	8.52(72)	9.98(99)	8.42(73)	9.98(100)
Pinoxaden 2.53% + Clodinafop propargyl 2.53% EC	60	1.00(0)	1.00(0)	1.00(0)	1.00(0)	8.05(64)	9.78(95)	7.80(64)	9.74(95)
Pinoxaden	50	1.41(1)	1.41(1)	1.90(3)	1.82(3)	8.66(74)	10.03(100)	8.80(78)	9.98(104)
Clodinafop propargyl	60	2.10(4)	1.82(3)	2.10(4)	2.49(5)	8.44(71)	9.73(94)	8.87(79)	10.11(102)
Fenoxaprop-p-ethyl	120	3.00(8)	2.75(7)	2.43(5)	2.49(5)	8.87(78)	9.84(96)	9.45(90)	10.39(108)
Weed free	-	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)
Untreated control	-	9.00(80)	9.78(95)	3.58(12)	4.10(16)	9.94(98)	9.84(96)	13.78(190)	14.37(207)
LSD (p=0.05)		0.90	0.76	0.75	0.89	0.90	0.44	2.5	2.14

Figures in parentheses are means of original values. Data are subjected to square root transformation.

Table 2. Effect of pre-mix of pinoxaden + clodinafop propargyl on weed biomass at 90 days after sowing during 2011-12 and 2012-13

Treatment	Dose (g/ha)	Weed biomass (g/m^2)						WCE (%)	
		Grassy		BLWs		Total		2011-12	2012-13
		2011-12	2012-13	2011-12	2012-13	2011-12	2012-13		
Pinoxaden 2.53% + Clodinafop propargyl 2.53% EC	40	4.04(15)	4.25(17)	6.89(47)	7.61(57)	7.93(62)	8.66(74.4)	92.5	92.1
Pinoxaden 2.53%+ Clodinafop propargyl 2.53% EC	50	1.19(1)	1.45(2)	6.75(45)	7.68(60)	6.79(46)	7.80(61.3)	99.5	99.0
Pinoxaden 2.53%+ Clodinafop propargyl 2.53% EC	60	1.00(0)	1.00(0)	6.12(38)	7.26(52)	6.19(38)	7.39(52.3)	100.0	100.0
Pinoxaden	50	2.10(4)	2.55(6)	6.06(37)	7.67(59)	6.37(40)	8.08(64.9)	98.0	97.0
Clodinafop propargyl	60	3.05(8)	3.56(12)	6.14(37)	7.38(54)	6.79(46)	8.14(65.5)	96.0	94.1
Fenoxaprop-p-ethyl	120	4.08(16)	4.36(18)	6.08(36)	7.53(56)	7.26(52)	8.72(74.1)	92.1	91.1
Weed free	-	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	100.0	100.0
Untreated control	-	14.24(202)	14.72(216)	7.31(53)	7.46(55)	15.99(255)	16.49(271)	0	0
LSD (P=0.05)		0.38	0.78	1.53	1.74	1.30	1.49	-	-

Figures in parentheses are means of original values. Data are subjected to square root transformation

Table 3. Effect of pre-mix of pinoxaden + clodinafop propargyl on yield attributing characters and yield of wheat during 2011-12 and 2012-13

Treatment	Dose (g/ha)	No. of spikes/m^2		Spike length (cm)		No. of grain/spike		1000-grain weight (g)		Yield (t/ha)	
		2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Pinoxaden 2.53%+ clodinafop propargyl 2.53% EC	40	308	297	11.3	11.0	38.7	38.3	45.7	45.5	4.1	4.1
Pinoxaden 2.53% + clodinafop propargyl 2.53% EC	50	342	327	11.7	11.6	40.7	40.3	48.5	48.1	4.6	4.5
Pinoxaden 2.53% + clodinafop propargyl 2.53% EC	60	347	330	12.0	11.8	41.5	40.9	48.9	48.5	4.6	4.5
Pinoxaden	50	336	322	11.5	11.2	39.7	39.3	46.8	46.5	4.5	4.4
Clodinafop propargyl	60	334	320	11.7	11.5	40.3	39.7	47.8	47.5	4.5	4.4
Fenoxaprop-p-ethyl	120	310	300	11.0	10.9	39.3	38.7	46.0	45.8	4.3	4.2
Weed free	-	372	366	12.4	12.1	42.7	42.3	48.9	48.8	5.2	5.2
Untreated control	-	200	204	10.5	10.8	35.9	36.3	44.8	45.1	2.3	2.5
LSD (p=0.05)		7.13	6.96	NS	NS	1.79	1.57	0.48	0.46	672.4	0.3

1000-grain weight (48.9 and 48.8 g) were observed under weed free condition during 2011-12 and 2012-13 respectively. The higher grain yield and yield attributing characters in pre-mix of pinoxaden + clodinafop propargyl at 60 g/ha was attributed to low weed density and weed biomass, which might have caused less weed competition with wheat resulted in the production of higher yield attributes which was reflected in higher yield.

It can be concluded that application of pre-mix of pinoxaden 2.53% + clodinafop propargyl 2.53% applied at 50-60 g/ha at 35 days after sowing is effective for the control of *Phalaris minor* and *Avena ludoviciana* and also produce higher grain yield of wheat.

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Management of weeds in sugarcane-wheat intercropping system in sub-tropical India

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ABSTRACT

Sugarcane being a widely spaced crop offers considerable space for cultivation of short duration intercrop. In sub-tropical India, sugarcane planted in autumn accounts for higher productivity due to extended period (approximately 12–16 months) of vegetative growth, but its feasibility is only possible if some intercrop especially wheat in *Rabi* season is sown as it can help farmer in generating additional income in midway of sugarcane season. Two rows of wheat has already been recommended in the north – western India, but the success was marred due to lack of suitable weed control methods in sugarcane – wheat intercropping system. Twelve weed control treatments including ten applications with post-emergent herbicides *i.e.* sulfosulfuron 25 g/ha and 37.5 g/ha, pinoxaden 50 g/ha and 75 g/ha, readymade blend of sulfosulfuron + metsulfuron 30 g/ha and 45 g/ha, readymade blend of mesosulfuron + iodosulfuron 14.4 g/ha and 21.6 g/ha, metsulfuron 5 g/ha , carfentrazone-ethyl 20 g/ha, a weed free treatment with two hoeings at 3 and 6 weeks after sowing wheat (WASW) and an unweeded control (no hoeing and no herbicide application) were evaluated for three years from 2008-09 to 2010-11 in randomized block design with three replications. The objective of the experiment was to identify the best possible method of weed control for maximizing the productivity of sugarcane wheat intercropping system. All the chemical and cultural weed control treatments including the application of herbicides and manual hoeings suppressed the weeds efficiently as compared to the unweeded control. Among the herbicidal spray, application of sulfosulfuron 25 g and 37.5 g/ha recorded the lowest pooled dry matter of weeds and thus exhibited the highest weed control efficiency (mean of three years) (61.2% and 63.5%, respectively). The highest pooled cane equivalent yield of 92.7 t/ha was recorded with sulfosulfuron + metsulfuron 30 g/ha. Application of any herbicide at a higher dose than normal, could not supplement additional millable canes and sugarcane yield. Application of readymade blends of sulfosulfuron + metsulfuron 30 g/ha and mesosulfuron + iodosulfuron 21.6 g/ha produced pooled intercropped wheat yield of 3.41 and 3.49 t/ha which surpassed the 3.35 t/ ha of wheat yield achieved with two manual hoeings at 3 and 6 WASW. The cane quality was not affected by application of any herbicide.

Key words: Herbicides, Intercropping system, Sugarcane, Sulfosulfuron, Weed control, Wheat

Severe decline in water table, degradation of soil and environment in the irrigated trans-gangetic tracts of sub-tropical India due to the paddy – wheat monoculture has forced the researchers to think of an optimal cropping rotation for the region. Some opine that sugarcane alongwith an intercrop could be a potential system which can match (or even surpass) the minimum support price (MSP) of wheat/rice offered by the government and thus can help the farmers in sustaining their current income level. Sugarcane in sub-tropical part of India is being sown twice a year, one as spring cane in the month of February – March and the other as autumn cane during the month of September – October. Autumn sugarcane takes around 12 to 14 months on account of extended growth period due to longer duration for tiller production (Rana *et al.* 2006) while the spring sugarcane takes 10-11 months to mature. Consequently, in a subsistence farming situation a farmer can not afford to loose the income from a *Rabi* crop, as larger gap in income flow may ruin his domestic economy. Hence, in intensively cultivated areas, introducing an intercrop within the main crop is one of the most promising options for crop diversification and narrowing the gap in income generation i.e. once a year from sugarcane to twice a year with an additional intercrop.

Intercropping in sugarcane has been recognized as a potential system for augmenting the productivity over space and time. The inter row distance for cultivating autumn sugarcane ranged from 0.9 m to 1.5 m in trans-gangetic plains and inclusion of intercrops in these inter row spaces offers a better

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scope for increasing the total productivity and income. There is generally a trend toward higher productivity in an intercropping system. Even in areas where yield of the companion crop was substantially reduced, the total yield was greater (Aggarwal *et al.* 1992, Imam *et al.* 1990 and Bokhtiar *et al.* 1995). Autumn planting of sugarcane is more remunerative than spring sugarcane as after initial germination of autumn sugarcane, its growth slows down during winter months (Nov. to 1st week Feb.) allowing a farmer to easily cultivate a *Rabi* intercrop in the wider inter-row spaces. To increase the sustainable agricultural production system in India, intercropping in sugarcane with short duration crops enables the small and marginal farmers to harvest more economic returns on account of better utilization of land, labour, nutrients and irrigation water. Several crops like lentil, potato, peas, cabbage, onion, garlic, winter maize, urdbean, okra, mentha *etc*. are recommended as intercropping in autumn and spring planted sugarcane (Singh *et al.* 1986, Lal and Singh 2004, Jamuna *et al.* 2007, Tripathi and Lawande 2008). Benefits of intercropping legumes like soybean, sunhemp and cowpea in sugarcane improved the soil properties, sustain the sugarcane yield and increases the total productivity of the system (Khandagave 2010, Li *et al.* 2013, Jamuna *et al.* (2007).

Wheat being the staple food of the farmers in sub-tropical India gets better price and assured marketing and thus is the most economically viable and feasible intercrop during the *Rabi* season. As per the availability of inter row spaces between sugarcane, two rows of wheat as an intercrop balances the competition for resources and thus has already been recommended to step up the production of both the crops (PAU 2011). Still this practice is not popular among the farmers as the reduced intercultural operations in an intercropping system may sometimes lead to enhanced weed infestation.

Weed management in an intercropping system has always been an issue as concentrated efforts are required to provide weed-free environments at regular intervals to both main/base crop and component crop for attaining higher productivity levels (Shah 2011). Reductions in yield due to weeds, both in sole and intercropped sugarcane, have been estimated to vary from 26 to 75% (Patil *et al.* 1991; Srivastava *et al.* 2005). Manual and cultural weed-control measures are often rendered uncertain due to interference of rains. The use of the herbicides is, thus, the only resort as it offers a good scope for timely and adequate control of weeds.

The weed control recommendations made for sole sugarcane crop using atrazine and metribuzin (Singh and Kumar 2013) or even that used in ratoon crop using diuron (Kumar *et al.* 2014) may not hold good in an intercropping system due to operational and phyto-toxicity issues. It was in this context that the present investigations was undertaken to find out economically viable alternative weed management strategy for autumn sugarcane – wheat intercropping system. An intercropping of wheat in sugarcane coupled with effective weed-control measures may help the farming community to realize the potential yield of both wheat and sugarcane.

MATERIALS AND METHODS

The field experiment was conducted during 2008–2011 at Ladhowal farm of Punjab Agricultural University, Ludhiana which represents the Indo-Gangetic alluvial plains and is situated at 30^0 56' N latitude and 75^0 52' E longitudes with an altitude of 247 m above the mean sea level. The area is characterized by sub-tropical and semi-arid type of climate with hot and dry summer from April to June followed by hot and humid period during July to September and cold winters from November to January. The mean maximum and minimum temperatures show considerable fluctuations during different parts of the year. Summer temperature hovers around 38^0C and touches 45^0C with dry summer spells. Winter experiences frequent frosty spells especially in December and January and minimum temperature dips up to 0.5^0C. The average annual rainfall of Ludhiana is 733 mm (Kingra *et al.* 1996), the major portion of which (75%) is received during July to September. The soil of the experimental field during first and third cropping season was loamy sand with pH of 7.5 and EC of 0.22 dS/m , low in organic carbon (0.31%) and available N (188 kg/ha) medium in available Olsen's P (13.4 kg/ha) and exchangeable K (257 kg/ha) in the top 15 cm soil depth. During the 2^{nd} cropping season soil was sandy loam in texture, low in organic carbon (0.36%), medium in available phosphorus (18.5 kg/ha) and medium in exchangeable potassium (305 kg/ha). The total rainfall received during the first, second and the third cropping season were 961.3, 740.7 and 1315.4 mm respectively.

The experiment comprised of a total of twelve weed control treatments including ten applications with post-emergent herbicides already recommended in sole wheat *i.e.* sulfosulfuron 25 g/ha and 37.5 g/ha, pinoxaden 50 g/ha and 75 g/ha, readymade blend of sulfosulfuron + metsulfuron 30 g/ha and 45 g/ha, readymade blend of mesosulfuron + iodosulfuron 14.4 g/ha and 21.6 g/ha, metsulfuron 5 g/ha, carfentrazone-ethyl 20 g/ha, a weed free treatment with two hoeings at 3 and 6 weeks after sowing wheat (WASW) and an unweeded control (no hoeing and no herbicide application). The lower doses of herbicides are at recommended doses to sole wheat while the higher dose is one and half times over the recommended one with an objective to assess the visual symptoms of toxicity to sugarcane, if any. All the herbicides were sprayed at 4 – 5 WASW but after the application of first irrigation, assuring presence of sufficient moisture at the time of spray. These treatments were evaluated under randomized block design with three replications. Sugarcane variety '*CoJ 85*' was planted in rows 90 cm apart using 50,000 three budded setts per ha (approximately 85 qtls seed) in autumn season during the first week of Oct. over the three consecutive years. The wheat variety *PBW 550* was intercropped as dual rows 20 cm apart in between two rows of autumn sugarcane in the 1st fortnight of Nov. after a pre sowing irrigation during all the three years of study. The gross plot size for sugarcane during first and third cropping season was 4.5 x 5.0 m = 22.5 m^2 while it was 5.4 x 5.0 m = 27.0 m^2 during the second cropping season. The plot size for wheat as intercrop during first and third cropping season was 3.6 x 5.0 m = 18.0 m^2 and during the second cropping season was 4.5 x 5.0 m = 22.5 m^2.

Recommended doses of fertilizers were applied to sugarcane (225 kg N/ha) and wheat (N: P_2O_5 : K_2O 25 : 12 : 12 kg/ha). N was applied in three equal splits to sugarcane (at planting, in end March and last dose in end April after the harvest of wheat alongside cane rows) and in two splits to wheat (half at sowing and half after first irrigation). Full dose of P and K fertilizers were applied at sowing only. All the other cultural operations were followed as per recommended package of practices to raise a healthy sugarcane and wheat crop (PAU 2011). Herbicides were applied 35-40 days after intercropping wheat using knapsack sprayer fitted with flat fan nozzle using a spray volume of 375 lts/ha. Sugarcane was harvested close to the ground manually from the central rows of each plot during second fortnight of following November in all the three planting seasons. Wheat was harvested in the first fortnight of April during all the three cropping seasons and was threshed manually within the plots.

Data collection and analysis

The weed count and biomass of prevalent weed flora during *Rabi* season was assessed one month after spray of herbicides by using three random samples from a quadrat of 0.25 m^2. The fresh sample of weeds so obtained from that quadrat were kept in hot air oven at 70^0C (till constant weight is recorded) for determining weed biomass and weed control efficiency. The weed control efficiency (WCE) was calculated using standard formula

Total yield of intercrop was recorded from the central rows of whole plot. Total number of sugarcane shoots were recorded at maximum tillering stage in June, two months after harvesting wheat. Five millable canes were randomly taken from the plot at sugarcane harvest and observations on yield attributes (cane length, internodes, millable canes, and single cane weight) and juice quality parameters (brix, Pol and purity) were recorded. Juice quality was determined following the procedure described by Gupta (1977). Sucrose per cent was determined as per Chen (1985). Cane equivalent yield was calculated by multiplying the average existing market price of wheat with its yield and dividing it by the price of sugarcane. Monetary returns are presented using the market prices of wheat as ` 10000, 11000, and 12850 per tonne while for sugarcane as ` 1800, 2000 and 2300 per tonne during 2008-09, 2009-10 and 2010-11 respectively. Benefit cost ratio (B:C) was derived by dividing the gross returns from the intercropping system by the total cost of production and was used for comparing the profitability of different weed control treatments over the unweeded control treatment. The sugar recovery as commercial cane sugar (CCS %) was determined as per Ahmed *et al.* (1998). Analysis of variance (ANOVA) on the collected data were calculated in a RCBD to test the level of significance at $P < 5.0\%$. Weed count and weed biomass data were square root transformed before performing ANOVA to normalize the distribution of residuals.

RESULTS AND DISCUSSION

Weed flora

The weed flora that emerged in the initial stages of autumn sugarcane was altogether different than those emerged in spring planted sugarcane in sub-tropical India. The dominant weeds, which were prevalent during the three *Rabi* seasons after the sugarcane and wheat planting were *Phalaris minor, Chenopodium album, Anagallis arvensis, Cyperus rotundus, Euphorbia simplex, Convolvulus arvensis, Rumex dentatus, Vicia sativa, Melilotus alba, Trigonella polycerata, Lepidium sativum, Fumaria parviflora,* and *Spergula arvensis.*

Weed density

The weed density observed 30-40 days after the herbicide spray in wheat intercropped in sugarcane crop differed significantly during all the three consecutive years of experimentation (2008-09, 2009-10 and 2010-11). The results in (**Table 1**) revealed that different weed control treatments recorded significantly lower weed density than the unweeded control. Among the weed control treatments, the lowest weed density or the best control was found with the post-emergence spray of mesosulfuron + iodosulfuron 14.4 g/ha in the first two experimental years and it was significantly better than the unweeded control. The pooled data too indicated excellent control by mesosulfuron + iodosulfuron 14.4 g/ha. Sulfosulfuron + metsulfuron 30 and 45 g/ha, sulfosulfuron 25 and 37.5 g/ha, pinoxaden 50 and 75 g/ha, carfentrazone-ethyl 20 g/ha and metsulfuron-methyl 5 g/ha too significantly lowered the weed density as compared to unweeded control but were statistically at par to two manual hoeings given at 3 and 6 WASW in all the years of study. The pooled data too followed the similar trend except for the application of mesosulfuron + iodosulfuron 14.4 g/ha which proved significantly better in restricting the weed density as compared to the metsulfuron-methyl 5.0 g/ha (**Table 1**). Some of the annual grasses might have escaped the killing action as metsulfuron-methyl is an organic compound classified as a sulfonylurea herbicide, which kills broad-leaf weeds and some annual grasses (Arnold *et al.* 2002). Using herbicides at higher dose (1.5 times the normal) could not ascertain any additional benefit in reducing the weed density.

Weed biomass

The minimum dry matter of weeds over the three years when pooled together were observed in treatment where two manual hoeings were given at 3 and 6 WASW. Post-emergence spray of sulfosulfuron 25 g and 37.5 g/ha, sulfosulfuron+ metsulfuron 30 g and 45 g/ha, metsulfuron-methyl 5 g/ha and carfentrazone-ethyl 20 g/ha reduced the dry matter of weeds at par to that observed under two hoeings at 3 and 6 WASW. But mesosulfuron + iodosulfuron 14.4 g and 21.6 g/ha as well as pinoxaden 50 g/ha recorded significantly higher weed dry matter than that obtained with two manual hoeings at 3 and 6 WASW (pooled data in **Table 1**). The appearance of new flush of weeds after a fortnight of application of these herbicides at the time of recording data might have increased the dry matter of weeds indicating lower residual effect after their spray while in case of manual hoeing, the weeds are cut 4-5 cm below the soil surface allowing them to emerge a little late after the completion of manual hoeing. All the chemical and cultural weed control treatments including the application of herbicides and manual hoeings proved significantly much better in effectively reducing the dry matter of weeds as compared to the unweeded control. Among the herbicidal spray, the lowest pooled dry matter of weeds were recorded when sulfosulfuron was applied 37.5 g/ha. The higher

Table 1. Weed density, dry matter of weeds and weed control efficiency as influenced by different weed control treatments

Treatment	Weed density/m^2				Weed biomass (g/m^2)				Weed control efficiency (%)			
	Yr 1	Yr 2	Yr 3	Pooled	Yr 1	Yr 2	Yr 3	Pooled	Yr 1	Yr 2	Yr 3	Mean
Sulfosulfuron 25 g/ha	8.65(74.7)	7.59(58.7)	8.05(64.0)	8.17(65.8)	7.51(55.9)	7.67(58.8)	8.45(71.3)	7.91(62.0)	71.8	59.2	46.4	61.2
Sulfosulfuron 37.5 g/ha	9.05(81.3)	7.49(57.3)	8.65(74.7)	8.45(71.1)	8.10(65.0)	6.57(42.7)	8.11(65.7)	7.64(57.8)	66.7	70.7	50.5	63.5
Pinoxaden 50 g/ha	9.30(86.7)	7.45(56.0)	7.81(61.3)	8.29(68.0)	8.34(69.2)	9.01(80.2)	9.25(84.7)	8.89(78.0)	65.5	44.0	37.4	51.6
Pinoxaden 75 g/ha	8.51(72.0)	6.70(45.3)	8.97(80.0)	8.16(65.8)	8.08(65.4)	7.84(61.8)	8.77(76.7)	8.30(68.0)	66.4	56.6	42.3	57.5
Sulfosulfuron + metsulfuron 30 g/ha	8.64(74.7)	7.97(62.7)	8.02(64.0)	8.25(67.1)	8.25(67.7)	7.51(55.8)	8.39(70.7)	8.08(64.8)	65.4	62.1	50.1	60.3
Sulfosulfuron + metsulfuron 45 g/ha	9.37(88.0)	7.55(56.0)	8.19(66.7)	8.43(70.2)	8.60(73.3)	7.43(56.3)	8.05(65.3)	8.10(65.0)	63.2	58.2	54.2	59.5
Mesosulfuron + iodosulfuron 14.4 g/ha	8.04(64.0)	6.46(41.3)	8.27(68.0)	7.65(57.8)	8.17(66.7)	9.03(81.2)	9.43(88.0)	8.90(78.6)	66.2	40.8	35.9	50.7
Mesosulfuron + iodosulfuron 21.6 g/ha	8.95(80.0)	6.74(45.3)	8.53(72.0)	8.16(65.8)	8.48(71.0)	8.84(77.4)	8.87(78.0)	8.74(75.5)	64.1	45.3	42.8	53.1
Metsulfuron-methyl 5 g/ha	9.13(82.7)	7.79(60.0)	9.32(86.7)	8.79(76.4)	7.68(58.2)	8.52(73.7)	8.21(67.7)	8.20(66.5)	70.2	46.6	52.1	58.1
Carfentrazone-ethyl 20 g/ha	8.73(76.0)	8.13(66.7)	7.85(61.3)	8.31(68.0)	8.12(65.5)	8.29(69.2)	8.78(76.7)	8.45(70.5)	66.5	50.1	42.5	56.0
Two hoeings at 3 and 6 WASW	8.48(72.0)	7.46(54.7)	8.75(76.0)	8.27(67.5)	7.11(49.7)	7.89(61.8)	7.48(55.7)	7.51(55.7)	75.0	57.8	58.6	65.6
Unweeded control (weedy check)	14.19(201)	13.59(184)	13.86(193)	13.92(192)	14.11(198)	12.16(148)	11.83(139)	12.76(162)	-	-	-	-
LSD (p=0.05)	1.80	2.01	1.88	0.87	1.55	2.10	1.92	1.12	-	-	-	-

Yr 1, Yr 2, and Yr 3 represents 2008-09, 2009-10 and 2010-11 respectively. WASW – Weeks after sowing wheat

Values of weed density and drymatter are transformed to square root while those in parentheses are the original values efficacy of sulfosulfuron towards better control of broad-leaf weeds might be the cause in registering the lowest ever recorded dry matter of weeds in the treated plot. Post-emergence application of all the herbicides irrespective of the dose in any individual year reduced the dry matter at par to each other except for the significant dominance of sulfosulfuron 37.5 g/ha over mesosulfuron + iodosulfuron 14.4 g and 21.6 g/ha as well as over pinoxaden 50 g/ha in the second year of study. The presence of higher number of broad-leaf weeds and its efficient control by sulfosulfuron 37.5 g/ha in the corresponding year might have led to such pronounced effect. Moreover, the higher and normal dose of any herbicide reduces the dry matter of weeds in a statistically similar fashion.

Weed control efficiency

The weed control efficiency among the weed management practices ranged from 63.2% to 75.0% in 2008-09, 40.8 – 70.7% in 2009-10 and 35.9 – 58.6% in 2011-12 (**Table 1**). The highest weed control efficiency of 65.6% (mean of three years) was obtained in treatment given two hoeings at 3 and 6 WASW. Among the herbicides, the maximum weed control efficiency (mean of three years) was exhibited by the application of sulfosulfuron 25 g and 37.5 g/ha (61.2% and 63.5%, respectively) followed by post-emergence application of sulfosulfuron + metsulfuron 30 g and 45 g/ha (60.3% and 59.5%, respectively).

Growth of sugarcane

Shoots of sugarcane form a bunch and it ultimately determines the millable canes. Unchecked growth of weeds in weedy check treatment drastically reduced the shoots of sugarcane and significantly recorded the minimum number in all the years of the study. The pooled data too followed similar trend (**Table 2**). Post-emergence application of herbicides at tillering stage of intercropped wheat did not affect the shoot number of sugarcane and recorded shoots at par to those obtained under two hoeings at 3 and 6 WASW over three years of experiment. The other growth parameters like internodes per cane, single cane weight and height of canes recorded at maturity were found to be least affected by the application of herbicides or manual hoeings as their values were at par to the unweeded check (**Table 2**). The pooled data for all the growth parameters of sugarcane also showed similar effect.

Millable canes and cane yield

Tolerance of sugarcane to different post-emergent herbicides applied to intercropped wheat during the *Rabi* season has lead to the production of millable canes and cane yield, statistically at par to that obtained under two manual hoeings given at 3 and 6 WASW. This was reflected by the statistically similar data in the pooled and individual years of study. But surely all the chemical and cultural control measures produced significantly better millable canes

Table 2. Growth components of sugarcane as influenced by different weed control treatments

Treatment	Shoots (000/ha)				Internodes per cane				Single cane wt. (g)				Height of canes (cm)			
	Yr 1	Yr 2	Yr 3	Pooled	Yr 1	Yr 2	Yr 3	Pooled	Yr 1	Yr 2	Yr 3	Pooled	Yr 1	Yr 2	Yr 3	Pooled
Sulfosulfuron 25 g/ha	175.3	158.2	160.1	164.5	16.3	14.6	15.1	15.3	816.5	809.1	827.3	817.6	192.9	167.7	172.5	177.7
Sulfosulfuron 37.5 g/ha	183.2	153.3	159.1	165.2	15.4	15.8	15.2	15.5	778.3	856.5	834.8	823.2	196.7	177.8	178.4	184.2
Pinoxaden 50 g/ha	183.2	145.7	150.1	159.7	15.2	14.4	15.3	15.0	804.4	860.1	810.3	824.9	205.0	168.7	180.8	184.8
Pinoxaden 75 g/ha	170.6	150.6	154.9	158.6	15.3	14.9	14.8	14.9	770.8	846.5	868.8	828.7	192.5	163.0	177.5	177.6
Sulfosulfuron + metsulfuron 30g/ha	180.5	150.8	162.4	167.3	14.7	14.4	13.9	14.3	814.5	883.8	860.1	852.8	206.3	175.3	182.1	187.9
Sulfosulfuron + metsulfuron 45g/ha	179.2	148.9	161.7	163.2	14.4	14.2	15.1	14.6	816.3	810.2	856.8	827.7	192.1	165.3	176.7	178.0
Mesosulfuron + iodosulfuron 14.4 g/ha	180.2	155.4	153.0	162.9	15.1	15.5	15.4	15.3	780.3	881.9	811.2	824.5	194.6	168.2	180.0	181.0
Mesosulfuron + Iodosulfuron 21.6 g/ha	189.8	142.9	154.9	162.5	14.4	14.8	14.6	14.6	882.4	920.9	735.2	846.2	194.5	172.6	191.3	186.1
Metsulfuron-methyl 5 g/ha	185.4	157.2	149.7	164.1	14.3	14.5	15.6	14.8	916.2	792.0	790.5	832.9	190.0	166.0	184.6	180.2
Carfentrazone-ethyl 20 g/ha	179.6	141.6	158.2	159.8	15.2	14.3	15.1	14.9	783.4	964.8	867.4	871.9	197.1	164.8	179.1	180.3
Two Hoeings at 3 and 6 WASW	186.3	144.1	154.0	161.4	14.9	14.3	13.8	14.3	820.1	906.3	805.2	843.8	185.8	170.9	185.9	180.9
Unweeded Control (weedy check)	126.4	122.3	115.9	121.5	15.4	14.9	15.2	15.1	789.2	873.4	831.2	831.3	185.4	161.3	168.7	171.8
LSD (p=0.05)	24.0	19.2	23.3	12.5	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Yr 1, Yr 2, and Yr 3 represents 2008-09, 2009-10 and 2010-11 respectively. WASW – Weeks after sowing wheat , NS – Non-significant and cane yield in individual years as well as when pooled, than the unweeded control (**Table 3**). The highest pooled cane yield of 74.0 t/ha was recorded with sulfosulfuron + metsulfuron 30 g/ha and similar results were also reflected in the individual years of study. The increase in pooled cane yield with different weed control treatments ranged from 32.5 - 45.7% over the unweeded control. The data also indicated that application of a herbicide at a higher dose than normal, could not supplement the millable canes and the sugarcane yield.

Wheat yield

Post-emergence herbicide application at variable rates helped in increasing the yield levels of intercropped wheat over the unweeded control treatment in all the years of study. Sulfosulfuron 25 g and 37.5 g/ha, sulfosulfuron + metsulfuron 30 g/ha, mesosulfuron + iodosulfuron 21.6 g/ha, carfentrazone-ethyl 20 g/ha and two hoeings (at 3 and 6 WASW) significantly increased the yield over the unweeded control in all the years of study. As per the pooled mean, all the herbicides irrespective of their application rates being at par to each other produced significantly better wheat yield ranging from 38.8 to 59.4% than the unweeded control (**Table 3**), but the application of sulfosulfuron + metsulfuron 30 g/ha, and mesosulfuron + iodosulfuron 21.6 g/ha was so pronounced that the intercropped wheat yield attained as high as 3.41 and 3.49 t/ha respectively surpassing even the treatment where two manual hoeings were given at 3 and 6 WASW (3.35 t/ha).

Cane equivalent yield

All the weed control treatments including the application of herbicides at variable rates and the weed free treatment of two hoeings at 3 and 6 WASW increased the cane equivalent yield significantly over the unweeded control in all the years of study. The pooled mean showed that the increase in cane equivalent yield with the weed control treatments ranged from 34.7% with pinoxaden 75 g/ha to 47.6% with the post emergence application of sulfosulfuron + metsulfuron 30 g/ha. Application of sulfosulfuron + metsulfuron 30 g/ha recorded maximum cane equivalent yield ranging from 86.8 to 96.5 t/ha in the individual years and the same effect was reflected in pooled mean (**Table 3**). All the herbicides when applied at variable doses produced statistically similar cane equivalent yield to each other as well as to the weed free treatment of two manual hoeings at 3 and 6 WASW. The results also indicated that the application of any herbicide in sugarcane wheat intercropping system should be made at the dose recommended in sole wheat crop as differences with it's application at higher dose was statistically at par.

Cane quality

Cane quality worked out in terms of PoL (%) and commercial cane sugar (%) (**Table 4**) registered non-significant effect between the treatments of weed control and the unweeded check. The per cent sucrose represented in terms of PoL % as well as CCS % is not affected by variable doses of herbicides indicating the quality to be a function of some other factors like enzymes and nutrition and not linked to the effect of weed control. Kumar *et al.* (2014) also reported non-significant results on quality aspects of sugarcane due to different weed control treatments.

Sugar yield

Sugar yield is a function of per cent CCS and the cane yield. So variation in sugarcane yield levels with the different application rates of herbicides or manual

Table 3. Yield components of sugarcane and wheat as influenced by different weed control treatments

Treatment	Millable canes (t/ha)				Cane yield (t/ha)				Wheat yield (t/ha)				Cane equivalent yield (t/ha)			
	Yr 1	Yr 2	Yr 3	Pooled	Yr 1	Yr 2	Yr 3	Pooled	Yr 1	Yr 2	Yr 3	Pooled	Yr 1	Yr 2	Yr 3	Pooled
Sulfosulfuron 25 g/ha	89.3	79.0	94.3	87.5	71.7	63.3	77.5	70.8	3.68	3.15	3.18	3.34	92.0	80.7	95.0	89.2
Sulfosulfuron 37.5 g/ha	85.3	77.1	90.3	84.3	65.5	66.0	74.6	68.7	3.35	3.29	3.29	3.31	84.0	84.1	92.7	86.9
Pinoxaden 50 g/ha	85.6	76.0	90.2	83.9	68.7	65.4	73.1	69.1	3.03	3.39	3.21	3.21	85.4	84.0	90.7	86.7
Pinoxaden 75 g/ha	86.4	73.1	85.8	81.8	66.0	61.8	74.1	67.3	3.48	2.96	2.99	3.14	85.2	78.1	90.6	84.6
Sulfosulfuron + metsulfuron 30g/ha	93.1	78.2	91.0	87.4	75.1	68.9	78.0	74.0	3.59	3.26	3.36	3.41	94.8	86.8	96.5	92.7
Sulfosulfuron + metsulfuron 45 g/ha	87.8	79.6	88.7	85.3	70.3	64.0	76.1	70.1	3.04	3.45	3.50	3.33	87.0	83.0	95.3	88.4
Mesosulfuron + iodosulfuron 14.4 g/ha	93.1	71.1	87.1	83.8	72.1	61.6	70.4	68.0	2.99	3.14	3.54	3.22	88.5	78.8	89.9	85.7
Mesosulfuron + iodosulfuron 21.6 g/ha	84.6	72.0	97.6	84.7	74.7	66.0	71.4	70.7	3.64	3.37	3.45	3.49	94.7	84.5	90.4	89.9
Metsulfuron-methyl 5 g/ha	80.0	81.3	89.1	83.5	73.0	64.7	69.7	69.1	3.10	3.20	2.81	3.04	90.0	82.3	85.2	85.8
Carfentrazone-ethyl 20 g/ha	87.8	68.7	87.8	81.4	68.3	66.2	76.1	70.2	3.17	2.92	3.32	3.14	85.7	82.3	94.4	87.4
Two hoeings at 3 and 6 WASW	85.2	69.5	87.3	80.7	69.9	62.9	70.1	67.6	3.90	3.04	3.11	3.35	91.4	79.6	87.1	86.0
Unweeded control (weedy check)	64.7	51.5	68.5	61.5	50.9	44.7	56.8	50.8	2.32	2.06	2.18	2.19	63.7	56.0	68.8	62.8
LSD (p=0.05)	14.2	13.5	12.3	7.8	12.3	11.2	10.8	8.0	0.82	0.72	0.71	0.47	12.5	11.6	11.0	8.4

Yr 1, Yr 2, and Yr 3 represents 2008-09, 2009-10 and 2010-11 respectively. WASW – Weeks after sowing wheat

Prices of sugarcane and wheat for calculating cane equivalent yield were taken as ` 1800, 2000 and 2300/- per tonne for sugarcane and ` 10000, 11000 and 12850/- per tonne for wheat during 2008-09, 2009-10 and 2010-11 respectively hoeings significantly changed the sugar yield. All the herbicides when applied at recommended or 1.5 times the recommended dose produced the sugar yield at par to the two manual hoeings at 3 and 6 WASW but produced significantly better sugar yield than the unweeded control. The higher doses of applied herbicides in sugarcane – wheat intercropping system statistically could not show any additional advantage in improving the sugar yield.

Table 4. Quality aspects of sugarcane as influenced by different weed control treatments

Treatment	PoL (%)			CCS (%)			Sugar yield (t/ha)		
	Yr 1	Yr 2	Pooled	Yr 1	Yr 2	Pooled	Yr 1	Yr 2	Pooled
Sulfosulfuron 25 g/ha	16.80	18.06	17.43	11.50	12.40	11.95	8.3	7.8	8.0
Sulfosulfuron 37.5 g/ha	16.63	18.45	17.54	11.39	12.65	12.02	7.5	8.4	7.9
Pinoxaden 50 g/ha	16.43	18.44	17.44	11.17	12.75	11.96	7.7	8.3	8.0
Pinoxaden 75 g/ha	16.96	18.73	17.85	11.62	12.98	12.30	7.7	8.0	7.9
Sulfosulfuron + metsulfuron 30 g/ha	17.33	17.66	17.50	11.86	12.16	12.01	8.9	8.4	8.6
Sulfosulfuron + metsulfuron 45 g/ha	16.97	18.17	17.57	11.64	12.57	12.11	8.2	8.1	8.1
Mesosulfuron + iodosulfuron 14.4 g/ha	16.26	18.16	17.21	11.10	12.58	11.84	8.0	7.8	7.9
Mesosulfuron + iodosulfuron 21.6 g/ha	17.41	18.92	18.16	11.93	13.20	12.56	8.9	8.8	8.8
Metsulfuron-methyl 5 g/ha	16.45	18.32	17.39	11.21	12.69	11.95	8.2	8.2	8.2
Carfentrazone-ethyl 20 g/ha	17.45	18.87	18.16	12.04	13.11	12.57	8.2	8.6	8.4
Two hoeings at 3 and 6 WASW	18.02	17.33	17.68	12.40	11.86	12.13	8.7	7.5	8.1
Unweeded control (weedy check)	16.99	17.14	17.07	11.68	11.69	11.69	6.0	5.2	5.6
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	1.45	NS	1.3

Yr 1 and Yr 2 represents 2008-09 and 2009-10 respectively. WASW – Weeks after sowing wheat CCS – commercial cane sugar

Table 5. Economics of different weed control treatments in sugarcane – wheat intercropping system

Treatment	Total cost of cultivation (x10^3 `)				Gross returns (x10^3 `)			
	Yr 1	Yr 2	Yr 3	Average	Yr 1	Yr 2	Yr 3	Mean
Sulfosulfuron 25 g/ha	95.28	103.61	117.39	105.43	165.60	161.40	218.50	181.83
Sulfosulfuron 37.5 g/ha	95.82	104.12	117.88	105.94	151.20	168.20	213.21	177.54
Pinoxaden 50 g/ha	95.81	104.13	117.92	105.95	153.72	168.00	208.61	176.78
Pinoxaden 75 g/ha	96.61	104.90	118.67	106.73	153.36	156.20	208.38	172.65
Sulfosulfuron + metsulfuron 30 g/ha	95.23	103.56	117.37	105.38	170.64	173.60	221.95	188.73
Sulfosulfuron + metsulfuron 45 g/ha	95.74	104.04	117.84	105.88	156.60	166.00	219.19	180.60
Mesosulfuron + iodosulfuron 14.4 g/ha	95.52	103.86	117.67	105.68	159.30	157.60	206.77	174.56
Mesosulfuron + iodosulfuron 21.6 g/ha	96.17	104.49	118.29	106.32	170.46	169.00	207.92	182.46
Metsulfuron-methyl 5 g/ha	94.60	102.93	116.73	104.75	162.00	164.60	195.96	174.19
Carfentrazone-ethyl 20 g/ha	94.69	103.03	116.85	104.86	154.26	164.60	217.12	178.66
Two hoeings at 3 and 6 WASW	98.70	107.73	123.62	110.02	164.52	159.20	200.33	174.68
Unweeded control (weedy check)	94.20	102.58	116.42	104.40	114.66	112.00	158.24	128.30

Yr 1, Yr 2, and Yr 3 represents 2008-09, 2009-10 and 2010-11 respectively. WASW – Weeks after sowing wheat

Prices of sugarcane were taken as ` 1800, 2000, 2300 per ton during 2008-09, 2009-10 and 2010-11 respectively

Table 6. Net returns and B:C of different weed control treatments followed in sugarcane – wheat intercropping system

Treatment	Net return (x10^3 `)				Benefit : Cost			
	Yr 1	Yr 2	Yr 3	Average	Yr 1	Yr 2	Yr 3	Mean
Sulfosulfuron 25 g/ha	70.32	57.79	101.11	76.41	1.74	1.56	1.86	1.72
Sulfosulfuron 37.5 g/ha	55.38	64.08	95.33	71.60	1.58	1.62	1.81	1.67
Pinoxaden 50 g/ha	57.91	63.87	90.69	70.82	1.60	1.61	1.77	1.66
Pinoxaden 75 g/ha	56.75	51.30	89.71	65.92	1.59	1.49	1.76	1.61
Sulfosulfuron + metsulfuron 30 g/ha	75.41	70.04	104.58	83.34	1.79	1.68	1.89	1.79
Sulfosulfuron + metsulfuron 45 g/ha	60.86	61.95	101.34	74.72	1.64	1.60	1.86	1.70
Mesosulfuron + iodosulfuron 14.4 g/ha	63.78	53.74	89.10	68.87	1.67	1.52	1.76	1.65
Mesosulfuron + iodosulfuron 21.6 g/ha	74.29	64.50	89.63	76.14	1.77	1.62	1.76	1.72
Metsulfuron-methyl 5 g/ha	67.40	61.67	79.23	69.43	1.71	1.60	1.68	1.66
Carfentrazone-ethyl 20 g/ha	59.57	61.56	100.27	73.80	1.63	1.60	1.86	1.69
Two hoeings at 3 and 6 WASW	65.82	51.47	76.71	64.67	1.67	1.48	1.62	1.59
Unweeded control (weedy check)	20.46	9.42	41.82	23.90	1.22	1.09	1.36	1.22

Yr 1, Yr 2, and Yr 3 represents 2008-09, 2009-10 and 2010-11 respectively. WASW – Weeks after sowing wheat

Economics

Manual weed management by hoeings incur huge cost of labour which increases the total cost of cultivation and thus rendering it to be non-viable option as compared to herbicide application (**Table 5**). Application of sulfosulfuron + metsulfuron 30 g/ha in wheat intercropped in sugarcane gave the highest net returns of ` 83344/- and a benefit cost ratio was 1.79 (**Table 6**). The next profitable alternative was use of sulfosulfuron 25 g/ha which lead to the net returns of ` 76407/- and a benefit cost ratio of 1.72. The similar benefit cost ratio was also obtained when mesosulfuron + iodosulfuron 21.6 g/ha was applied to control weeds in sugarcane – wheat cropping system.

It was concluded that the productivity of intercropping of wheat in autumn sugarcane can be enhanced effectively by controlling *Rabi* weeds with the application of sulfosulfuron, sulfosulfuron + metsulfuron, mesosulfuron + iodosulfuron, metsulfuron-methyl, carfentrazone-ethyl, pinoxaden at a dose already recommended to wheat crop in sub-tropical part of India.

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Management of diverse weed flora of wheat by herbicide combinations

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ABSTRACT

A field experiment was conducted at College of Agriculture, Gwalior, India during *Rabi* (winter) seasons of 2014-15 and 2015-16 to evaluate the bio-efficacy of different herbicides to control diverse weed flora especially *Phalaris minor* in wheat. The experiment was laid out in a randomized complete block design, replicated three times, and consisted of 12 treatments including four treatment as pendimethalin (0.75 kg/ ha) as pre-emergence (PE); sulfosulfuron (0.025 kg/ha), metribuzin (0.21 kg/ha), clodinafop (0.06 kg/ha) as post-emergence (PoE) used individually and six of different herbicidal combinations as pendimethalin + metribuzin (1.0 + 0.175 kg/ ha PE), pendimethalin + sulfosulfuron (1.0 + 0.018 kg/ha PE and PoE), sulfosulfuron + metsulfuron (0.03 + 0.002 kg/ha at 5 WAS), pinoxaden + metsulfuron (0.06 + 0.004 kg/ha at 5 WAS), mesosulfuron + iodosulfuron(0.012 + 0.0024 kg/ha at 5 WAS), clodinafop + metsulfuron (0.06 + 0.004 kg/ha at 5 WAS), weedy check and as two hand weedings at 30 and 60 DAS. The highest mortality of weeds and the maximum grain yield of 5.00 t/ha and 4.07 t/ha with 38.2%, 31.0% increase in grain yield over weedy check were recorded with two hand weedings at 30 and 60 DAS (weed free) followed by herbicidal combination as pinoxaden + metsulfuron (0.06 + 0.004 kg/ha at 5 WAS) as PoE application during 2014-15 and 2015-16, respectively. Whereas, the highest B:C ratio of (3.69) was obtained with pinoxaden + metsulfuron (pre-mix) followed by sulfosulfuron + metsulfuron (3.67).

Key words: Chemical control, Hand weeding, Herbicide combinations, Weed flora, Wheat

Wheat (*Triticum aestivum* L.) occupies about 17% of the world's cropped land and contributes 35% of the staple food and 20% of the calories (Anonymous 2002). In India, it has been a staple food for a large population and its continued production is essential for food security. It is grown in an area of about 31.0 million hactares with production and productivity of 88.9 million tones and 2.87 t/ha, respectively (DES, 2015). Weeds are one of the main problems to maintaining wheat production and productivity levels. The estimated yield loss worldwide caused by weeds varied between 7.7 to 23.9% depending on the region (Kosina *et al.* 2007). Wheat is infested with diverse weed flora, as it is grown in diverse agro-climatic conditions, under different cropping sequence, tillage and irrigation regimes (Chhokar *et al.* 2012). If the weeds are not controlled at the critical stages of crop growth, they may cause reduction in yield up to 66% (Kumar *et al.* 2011). For controlling weeds in wheat, growers mostly rely on herbicides due to cost and time effectiveness. To control diverse weed flora in wheat effectively, different herbicidal combinations are required (Singh *et al.* 2015). The grain yield of wheat is significantly increased by use of different chemicals for weed control as compared with weedy check (Chaudhry *et al.* 2008). For the past few decades, several herbicides have been employed for weed management in wheat. The development of herbicide resistance by certain weeds like *Phalaris minor* is mainly due to the use of single herbicides over a long period. Hand weeding though considered being the most effective weed management tool but it is never an economical weed control method (Akhtar *et al.* 2000). Though the chemical method is being discouraged worldwide, however, its immediate effect and economic returns cannot be ignored totally by the farmers of countries like India. Instead, the ill effects of herbicides can be minimized through their judicious use at recommended doses. Therefore, the present investigation was undertaken to evaluate different weed management practices and the bioefficacy of herbicides against complex weed flora and their effect on productivity and profitability of wheat.

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MATERIALS AND METHODS

A field experiment was carried out at the research farm of Department of Agronomy, RVSKVV, College of Agriculture, Gwalior during *Rabi* seasons of 2014-15 and 2015-16. The soil contained 0.51% organic carbon with the pH of 7.8 and electrical conductivity 0.34 dS/m in the top 15 cm of soil. The initial N (191.2 kg/ha) content of soil was low, P (12.3 kg/ha) content in soil was marginally low and K (206 kg/ha) was medium with sandy clay loam in texture. The experiment was laid out in a randomized complete block design, replicated three times, and consisted of twelve treatments including four treatment as pendimethalin (0.75 kg/ha) as pre-emergence, sulfosulfuron (0.025 kg/ha), metribuzin (0.21 kg/ha), clodinafop (0.06 kg/ha) as post-emergence used individually and six of different herbicidal combinations as pendimethalin + metribuzin (1.0 + 0.175 kg/ha PE), pendimethalin + sulfosulfuron (1.0 + 0.018 kg/ ha PE and PoE), sulfosulfuron + metsulfuron (0.03 + 0.002 kg/ha at 5 WAS), pinoxaden + metsulfuron (0.06 + 0.004 kg/ha at 5 WAS), mesosulfuron + iodosulfuron (0.012 + 0.0024 kg/ha at 5 WAS), clodinafop + metsulfuron (0.06 + 0.004 kg/ha at 5 WAS), one kept weedy check for comparison and one cultural practice of weed control as two hand weedings at 30 and 60 DAS.

Wheat variety '*MP 4010*' was sown in rows 20 cm apart on 3rd December 2014 and harvested on 28th march 2015. The recommended dose of NPK was 120:60,:40 kg/ha and were supplied by urea, DAP and MOP, respectively. The full dose of P and K and half dose of N were applied at the time of sowing, whereas rest of the N was given in two equal splits one as top dressed at crown root initiation and another at late jointing stage of the crop. Irrigation was applied at all the critical stages of crop growth during the experimentation. Herbicides were applied at appropriate rate and suitable timings with the help of knapsack sprayer with flat-fan nozzle at spray volume of 600 liters water/ha. Observations on weed density and dry matter of weeds were recorded from 1.0 m^2 quadrate in each plot to determine species wise weed density and dry weight of weeds at 60 DAS. Statistical analysis of the data was carried out using analysis of variance technique as applicable to RCBD (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Effect on weeds

The complex weed flora of the experimental field comprised of grassy weeds as *Phalaris minor*, *Cyperus rotundus* and broad-leaved weeds as *Chenopodium album*, *Spergula arvensis*, *Convolvulus arvensis* during both the years of experimentation. *Rumex dentatus* was observed only in 2014-15 but was washed out from field during next year of experimentation. During 2015-16 in addition to above mentioned weeds, *Anagalis arvensis* was also observed.

In general, the weed density in the experimental field was less, it may be because the initial flush of weeds in the field was destroyed due to ploughing at the time of field preparation. All weed control treatments significantly reduced the weed density of *Phalaris minor* and *Chenopodium album* during 2014-15 and *P. minor* and *C. album*, *Cyperus rotundus, Spergula arvensis, Convolvulus arvensis* and *Anagalis arvensis* during 2015-16. While density of *C. rotundus, S. arvensis, C. arvensis* and *Rumex dentatus* was not reduced by any treatment significantly during 2014-15 and *A. arvensis* during 2015-16.

All the treatments reduced the dry weight of weeds significantly as compared to weedy check. The lowest weed dry weight was recorded in cultural method of weed control where two hand weedings were done at 30 and 60 DAS. The highest weed control efficiency of 91.74 and 93.31% was recorded with two hand weedings at 30 and 60 DAS during 2014-15 and 2015-16, respectively. It was followed by the herbicide combinations as mesosulfuron + idosulfuron (87.61%) during 2014-15 and by pinoxaden + metsulfuron (89.75%) during 2015-16. The treatments where sulfosulfuron applied individually gave highest WCE of 79.82% and 80.01% during 2014-15 and 2015-16, respectively. It is mainly because sulfosulfuron is a selective, systemic sulfonyl urea herbicide, absorbed through both roots and leaves. It translocates throughout the plant and acts as an inhibitor of amino acid biosynthesis, hence stopping cell division and plant growth.

The weed control efficiency under clodinafop was lesser than that of different other treatments during both the years.The total weed density during 2014-15 was lowest where sulfosulfuron and metsulfuron were applied conjointly and the weed management practice where two hand weedings were done at 30 and 60 DAS resulted in reduced weed density during 2015-16. Two hand weeding at 30 and 60 DAS resulted in highest weed control efficiency (91.7 and 93.3%) followed by the herbicidal combinations of mesosulfuron + iodosulfuron (87.6%) during 2014-15 and pinoxaden + metsulfuron (89.7%) during 2015-16. Among alone application of herbicidal treatments, application of sulfosulfuron 0.025 kg/ha resulted in efficient weed control of 79.8 and 80.0 during 2014-15 and 2015-16, respectively.

Effect on crop

The plant height of wheat crop was not influenced significantly under different weed management treatments during both the years of experimentation. No visual phytotoxic effect was observed on crop due to application of herbicide either individually or in combinations, except combined application of sulfosulfuron and metsulfuron. During initial growth period of crop, the application of sulfosulfuron in combination with metsulfuron (0.03 + 0.002 kg/ha) had influenced the crop adversely which was recovered within 10 -15 days after herbicidal treatment application.

Number of tillers, length of ear head and number of grains/ear were found the highest under two hand weedings done at 30 and 60 DAS which was at par with pinoxadon + metsulfuron (0.06 + 0.004 kg/ha). The number of grains/ear was the highest with mesosulfuron + iodosulfuron (0.012 + 0.0024 kg/ha as PoE). Among the individual herbicides, sulfosulfuron resulted in the highest number of grains/ear during 2014-15, and during 2015-16 clodinafop resulted the best. The highest grain yield of 5.03 t/ha was achieved with two hand weeding and was at par with sulfosulfuron + metsulfuron and mesosulfuron + iodosulfuron. Sulfosulfuron alone gave significantly the highest grain yield during 2014-15. Among various herbicidal combinations, application of pinoxaden and metsulfuron conjointly resulted in significantly the highest straw yield over weedy check.

Economics

All the weed control treatments were significantly superior over weedy check in terms of monetary returns during both the years. The highest net income and B:C ratio (` 71182/ha and 3.69) were fetched under pinoxaden + metsulfuron during 2014-15, but sulfosulfuron + metsulfuron (` 79296/ha and 3.14) resulted in the highest net returns and B C ratio during 2015-16. Alone application of sulfosulfuron 0.025 kg/ha resulted in the highest net returns and B C ratio (` 55353/ha, ` 48141/ha and 3.11, 2.84) during 2014-15 and 2015-16, respectively.

It has been concluded that application of metsulfuron in combination with sulfosulfuron and pinoxaden resulted in better weed control, higher crop yields and benefits .

Table 1. Effect of different herbicides and their combinations on weed population (no/m^2) in wheat (mean of 2014-15 and 2015-16)

Treatment	*Phalaris minor*		*Cyperus rotundus*		*Chenopodium album*		*Spergula arvensis*		*Convolvulus arvensiss*		*Rumex dantatus*	*Anagallis arvensis*	Total weeds	
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
Pendimelhalin 0.75 kg/ha PE	0.43 (2.33)	1.14 (13.0)	1.29 (18.67)	1.37 (24.33)	0.95 (8.00)	1.43 (27.33)	1.50 (3.00)	1.56 (2.00)	0.71 (0.00)	0.88 (0.33)	1.29 (1.33)	0.71 (0.00)	1.56 (33.33)	6.09 (67.00)
Sulfosulfuron 0.025 kg/ha PoE	0.00 (0.00)	0.40 (1.67)	1.41 (26.00)	1.11 (12.00)	0.36 (1.67)	1.19 (15.33)	1.05 (0.67)	1.34 (1.33)	0.88 (0.33)	0.71 (0.00)	0.71 (0.00)	1.17 (1.0)	1.38 (28.67)	5.63 (31.33
Metribuzin 0.210 kg/ha PE	0.54 (3.67)	1.07 (12.0)	1.43 (26.00)	1.68 (20.67)	0.16 (0.67)	1.22 (16.33)	0.71 (0.00)	1.64 (2.33)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	1.29 (1.33)	1.47 (30.33)	7.28 (52.67)
Clodinafop 0.060 kg/ha PoE	0.88 (7.00)	0.57 (3.0)	1.48 (29.67)	1.33 (21.00)	0.00 (0.00)	1.35 (22.00)	0.71 (0.00)	1.17 (1.00)	1.25 (1.67)	1.29 (1.33)	1.10 (1.00)	1.65 (2.67)	1.55 (39.33)	7.17 (51.00)
Pendimelhalin + metribuzin 1.0 + 0.175 kg/ha PE	0.16 (0.67)	0.85 (6.33)	1.36 (24.00)	1.14 (15.33)	0.00 (0.00)	1.42 (26.00)	1.25 (1.67)	1.56 (2.00)	0.88 (0.33)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	1.45 (26.67)	7.02 (49.67)
Pendimelhalin *fb* sulfosulfuron 1.0 + 0.018 kg/ha PE and PoE	0.00 (0.00)	0.72 (4.67)	1.34 (33.33)	0.99 (9.33)	0.26 (1.67)	0.78 (5.66)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	1.00 (0.67)	0.71 (0.00)	1.55 (35.67)	5.38 (29.33)
Sulfosulfuron + metsulfuron (total) 0.02 + 0.002 kg/ha PoE	0.00 (0.00)	0.16 (0.67)	1.18 (14.33)	0.71 (4.67)	0.00 (0.00)	1.20 (16.33)	0.88 (0.33)	0.88 (0.33)	0.71 (0.00)	0.88 (0.33)	0.71 (0.00)	1.68 (2.33)	1.15 (14.67)	3.78 (14.00)
Pinoxaden + metsulfuron (premix) 0.06 + 0.004 kg/ha PoE	0.00 (0.00)	0.52 (2.67)	1.30 (20.33)	0.95 (8.00)	0.51 (3.33)	1.04 (10.33)	0.71 (0.00)	1.29 (1.33)	1.00 (0.67)	1.00 (0.67)	0.71 (0.00)	1.74 (2.67)	1.40 (24.33)	5.65 (31.67)
Mesosulfuron + iodosulfuron (atlantis) 0.012 + 0.0024 kg/ha PoE	0.00 (0.00)	0.32 (1.33)	1.29 (20.00)	0.87 (6.67)	0.00 (0.00)	1.14 (13.33)	0.71 (0.00)	1.00 (0.67)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	1.17 (1.00)	1.26 (20.00)	4.52 (20.00)
Clodinafop + metsulfuron (vesta) 0.06 + 0.004 kg/ha PoE	0.30 (2.33)	0.42 (1.67)	0.93 (16.00)	0.93 (7.67)	0.76 (5.00)	1.30 (59.0)	0.71 (0.00)	1.34 (1.33)	0.71 (0.00)	0.88 (0.33)	0.71 (0.00)	1.00 (0.67)	1.33 (23.33)	5.05 (25.00)
Two hand weedings at 30 and 60 DAS	0.00 (0.00)	0.00 (0.0)	1.20 (15.67)	0.74 (5.00)	0.23 (1.33)	0.36 (1.67)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.88 (0.33)	0.71 (0.00)	0.71 (0.00)	1.28 (17.00)	2.71 (7.00)
Weedy check	1.82 (66.67)	1.78 (59.3)	1.80 (63.33)	1.68 (49.00)	1.68 (47.67)	1.69 (51.00)	1.64 (2.67)	2.24 (4.67)	1.44 (2.67)	1.76 (2.67)	1.64 (2.67)	1.86 (3.0)	2.30 (185.7)	13.04 (169.7)
LSD (p=0.05)	0.44 Log x+1	0.32 $\sqrt{x+0.5}$	NS Log x+1	0.32 Log x+1	0.42 Log x+1	0.34 Log x+1	NS $\sqrt{x+0.5}$	0.62 $\sqrt{x+0.5}$	NS $\sqrt{x+0.5}$	0.48 $\sqrt{x+0.5}$	NS $\sqrt{x+0.5}$	0.69 $\sqrt{x+0.5}$	0.18 Log x	2.29 Log x

Original values given in parentheses were subject to square root transformation

Table2. Effect of different herbicides and their combinations on growth, yield attributes and economics of wheat during 2014-15 and 2015-16

Treatment	Plant height (cm)		No. of tillers/plant		Ear head length (cm)		No. of grains/ear		Grain yield (t/ha)		Straw yield (t/ha)		Dry weight (g/m^2) 60 DAS		WCE (%)		B.C. Ratio	
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
Pendimelhalin 0.75 kg/ha PE	91.1	90.8	4.27	3.87	8.83	8.73	47.3	51.0	3.50	3.19	5.05	4.77	64	76.0	70.6	63.5	2.63	2.41
Sulfosulfuron 0.025 kg/ha PoE	90.6	90.6	5.00	4.83	9.77	9.67	52.0	53.1	4.19	3.80	5.52	5.09	44	32.7	79.8	80.0	3.11	2.84
Metribuzin 0.210 kg/ha PE	93.7	93.7	4.20	4.30	8.77	9.00	50.0	52.7	3.50	3.26	5.03	4.79	84	50.7	61.5	64.9	2.66	2.51
Clodinafop 0.060 kg/ha PoE	93.7	94.0	4.00	4.67	8.70	8.90	51.7	54.0	3.74	3.51	5.38	4.99	65	35.0	70.2	73.9	2.80	2.64
Pendimelhalin + metribuzin 1.0 + 0.175 kg/ha PE	92.9	94.5	4.40	4.60	9.40	9.93	52.3	52.7	3.93	3.58	5.35	4.81	71	50.0	67.4	68.5	2.82	2.56
Pendimelhalin *fb* sulfosulfuron 1.0 + 0.018 kg/ha PE and PoE	89.0	89.1	5.13	4.93	9.57	9.43	55.1	52.0	4.26	3.70	6.15	5.09	78	42.0	64.2	68.7	3.10	2.69
Sulfosulfuron + metsulfuron (total) 0.03 + 0.002 kg/ha PoE	92.9	94.4	5.37	4.93	9.97	9.70	55.3	55.7	4.96	4.20	6.51	5.19	30	17.0	86.2	87.7	3.67	3.14
Pinoxaden + metsulfuron (premix) 0.06 + 0.004 kg/ha PoE	92.0	92.8	5.53	4.83	10.13	9.30	53.7	55.3	5.00	4.07	6.74	5.23	28	11.3	87.1	89.7	3.69	2.99
Mesosulfuron + iodosulfuron (atlantis) 0.012 + 0.0024 kg/ha PoE	94.5	90.2	5.30	5.00	10.10	9.40	56.7	56.0	4.91	4.00	6.70	5.01	27	17.7	87.6	88.4	3.53	2.91
Clodinafop + Metsulfuron (vesta) 0.06 + 0.004 kg/ha PoE	93.7	92.2	5.33	4.80	9.93	9.23	55.7	55.7	4.56	3.80	6.52	5.14	39	18.0	82.1	85.1	3.41	2.82
Two hand weedings at 30 and 60 DAS Weed free)	94.6	90.6	5.40	5.13	10.47	9.57	56.0	55.3	5.03	4.30	6.74	5.16	18	7.7	91.7	93.3	2.98	2.56
Weedy check	86.1	89.9	3.40	3.30	7.87	7.90	37.0	41.3	3.09	2.81	4.80	4.22	218	165.7	-	-	2.44	2.19
LSD (p=0.05)	NS	NS	0.66	0.68	0.64	0.88	5.91	6.02	0.26	0.53	0.30	0.95	73	22.72		-	-	-

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Efficacy of imazethapyr applied alone and its mixture with other herbicides in green gram and their residual effect on mustard

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ABSTRACT

An experiment on evaluation of herbicides in greengram and their residual effect on succeeding mustard crop was conducted at Research farm of Department of Agronomy, CCSHAU, Hisar during *Kharif* 2013 and *Rabi* 2013-14. Weed flora of the experimental field was dominated by *Echinocloa colona* (78%), *Cyperus rotundus* (18%) and other weeds (4%) at 30 DAS. Pre-emergence application of ready mix (RM) imazethapyr + pendimethalin at 1000 g/ha provided good control (80%) of *Echinocloa colona* up to 30 DAS. At 60 DAS, imazethapyr + imazamox (RM) at 80 g/ha applied at 3-4 leaf stage provided maximum control of weeds, which was at par with two hoeings employed at 20 and 40 DAS. Post-emergence use of imazethapyr + imazamox (RM) at 60-80 g/ha exhibited 70-80% control of weeds with slight crop suppression which mitigated within 10-15 days after spray resulting maximum crop growth and seed yield. Early post-emergence application of imazethapyr at 50, 60 and 70 g/ha although caused mild injury to greengram in terms of yellowing of leaves and stunted crop growth up to 30, but it diminished within two weeks. Maximum seed yield (1078 kg/ha) of green gram was obtained with two hoeings at 20 and 40 DAS followed by imazethapyr + imazamox (RM) at 80 g/ha and imazethapyr at 70 g/ha applied at 3-4 leaf stage. All herbicides, irrespective of their dose and time of application, did not cause any injury to succeeding mustard crop due to high rainfall (594 mm) during crop growing season that resulted in to enhanced microbial degradation of herbicides.

Key words: Greengram, Herbicide efficacy, Herbicide persistence, Imazethapyr, Mustard, Phytotoxicity

The reduction in yield and quality of crop depends upon the weed species their duration and degree of infestation. Being a short duration crop, greengram is subjected to heavy infestation of weeds such as *Trianthema portulacastrum, Digera arvensis, Dactyloctenium aegyptium, Echinocloa colona, Cyperus rotundus, Corchorus aestuans, Mollugo* spp., *Cleome viscosa* and *T. terrestris* in Haryana state (Punia *et al.* 2013). In greengram, weed flora is more complex during *Kharif* season because of frequent rains, high temperature and wider row spacing. Singh *et al.* (1996) reported that yield of greengram was decreased by 35% where the crop was not weeded for first 30 days after sowing (DAS). Cultural and mechanical weed control can be practiced, but is not always feasible due to their high cost, non-availability of labour at appropriate time, prevailing weather conditions, long window of weed emergence in the growing season and continuous moisture during rainy season. So, chemical method of weed management offers good scope for harvesting a good crop of green- gram. Arvadiya *et al.* (1996) however, observed that pre-emergence application (PE) of pendimethalin at 1.0 kg/ha and two HW (20 and 40 DAS) gave similar yield. Bajpai *et al.* (1988) reported that application of pendimethalin at 1.0 kg/ha showed marked reduction in intensity of *E. colona, Phyllanthus niruri, Ageratum conyzoides* and other broad-leaved weeds. Singh and Kumar (2008) found that post-emergence application of imazethapyr at 75 and 100 g/ha reduced the density and dry biomass of broad as well as narrow leaved weeds significantly as compared to PPI, PE and PoE herbicides under study in soybean. Mishra and Bhanu (2006) reported that imazethapyr at 0.10 kg/ha (as PPI or PoE) was most effective against *E. geniculata* and pre-plant incorporation (PPI) of imazethapyr was superior to its post-emergence (PoE) application in increasing seed yield. Singh *et al.* (2014) reported that application of imazethapyr at 75 and 100 g/ha at 25 DAS gave good control of weeds and the weed control efficiency was comparable to that of two HW. Application of imazethapyr at 75 and 100 g/ha at 15 DAS resulted in 144.6 and 146.4% higher grain yield respectively over unweeded control.

Finding the duration of herbicide persistence at applied rate will be helpful for determining the toxicity of herbicide to sensitive crop. Jourdan *et al.* (1998) studied imazethapyr bioactivity and movement in soil

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and found that under low soil moisture and low temperature, a high level of imazethapyr residue was retained in the top 10 cm for 3 months. Punia *et al.* (2011) reported that post-emergence application of imazethapyr at 80 and 100 g/ha although caused mild injury to cluster bean but caused severe injury to succeeding mustard crop, but on the other hand, Sangwan *et al.* (2016) evaluated the performance of imazethapyr and its mixture with pendimethalin and imazamox in cluster bean and their residual effect on succeeding mustard crop, but no residual carry over effect of these herbicides was observed on succeeding mustard crop due to high rainfall and temperature during the crop season. Hence, the present experiment was planned to evaluate the efficacy of imazethapyr applied alone and in combination with pendimethalin or imazamox in greengram and their residual effect on succeeding mustard.

MATERIALS AND METHODS

An experiment was conducted at CCSHAU, Hisar during *Kharif* 2013 and *Rabi* 2013-14. The soil of the experimental field was sandy-loam in texture with 55% sand, 34% silt and 11% clay, slightly alkaline in reaction with pH 8.1, medium in fertility with 0.6% organic carbon, sufficient in N content (320 kg/ha), medium in P (17 kg/ha) and sufficient in K (317 kg/ha). The experiment was conducted in a randomized block design with three replications and 15 treatments. Treatments consisted of PE application of pendimethalin 1.0 kg/ha, ready mix (RM) of pendimethalin + imazethapyr (Valor) 0.8, 0.9 and 1.0 kg/ha and PoE application of imazethapyr 50, 60 and 70 g/ha, imazethapyr + imazamox (Odyssey) 50, 60, 70 and 80 g/ha along with weed free and weedy check. Greengram variety '*MH-421*' was drilled on July 22 June, 2013 in a plot size of 5.4 x 10 m, keeping row to row distance of 30 cm by using seed rate of 20 kg/ha and harvested on 23 September, 2013. Application of PE and PoE herbicides in different treatments were done by using flat-fan nozzle mounted on a backpack sprayer with a spray discharge of 250 l/ha at 42 p.s.i. pressure. Weed density and weed dry weight were recorded by randomly placing a quadrant (0.25 m^2) in each plot at 30 and 60 DAS. Plant material was dried at 65 ^{0}C for 48 hours before determining dry weight and this was used for calculating weed control efficiency (WCE). Per cent control of weeds was recorded at 15, 30, 45 and 60 DAS by visually comparing with weedy check. Visual crop injury to greengram due to different herbicides was quantified visually at 15, 30, 45 and 60 DAT (days after treatment) on 0-100 scale where 0 = no effect and 100 = complete mortality. Succeeding mustard var. '*RH30*' was sown after slight disking the field without disturbing the original layout. The weed density data with zero value were subjected to square root transformation and per cent data of weed control and visual crop injury were subjected to arcsine transformation in order to normalize their distribution. To evaluate the comparative performance of various treatments, data were subjected to one way ANOVA. The significance difference among treatments was tested by calculating LSD at p=0.05 level of significance.

RESULTS AND DISCUSSION

Weed density

The major weeds appeared in the experimental field were *E. colona* and *C. rotundus* (**Table 1**). Other weeds although low in density such as *Dactylocteinum aegyptium, Corchorus olitorius, Celosia argentia, Trianthema portulacastrum, Digera arvensis etc*. also infested the field. At 30 DAS, *E. colona* was the major weed infested the experimental area with relative density (RD) of 8% but at 60 DAS, *C. rotundus* with RD of 62% was the major weed. At 30 DAS, among herbicide treatments, ready mix combination of pendimethalin with imazethapyr at 900 and 1000 g/ha was the most effective treatment resulting in significant reduction of *E. colona* in comparison to weedy check (**Table 1**). At 60 DAS, all doses of imazethapyr alone and imazethapyr + imazamox (RM) used at 3-4 leaf stage provided excellent control of *E. colona*, but the plots treated with imazethapyr + imazamox 80 g/ha proved significantly superior to all other herbicidal treatments at all the stages (**Table 1**). Among the herbicide treatments, the lowest weed density (8.3/m^2) was recorded with imazethapyr + pendimethalin (RM) at 1000 g/ha applied as PE followed by its lower doses at 800 and 900 g/ha at 30 DAS (**Table 1**). At 60 DAS, effect of PoE application of imazethapyr + imazamox (RM) was visible as density of *C. rotundus* with use of this herbicide mixture was significantly reduced. There was no control of *C. rotundus* by PE application of pendimethalin at any stage (**Table 1**).

Dry weight of weeds

Among herbicidal treatments, significantly lower weed dry weight (7.4 g/m^2) was recorded with PE application of imazethapyr + pendimethalin (RM) at 1000 g/ha followed by imazethapyr + pendimethalin (RM) at 900 g/ha (**Table 1**). At 60 DAS, significantly lower dry weight of weeds (25 g/m^2) was recorded with two hoeing given at 20 and 40 DAS, which was significantly less over all other treatments. Although all herbicide treatments caused significant reduction in dry weight but ready mix formulation of imazethapyr + imazamox applied at 3-4 leaf stage at 80 g/ha was more effective than other treatments as dry weight of weeds in this treatment was 78 g/ha which was significantly less than the other herbicides (**Table 1**).

Per cent control of weeds

At 15 DAS, highest weed control (85%) was recorded with imazethapyr + pendimethalin (RM) at 1000 g/ha applied as PE. At 30 DAS, highest weed control (85%) was recorded with PE application of imazethapyr + pendimethalin (RM) at 1000 g/ha, which was at par with PE application of imazethapyr + pendimethalin (RM) at 800 and 900 g/ha (81 and 83%, respectively) (**Figure 1**). At 60 DAS, 90% control of *E. colona* was recorded with imazethapyr + imazamox at 80 g/ha followed by early post-emergence use of imazethapyr + imazamox (RM) at 60 and 70 g/ha (**Figure 1**). Although none of herbicide combination proved effective against *C. rotundus* but post-emergence application imazethapyr at 60 and 70 g/ha and its ready mix combination with imazamox at 60, 70 and 80 g/ha controlled 50% population of this weed (**Figure 2**). Although PE application of imazethapyr + pendimethalin (RM) at 1000 g/ha gave 46.7% control of *C. rotundus* up to 15 DAS but control decreased to only 28.3% at 60 DAS.

Plant dry weight and visual phytotoxicity (%) on green gram

At 30 DAS, the highest dry matter accumulation was recorded with imazethapyr + pendimethalin (RM) at 1000 g/ha (7.7 g/plant), which was at par

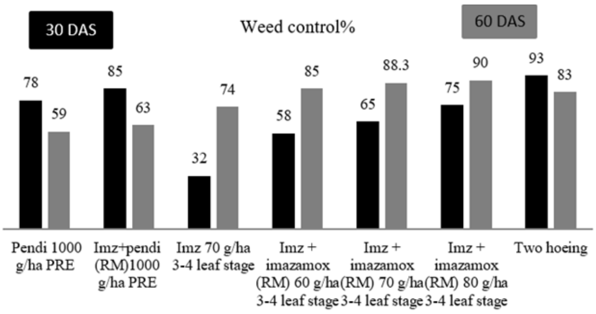

Figure 1. Per cent control of *E. colona* due to different weed control treatments at 30 and 60 DAS

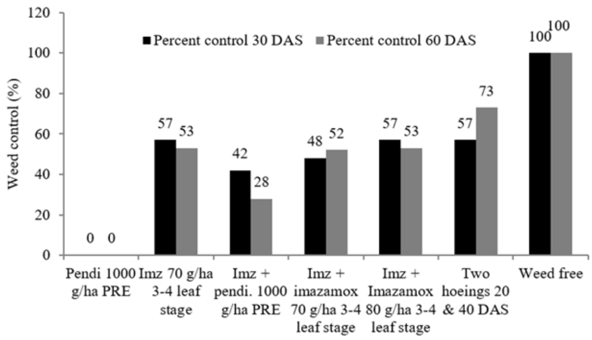

Figure 2. Per cent control of *C. rotundus* due to different weed control treatments at 30 and 60 DAS

Table 1. Effect of different herbicidal treatments on weed density and dry weight in green gram

Treatment	Dose (g/ha)	Application time	Weed density (no./m^2) *Echinocloa colona* 30 DAS	*Echinocloa colona* 60 DAS	*Cyperus rotundus* 30 DAS	*Cyperus rotundus* 60 DAS	Weed dry weight (g/m^2) 30 DAS	Weed dry weight (g/m^2) 60 DAS
Pendimethalin	1000	PE	8.4 (69.0)	4.9 (22.7)	5.4 (30.0)	9.1 (81.3)	3.5 (11.3)	14.3 (203.0)
Imazethapyr	50	3-4 leaf stage	11.6 (132.3)	2.9 (7.3)	4.6 (20.3)	8.3 (68.3)	4.6 (20.2)	11.5 (131.7)
Imazethapyr	60	3-4 leaf stage	11.1 (122.3)	2.7 (6.3)	4.3 (17.3)	7.6 (56.7)	4.3 (17.2)	10.8 (115.0)
Imazethapyr	70	3-4 leaf stage	10.8 (115.7)	2.7 (6.0)	3.8 (13.7)	6.9 (46.7)	4.2 (16.7)	10.2 (103.3)
Imazethapyr + pendimethalin (RM)	800	PE	6.9 (46.7)	5.7 (32.0)	3.7 (12.7)	8.1 (65.0)	3.3 (9.8)	14.2 (200.3)
Imazethapyr + pendimethalin (RM)	900	PE	5.0 (24.0)	5.1 (25.3)	3.3 (9.7)	7.0 (48.0)	3.2 (9.1)	13.6 (185.0)
Imazethapyr + pendimethalin (RM)	1000	PE	4.4 (18.7)	3.8 (13.3)	3.1 (8.3)	6.4 (40.0)	2.9 (7.4)	13.1 (170.2)
Imazethapyr + imazamox (RM)	50	3-4 leaf stage	9.1 (82.3)	2.9 (7.7)	5.0 (24.0)	7.9 (56.7)	4.0 (15.4)	12.1 (145.8)
Imazethapyr + imazamox (RM)	60	3-4 leaf stage	8.9 (78.7)	2.8 (6.7)	3.2 (19.3)	6.8 (45.0)	4.0 (15.1)	10.5 (108.8)
Imazethapyr + imazamox (RM)	70	3-4 leaf stage	7.6 (57.3)	2.3 (4.3)	4.4 (18.3)	6.1 (36.7)	4.0 (14.9)	10.0 (99.8)
Imazethapyr + imazamox (RM)	80	3-4 leaf stage	5.5 (29.3)	2.1 (3.3)	4.3 (17.3)	4.9 (23.3)	3.5 (11.0)	8.9 (78.0)
One hoeing	-	20 DAS	1.6 (1.7)	1.9 (2.7)	3.1 (8.3)	6.9 (47.3)	1.8 (2.3)	9.5 (90.0)
Two hoeings		20 and 40 DAS	1.5 (1.3)	1.5 (1.3)	2.3 (4.3)	4.2 (16.7)	1.8 (2.2)	5.1 (25.0)
Weedy check	-	-	12.1 (145.0)	6.8 (45.0)	5.8 (32.3)	9.2 (84.0)	6.3 (38.3)	19.0 (360.0)
Weed free	-	-	1.0 (0)	1.0 (0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)
LSD (p= 0.05)			0.3	0.3	0.4	0.4	0.3	0.5

Data in parentheses was subjected to square root transformation with pendimethalin at 1000 g/ha, imazethapyr + pendimethalin at 800 and 900 g/ha (**Table 2**). At 60 DAS, maximum dry matter (28.9 g/plant) was recorded with two hoeings employed at 20 and 40 DAS, which was at par with imazethapyr + pendimethalin (RM) at 900 and 1000 g/ha applied as PE and pendimethalin at 1000 g/ha. At harvesting, maximum dry matter was recorded with imazethapyr + imazamox (RM) at 80 g/ha (42.0 g/plant), which was at par with imazethapyr + imazamox (RM) at 50- 70 g/ha applied at 3-4 leaf stage and two hoeing given at 20 and 40 DAS (**Table 2**).

None of PE herbicides caused toxicity to green gram crop. Higher doses of imazethapyr (60 and 70 g/ha) and its ready mix combination with imazamox applied at 3-4 leaf-stage caused 11.3-23.3% toxicity to green gram, which mitigated within 15 days after application as it evident by visual phyto-toxicity recorded at 45 and 60 DAS. At 30 DAS, higher visual phyto-toxicity (23.3%) on crop was recorded with imazethapyr + imazamox (RM) at 80 g/ha applied at 3-4 leaf stage which was at par with imazethapyr + imazamox (RM) at 60 and 70 g/ha (**Table 2**).

Yield and yield attributes

Maximum number of pods/plant (37.1) and seeds/pod (11.8) were recorded in weed free treatment closely followed by two hoeings at 20 and 40 DAS (**Table 3**). Among herbicidal treatments, maximum number of pods/plant (34.6) were

Table 2. Dry weight of plant and Visual phyto-toxicity (0-100 scale) on greengram due to different weed control treatments at different intervals

Treatment	Dose (g/ha)	Application time	Dry weight of plant (g/m^2)			Phyto-toxicity (%)			
			30 DAS	60 DAS	Harvest	15 DAS	30 DAS	45 DAS	60 DAS
Pendimethalin	1000	PE	6.7	27.0	34.5	0	0.00	0	0
Imazethapyr	50	3-4 leaf stage	5.0	14.1	32.5	0	0.00	0	0
Imazethapyr	60	3-4 leaf stage	4.7	17.9	33.0	0	11.3	0	0
Imazethapyr	70	3-4 leaf stage	4.4	18.7	36.9	0	16.9	0	0
Imazethapyr + pendimethalin (RM)	800	PE	6.2	22.2	32.4	0	0.00	0	0
Imazethapyr + pendimethalin (RM)	900	PE	7.0	27.8	34.1	0	0.00	0	0
Imazethapyr + pendimethalin (RM)	1000	PE	7.7	28.0	36.5	0	0.00	0	0
Imazethapyr + imazamox(RM)	50	3-4 leaf stage	4.9	19.0	39.2	0	17.4	0	0
Imazethapyr + imazamox(RM)	60	3-4 leaf stage	4.7	22.1	41.0	0	20.3	0	0
Imazethapyr + imazamox(RM)	70	3-4 leaf stage	4.1	23.5	41.5	0	21.0	0	0
Imazethapyr + imazamox(RM)	80	3-4 leaf stage	3.7	24.6	42.0	0	23.3	0	0
One hoeing		20 DAS	4.8	27.4	33.0	0	0.00	0	0
Two hoeings	-	20 & 40 DAS	4.9	28.9	40.7	0	0.00	0	0
Weedy check	-	-	4.0	17.9	23.9	0	0.00	0	0
Weed free	-	-	7.8	29.7	42.4	0	0.00	0	0
LSD (p=0.05)			1.6	3.4	3.8		4.2		

Table 3. Effect of different herbicides on yield and yield attributes of greengram

Treatment	Dose (g/ha)	Application time	Pods/ Plant (no.)	Seeds/ Pod (no.)	Biological yield (t/ha)	Seed yield (kg/ha)	HI (%)	B: C ratio
Pendimethalin	1000	PE	25.3	8.5	2.44	492	20.4	1.38
Imazethapyr	50	3-4 leaf stage	31.4	8.3	2.96	721	24.2	2.04
Imazethapyr	60	3-4 leaf stage	31.9	8.9	3.22	837	25.3	2.33
Imazethapyr	70	3-4 leaf stage	32.8	9.9	3.26	915	27.7	2.51
Imazethapyr + pendimethalin (RM)	800	PE	25.2	8.1	2.52	565	22.7	1.55
Imazethapyr + pendimethalin (RM)	900	PE	27.5	8.7	2.70	580	22.7	1.58
Imazethapyr + pendimethalin (RM)	1000	PE	30.3	9.4	3.00	780	26.6	2.07
Imazethapyr + imazamox(RM)	50	3-4 leaf stage	31.2	10.3	2.93	764	25.8	2.14
Imazethapyr + imazamox(RM)	60	3-4 leaf stage	32.4	10.6	3.27	849	26.0	2.35
Imazethapyr + imazamox(RM)	70	3-4 leaf stage	33.3	10.9	3.30	880	27.1	2.40
Imazethapyr + imazamox(RM)	80	3-4 leaf stage	34.6	11.0	3.37	995	29.0	2.67
One hoeing	-	20 DAS	34.7	10.0	3.89	1013	26.7	1.86
Two hoeings		20 & 40 DAS	36.0	10.9	3.93	1078	27.8	2.47
Weedy check	-	-	19.6	6.9	1.54	290	19.0	0.91
Weed free	-	-	37.1	11.8	4.10	1143	28.1	1.74
LSD (p=0.05)			6.2	1.1	0.34	36	1.0	-

Table 4. Number of plants / m. r. l., number of pods/plant and seed yield of mustard as affected by residual carryover effect of different herbicides applied in green gram

Treatment	Dose (g/ha)	Application time	No. of plants / m. r. l.	No. of pods/ plant	Seed yield t/ha
Pendimethalin	1000	PE	11.0	299.3	2.48
Imazethapyr	50	3-4 leaf stage	11.7	306.7	2.47
Imazethapyr	60	3-4 leaf stage	6.7	306.7	2.50
Imazethapyr	70	3-4 leaf stage	9.0	303.3	2.52
Imazethapyr + pendimethalin (RM)	800	PE	9.3	301.7	2.47
Imazethapyr + pendimethalin (RM)	900	PE	10.7	298.3	2.50
Imazethapyr + pendimethalin (RM)	1000	PE	12.0	306.7	2.50
Imazethapyr + imazamox(RM)	50	3-4 leaf stage	7.3	306.7	2.45
Imazethapyr + imazamox(RM)	60	3-4 leaf stage	10.3	306.7	2.48
Imazethapyr + imazamox(RM)	70	3-4 leaf stage	10.0	310.0	2.47
Imazethapyr + imazamox(RM)	80	3-4 leaf stage	10.7	323.3	2.45
One hoeing		20 DAS	9.7	313.3	2.48
Two hoeing	-	20 and 40 DAS	10.3	313.3	2.50
Weedy check	-	-	7.3	306.7	2.52
Weed free	-	-	10.0	303.3	2.47
LSD (p=0.05)			NS	NS	NS

recorded with imazethapyr + imazamox (RM) at 80 g/ha, which were significantly higher than all PE herbicides and maximum number of seeds/pod (11) were recorded with imazethapyr + imazamox (RM) at 80 g/ha which was at par with all other 3 doses of imazethapyr + imazamox at 50-70 g/ha and imazethapyr alone at 70 g/ha applied at 3-4 leaf stage (**Table 3**). Weed free treatment by virtue of providing a favourable environment registered maximum seed yield (1.14 t/ha), which was significantly higher over all other treatments (**Table 3**). Post-emergence application of imazethapyr at 70 g/ha at 3-4 leaf stage also increased the seed yield (0.91 t/ha), significantly which was at par with the imazethapyr + imazamox (RM) at 70 g/ha. The maximum harvest index (29%) and B:C ratio (2.67) were recorded with imazethapyr+ imazamox (RM) 80 g/ha applied at 3-4 leaf stage closely followed by imazethapyr at 70 g/ha applied at 3-4 leaf stage (**Table 3**).

Residual effect of herbicides applied in green gram on succeeding mustard crop

Number of plants/meter row length (m.r.l.), no. of pods/plant and seed yield of mustard did not differ significantly by residual carryover effect of different herbicides applied in greengram due to enhanced microbial degradation of these herbicides due to occurrence of heavy rainfall between time of herbicide application and planting of mustard in *Kharif* 2013-14 (**Table 4**).

From the present study, it can be inferred that of two hoeings at 20 and 40 DAS or PoE application of imazethapyr + imazamox at 80 g/ha or imazethapyr alone at 70 g/ha should be adopted for the control of weeds in green gram without any adverse effect on succeeding mustard crop.

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Integrated weed management in cotton under irrigated condition of middle Gujarat

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ABSTRACT

A field experiment was conducted for two consecutive *Kharif* seasons of 2014 and 2015 at research farm of AICRP-Weed Management, AAU, Anand to study the integrated weed management in cotton under irrigated condition. Pre-emergence application of pendimethalin 1000 g/ha *fb* hand weeding twice at 20 and 50 DAS, and pyrithiobac-sodium + quizalofop-p-ethyl (62.5 + 50 g/ha) as PoE *fb* directed spray of glyphosate 2000 g/ha at 60 DAS recorded significantly lower weed dry biomass as well as higher seed cotton yield and benefit cost ratio as compared to rest of the treatments. The weed control efficiency of these treatments proved to be 90 and 86% during 2014 and 2015, respectively.

Key words: Cotton, Herbicides, Integrated weed management, Weed density, Yield

India is the leading country in terms of area under cotton in the world. Gujarat, Maharashtra and Telangana are the major cotton growing states contributing around 70% of the area and 67% of cotton production in India. Cotton crop is the main *Kharif* crop in irrigated middle-western plain of Gujarat. It covers around 27.61 lakh ha area, which is next to Maharashtra in India (Anonymous 2015). Losses in seed cotton yield due to presence of weeds is maximum. Weeds not only compete with the crop for nutrients, light, moisture, space and energy but, also harbor insects and disease organism thus, reducing the growth and yield of cotton due to weed competition (Papamichail *et al.* 2002). Cotton generally needs weed management in early stages of growth. Weed control in cotton from sowing to 8 weeks may increase the seed cotton yield from 30-40% (Jarwar *et al.* 2005). Manual measures for weed control without herbicide application is the most labour intensive and impractical method in modern agricultural production system. Under such circumstances, herbicides have remained the principal tool and foundation of most effective weed control programmes (Zhang 2003, Norsworthy *et al*. 2012). Yadav and Singh (2005) suggested the integrated use of various methods of weed control.

Therefore, the present study was undertaken to determine the efficacy of different herbicides as pre- and post-emergence, for controlling the weeds and their effect on seed cotton yield and economics of cotton.

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MATERIALS AND METHODS

A field experiment was conducted at research farm of AICRP Weed Management, Anand Agricultural University, Anand (Gujarat) during the *Kharif* seasons of 2014 and 2015. The soil of the experimental field was sandy loam in texture with pH of 8.10 and EC of 0.34 dS/m. The organic carbon, available nitrogen, phosphorus and potash of the soil were 0.46% (low), 240.57 kg/ha (low), 15.54 kg/ha (medium) and 233.29 kg/ha (medium), respectively. The experiment was comprised of ten treatments *viz.* application of pendimethalin 1000 g/ha PE *fb* HW at 20 and 50 DAS, pendimethalin1000 g/ha PE *fb* pyrithiobac-sodium 62.5 g/ha PoE, pendimethalin 1000 g/ha PE *fb* pyrithiobac + quizalofop-p-ethyl (62.5 + 50 g/ha) PoE, pyrithiobac-sodium + quizalofop-p-ethyl (62.5 + 50 g/ha) PoE, pyrithiobac + quizalofop (62.5 + 50 g/ha) PoE *fb* manual weeding 50 DAS, pyrithiobac + quizalofop (62.5 + 50 g/ha) PoE *fb* directed spray of paraquat 600 g/ha at 60 DAS, pyrithiobac + quizalofop (62.5 + 50 g/ha) PoE *fb* directed spray of glyphosate 2000 g/ha at 60 DAS, pendimethalin 1000 g/ha PE *fb* glyphosate directed spray 2000 g/ha at 45 DAS, mechanical weeding (20, 40 and 60 DAS) and weedy check. Experiment was laid out in randomized complete block design with three replications.

Bt. cotton (*GCH8*) was sown keeping the seed rate of 2.5 kg/ha with 120 cm row to row and 45 cm plant to plant distance. The crop was fertilized with 280 kg N/ha supplied through urea only. One fourth quantity of nitrogen (70 kg/ha) was applied as a basal and remaining quantity of nitrogen applied at different growth stages of cotton, *viz*. square formation, flowering and boll formation stages as top dressing in three equal splits. The pre-emergence herbicides were applied to soil on next day of sowing, while post-emergence herbicide spray was done at 20-25 DAS based on soil moisture condition as per the treatments. The weed density and dry weight of weeds were recorded at 90 DAS. Weed control efficiency (WCE) was calculated on the basis of formulae suggested by Mani *et al.* (1973). BCR value was also worked out by considering the prevailing market price on the basis of pooled seed cotton and stalk yields.

RESULTS AND DISCUSSION

Effect on weeds

The predominant weeds identified in the experimental site were *Eleusine indica, Commelina benghalensis, Eragrostis major, Dactyloctenium aegyptium, Digitaria sanguinalis* and *Cyperus iria* among the monocots and *Digera arvensis, Phyllanthus niruri, Euphorbia hirta, Oldenlandia umbellate* and *Boerhavia diffusa* among dicots. Grassy weeds were predominated (72.1%) followed by broad-leaved weeds (27.9). *Eleusine indica* and *Digera arvensis* were found to be predominant weed species among the grassy and broad-leaved weeds, respectively.

All the weed control treatments caused remark able reduction in monocot, dicot and total weed density and weed dry matter production when compared with weedy check (**Table 1**). The weed density in terms of monocot, dicot and total weeds at 90 DAS was found to be non-significant due to different weed management practices. Marginally lower number of monocot, dicot as well as total weeds were recorded under application of pyrithiobac + quizalofop (62.5 + 50 g/ha) PoE *fb* directed spray of glyphosate 2000 g/ha 60 DAS followed by pendimethalin 1000 g/ha PE *fb* twice hand weeding ay 20 and 50 DAS. Minimum weed dry biomass of dicot and total weeds were also registered under directed application of pendimethalin 1000 g/ha PE *fb* HW at 20 and 50 DAS followed by pyrithiobac + quizalofop (62.5 + 50 g/ha) PoE *fb* directed spray of glyphosate 2000 g/ha at 60 DAS. The reduction in weed dry weight under said treatments might be due to pendimethalin, which inhibits the cell division and root and shoot growth of the weeds preventing them from emerging, particularly during the crucial development phase of the crop. The results were in accordance with the finding of Gnanavel and Babu (2008) and Chinnusamy and Chinnagounder (2013). The highest weed dry biomass of monocot (18.1g/m^2), dicot (16.3 g/m^2) and total weed (25.6g/m^2) were recorded under weedy check treatment (**Table 1**).

Effect on crop

All the weed management practices significantly increased the seed cotton and stalk yield/ha (**Table 2**) over unweeded. Pre-emergence application of pendimethalin at 1000 g/ha *fb* hand weeding at 20 and 50 DAS, pyrithiobac-sodium + quizalofop-p-ethyl (62.5 + 50 g/ha) PoE *fb* directed spray of glyphosate 2000 g/ha 60 DAS, pyrithiobac-sodium + quizalofop-p-ethyl (62.5 + 50 g/ha) PoE *fb* directed spray of paraquat 600 g/ha and mechanical weeding (20, 40 and 60 DAS) remained at par with each other and recorded significantly higher seed cotton yield as Gnanavel and Babu (2008) observed that application

Table 1. Weed density and biomass as influenced by integrated weed management practices at 90 DAS in cotton

Treatment	Weed density (no./m^2)			Weed dry biomass (g/m^2)		
	Monocot weed	Dicot weed	Total weed	Monocot weed	Dicot weed	Total weed
Pendimethalin 1000 g/ha PE *fb* HW at 20 and 50 DAS	5.11(25.4)	8.15(69.7)	9.66(95.0)	6.21(43.1)	4.64(22.6)	8.04(65.7)
Pendimethalin 1000 g/ha PE *fb* pyrithiobac-sodium 62.5 g/ha PoE	5.98(35.0)	3.93(14.7)	7.11(49.7)	15.8(267)	9.01(85.7)	18.2(352)
Pendimethalin 1000 g/ha PE *fb* pyrithiobac + quizalofop-p-ethyl (62.5 + 50 g/ha) PoE	5.66(31.5)	4.37(18.8)	7.10(50.3)	14.6(230)	8.44(76.1)	16.8(306)
Pyrithiobac-sodium + quizalofop-p-ethyl (62.5 + 50 g/ha)PoE	8.42(70.0)	6.32(46.0)	10.7(116)	14.3(240)	13.6(186)	20.3(426)
Pyrithiobac + quizalofop (62.5 + 50 g/ha) PoE *fb* manual weeding 50 DAS	6.24(39.2)	7.11(57.7)	9.76(96.8)	6.11(36.9)	5.82(37.2)	8.57(74.2)
Pyrithiobac + quizalofop (62.5 + 50 g/ha) PoE *fb* directed spray of paraquat 600 g/ha at 60 DAS	5.88(34.2)	6.06(36.0)	8.41(70.2)	10.4(121)	7.21(51.8)	12.8(173)
Pyrithiobac + quizalofop (62.5 + 50 g/ha) PoE *fb* directed spray of glyphosate 2000 g/ha at 60 DAS	5.08(29.4)	2.59(5.90)	5.68(35.2)	7.69(66.8)	4.44(19.6)	9.00(86.4)
Pendimethalin 1000 g/ha PE *fb* glyphosate directed spray 2000 g/ha at 45 DAS	5.31(27.4)	5.24(29.0)	7.45(56.4)	13.5(183)	7.58(57.9)	15.5(241)
Mechanical weeding (20, 40 and 60 DAS)	7.07(50.7)	6.43(47.0)	9.57(97.7)	10.5(110)	4.22(20.7)	11.4(131)
Weedy check	7.58(57.2)	4.67(22.0)	8.90(79.2)	18.1(358)	16.3(295)	25.6(653)
LSD (p=0.05)	NS	NS	NS	NS	5.64	6.45

Data in parentheses were subjected to $(\sqrt{x+1})$ transformation; Data given in parentheses are original value

Table 2. Yield and economics of cotton as influenced by integrated weed management practices

Treatment	Seed cotton yield (t/ha)	Stalk yield (t/ha)	Gross returns (x10^3 `/ha)	Additional cost over control (x10^3 `/ha)	Cost of cultivation (x10^3 `/ha)	Net returns (x10^3 `/ha)	WCE at 90 DAS (%)	Weed Index (%)	B:C ratio
Pendimethalin 1000 g/ha PE *fb* HW at 20 and 50 DAS	3.30	5.66	140.9	8.13	58.25	82.71	90	0	2.42
Pendimethalin 1000 g/ha PE *fb* pyrithiobac-sodium 62.5 g/ha PoE	2.29	4.42	98.31	4.95	55.08	43.23	44	31	1.78
Pendimethalin 1000 g/ha PE *fb* pyrithiobac + quizalofop-p-ethyl (62.5 + 50 g/ha) PoE	2.25	4.82	97.07	6.55	56.68	40.39	52	32	1.71
Pyrithiobac-sodium + quizalofop-p-ethyl (62.5 + 50 g/ha) PoE	1.71	3.51	73.62	4.12	54.25	19.37	33	48	1.36
Pyrithiobac + quizalofop (62.5 + 50 g/ha) PoE *fb* manual weeding 50 DAS	2.73	4.55	116.4	6.10	57.09	59.39	88	17	2.04
Pyrithiobac + quizalofop (62.5 + 50 g/ha) PoE *fb* directed spray of paraquat 600 g/ha at 60 DAS	2.90	5.27	124.1	5.80	55.92	68.25	72	12	2.22
Pyrithiobac + quizalofop (62.5 + 50 g/ha) PoE *fb* directed spray of glyphosate 2000 g/ha at 60 DAS	3.08	5.36	131.6	6.38	56.51	75.13	86	7	2.33
Pendimethalin 1000 g/ha PE *fb* glyphosate directed spray 2000 g/ha at 45 DAS	2.19	4.42	94.21	4.70	54.82	39.39	62	34	1.72
Mechanical weeding (20, 40 and 60 DAS)	2.78	5.01	118.9	6.00	56.13	62.86	79	16	2.12
Weedy check	0.81	1.80	35.01	0.0	50.13	-15.12	-	76	0.70
LSD (p=0.05)	0.54	0.87	-	-	-	-	-	-	-

of pendimethalin at lower dose in conjunction with hand weeding provided significantly higher seed cotton yields than application of herbicides alone at higher doses. Similarly, Ali *et al.* (2005) reported that seed cotton yield increase to the tune of 199.4% under application of pendimethalin in combination with inter-culturing and hand weeding. Among the herbicidal treatments, desired seed cotton yield was not achieved in case of pyrithiobac-sodium + quizalofop-p-ethyl (62.5 + 50 g/ha) PoE. Similar line of results was also noticed for stalk yield. More than 79% weed control efficiency was recorded in pendimethalin 1000 g/ha PE *fb* hand weeding carried out at 20 and 50 DAS, pyrithiobac-sodium + quizalofop-p-ethyl (62.5 + 50 g/ha) PoE *fb* manual weeding at 50 DAS, pyrithiobac-sodium + quizalofop-p-ethyl (62.5 + 50 g/ha) PoE *fb* directed spray of glyphosate 2000 g/ha at 60 DAS and mechanical weeding (20, 40 and 60 DAS).

Economics

Pre-emergence application of pendimethalin 1000 g/ha *fb* HW at 20 and 50 DAS recorded maximum gross, net returns and B:C ratio of ` 140900/ha, ` 827100/ha and 2.42, respectively followed by pyrithiobac + quizalofop (62.5 + 50 g/ha) PoE *fb* directed spray of glyphosate 2000 g/ha at 60 DAS, which recorded the values of ` 131600/ha, ` 75130/ha and 2.33, respectively (**Table 2**). Weedy check recorded minimum gross and net return as well as benefit cost ration as compared to other treatments.

It was concluded that pre-emergence application of pendimethalin 1000 g/ha *fb* hand weeding at 20 and 50 DAS, and post-emergence application of pyrithiobac + quizalofop (62.5 + 50 g/ha) *fb* directed spray of glyphosate 2000 g/ha were found effective for controlling weeds and increased seed cotton yield and net return with higher cost benefit ratio as compared to rest of the treatments.

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Impact of herbicide mixtures on earth worm population, organic carbon content and β glucosidase enzyme activity in soil

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ABSTRACT

Earthworm population, soil organic carbon content and β glucosidase enzyme activity in the soil are considered as the indicators of soil quality and biomarkers for toxicity and bioaccumulation assessment. Hence, field experiments were conducted during first crop season (*Kharif* 2014) and second crop season (*Rabi* 2014-15) to study the impact of pre- mix herbicide mixtures bispyribac-sodium + metamifop and penoxsulam + cyhalofop-butyl on earth worm population , soil organic carbon content and β glucosidase enzyme activity in soil. The experiments were conducted in randomized block design with 12 treatments and three replications at Upaniyoor Padashekaram in Thiruvananthapuram district of Kerala, India. The treatments were bispyribac-sodium + metamifop at 60, 70, 80 and 90 g/ha, penoxsulam + cyhalofop-butyl at 120, 125, 130 and 135 g/ha, bispyribac-sodium applied alone 25 g/ha, penoxsulam applied alone at 22.5 g/ha, hand weeding twice and weedy check. All the herbicide treated plots registered earthworm population at par to weedy check and hand weeding. The organic carbon content in soil was higher in herbicide treated plots as compared to weedy check at all the stages of crop growth. Herbicide treated plots were comparable to non-herbicide treated plots with respect to glucosidase activity. It was concluded that the pre-mix bispyriibac-sodium + metamifop and penoxsulam + cyhalofop are environmentally safe.

Key words: Earthworms, β glucosidase enzyme activity, Herbicide impact, Non-target organism

Earthworm population, soil organic carbon content and β glucosidase enzyme activity in the soil are used as bioindicators of soil fertility and biomarkers for toxicity and bioaccumulation assessment (Nusetti *et al.* 1999, Gobi *et al.* 2004). Since, earthworms play a major role in soil quality by shredding residues, stimulating microbial activity and decomposition, improving soil fertility and soil physical properties; they are of great significance in the recycling of carbon and nitrogen in the ecosystem. Soil organic carbon is the important constituent of soil providing energy to the microorganisms and releasing nutrients to the plants through mineralization process (Abbas *et al.* 2015). β glucosidase enzymes releases low molecular sugars from organic matter, the important energy sources of microorganisms (Tabatabai 1994, Bandick and Dick 1999).

Weeds are the major biological constraint in direct-seeded rice due to the simultaneous emergence of crop and weeds and absence of water at the time of seedling emergence. Herbicidal management of weeds is the only viable and economic option for the control of weeds. But the continuous use of same herbicide or herbicides with similar mode of action will lead to the development of herbicide resistance and shift in weed flora either slowly or rapidly. One of the recent effective ways to overcome this problem is the use of herbicide mixtures. Herbicide mixtures contain two or more herbicides with different mode of action. Penoxsulam + cyhalofop-butyl 6% OD and bispyribac-sodium + metamifop 14% SE are the two new generation pre-mix herbicide mixtures which are having broad-spectrum activity and are more effective in controlling weeds compared to the individual application (Raj 2016). Penoxsulam + cyhalofop-butyl 6% OD is a pre- mix herbicide mixture containing, penoxsulam, a post-emergence broad-spectrum herbicide of triazolopyrimidine group inhibiting the enzyme acetolactate synthase and cyhalofop-butyl, also a post-emergence grass effective herbicide of group aryloxyphenoxy-propionate, inhibiting acetyl CoA carboxylase enzyme. Similarly, bispyribac-sodium + metamifop 14% SE contains, bispyribac-sodium, a post-emergence herbicide of group pyrimidinylcar-boxate inhibiting acetolactate synthase and metamifop also a post-emergence grass effective herbicide of group aryloxyphenoxypropionate group inhibiting acetyl CoA carboxylase.

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Latha and Gopal (2010) reported that large proportion of herbicides accumulate in the top 0-15 cm layer of soil due to the application of pre- and post-emergence herbicides. Several workers opined that herbicides have adverse effect on the survival of earthworms as well as its growth and reproduction and organic carbon content in soil (Zhou *et al*. 2007, Correia and Moreira 2010). Trimurtulu *et al*. (2015) pointed out that the herbicides, pendimethalin, oxyfluorfen and pretilachlor increased the organic carbon content in soil. However, Baboo *et al*. (2013) reported significant reduction in organic carbon level in soil after the application of herbicide. Mishra *et al*. (2013) revealed that significant quantity of organic matter accumulated in weedy check and hand weeded conditions compared to herbicides. β glucosidase enzyme is a soil quality indicator which gives the reflection of past biological activity and the capacity of soil to stabilize the soil organic matter (Bandick and Dick 1999, Ndiaye *et al*. 2000). Depending on the nature and concentration of herbicide, incubation period and soil condition, application of herbicide influence the β glucosidase activity in soil (Hussain *et al*. 2009).

According to Constenla *et al*. (1990) and Hoerlein (1994), preferred herbicides should not only have good efficacy in controlling weeds, but also pose minimum adverse effects to crop, ecology and environment. Hence the present investigation was undertaken to study the effect of herbicide mixtures, penoxsulam + cyhalofop-butyl and bispyribac-sodium + metamifop on earth worm population, soil organic carbon content and β glucosidase enzyme activity in soil, to ensure the environmental safety of these herbicide mixtures.

MATERIALS AND METHODS

Field experiments were conducted during the first (*Kharif* 2014) and second (*Rabi* 2014-15) crop seasons of 2014-15 at Upaniyoor Padashekaram (8°26.762' N latitude and 77°0.136’E longitude and 29 m above mean sea level) in Thiruvananthapuram district, Kerala, India. The experimental site has humid tropical climate. The average annual rainfall received during the period of experimentation was 875.5 mm during first crop season and 203.4 mm during second crop season.The mean maximum and minimum temperature recorded during first and second crop seasons were 30.1ºC and 24.4ºC and 30.8ºC and 22.6ºC, respectively. The total number of rainy days during first and second crop seasons were 46 and 21, respectively.

The soil was sandy clay loam, acidic in reaction, high in organic carbon and medium in N, P and K status.The experiment was laid out in a randomized block design with 12 treatments and three replications. The treatments were bispyribac-sodium + metamifop at 60, 70, 80 and 90 g/ha, penoxsulam + cyhalofop-butyl at 120, 125, 130 and 135 g/ha, bispyribac-sodium applied alone 25 g/ha, penoxsulam applied alone 22.5 g/ha, hand weeding twice and weedy check. The herbicides were applied on 15 DAS as per the treatment schedule using knapsack sprayer fitted with flat fan nozzle. The spray fluid used for the study was 500 l/ha. The variety used was ‘*Kanchana*’, a short duration variety released from Regional Agricultural Research Station, Pattambi of Kerala Agricultural University. The crop was fertilized with 70:35:35 kg/ha N, P and K, with one third N and K and half P applied on 15 DAS (days after sowing), one third N and K and half P on 35^{th} day and remaining one third N and K on 55^{th} day of sowing.

Soil samples for soil organic carbon estimation and β glucosidaseenzyme activity were collected with the help of soil auger at 15 DAS (just before herbicide application), 30 DAS (15 days after herbicide application), 60 DAS (45 days after herbicide application) and at harvest stage. Four samples of soil were collected from each experimental plot to a depth of 15 cm, mixed thoroughly to form a composite sample and kept in a polythene bag and stored at 4°C. The enzyme assay was completed within a week. β glucosidaseenzyme assay was carried out by incubating the soil with buffered (pH 6.0) para nitrophenyl β glucopyranoside. Para nitrophenol released was determined and expressed as µg para nitro phenol g/soil/h (Eivasi and Tabatabai 1988). After the estimation of β glucosidaseenzyme activity in soil, soil samples were shade dried, sieved through a 0.2 mm sieve and analysed for organic carbon content by rapid titration method (Walkley and Black 1934).

Estimation of earthworms was carried out before the sowing and after the harvest of first and second crop. Two representative samples from each plot were collected for the estimation of earthworm population. Sampling area was plotted with one metre square wooden frame. Soil samples were drawn up to 10 cm depth (Bano and Kale 1991). The soil lumps were broken and the soil was passed through the fingers to sort out the worms. The smaller worms were collected by passing through a sieve of 3-4 mm size. The worms were then counted.The data generated were statistically analysed using analysis of variance technique (ANOVA) and difference between the treatment means was compared at 5% probability level.

RESULTS AND DISCUSSION

Effect on earth worm population

Data on earthworm population indicated that before herbicide spraying, the average number of earthworms present in the experimental field was 3.8/ m^2 and 3.2/m^2 for the first and second crop seasons, respectively and no significant difference was observed among the treatments (**Table 1**). After the experiment, during both the seasons, an increase in earthworm population was observed irrespective of the treatments.The earthworm population recorded after the first and second crop was 3.9 and 7.3 no./ m^2, respectively and no significant variation could be observed among the treatments (**Table 1**). Though not significant, all the herbicide treated plots registered the same number or more of earthworms per square metre compared to weedy check and hand weeding (**Table 1**). This implies that, the tested herbicide mixtures and their doses did not leave any toxic residue in soil to affect the earthworm population.The results of the experiment also conforms the findings of Scott and Pollak (2005). Zarea (2010) also reported that, herbicides in general showed low toxicity towards earthworms. Post experiment observations of second season indicated an increase in earthworm population, in all the treatments as compared to first crop season. This might be due to higher organic carbon content in the soil (**Table 2**) resulting from the higher glucosidase enzyme activity (**Table 3**). β glucosidase is an enzyme plays a major role in the microbial degradation of cellulose to glucose, an important source of carbon for the life of microorganisms in soil (Tabatabai 1994). Fonte *et al.* (2009) opined that earth worm population in the soil appears to be closely linked with total carbon and N content in the soil.

Effect on organic carbon content in soil

Data on organic carbon content indicated an increasing trend from 15 to 60 DAS and a decline at harvest stage (**Table 2**). The highest soil organic carbon content noticed at 60 DAS corresponds to booting stage of the crop. At 15 DAS (just before herbicide application), there was no significant difference among the treatments in organic carbon status of the soil during both the seasons.

Weed management treatments significantly influenced the organic carbon content of the soil at 30 and 60 DAS and at harvest stage during both the seasons (**Table 2**). It has been observed that compared to weedy check, the hand weeding treatment and herbicide treatments recorded comparable or higher organic carbon content in the soil at 30 DAS (15 days after herbicide application), 60 DAS (45 days after herbicide application) and at harvest stage. These results indicated that, applied herbicides at their tested doses did not have any adverse impact on the organic carbon content of the soil. This might be due to increased microbial activity resulting from the release of root exudates into the rhizosphere. Presence of herbicides in the rhizosphere of plant influence the physiological activities of the host plant root system which lead to the release of more quanta of exudates and indirectly result in higher level of organic carbon in the rhizosphere soil (Trimurtulu *et al.* 2015). Root exudates are organic substrates comprising of simple and complex sugars, amino acids, vitamins, proteins and phenolics which stimulate the microbial growth (Dakora and Philips 2002). The quantity of organic carbon released by plants to the rhizosphere may amount to 40% of the total dry matter produced by the plant (Lynch and Whips 1990). Sebiomo *et al.* (2011) reported an increase in organic matter content

Table 1. Effect of herbicide mixtures on earth worm population in soil

Treatment	Before the experiment (no./m^2)		After the experiment (no./m^2)	
	Kharif 2014	*Rabi* 2014-15	*Kharif* 2014	*Rabi* 2014-15
Bispyribac-sodium + metamifop 60 g/ha	1.65(2.7)	2.12(4.0)	2.7(1.65)	6.7(2.65)
Bispyribac-sodium + metamifop 70 g/ha	2.12(4.0)	2.7(1.65)	4.0(2.12)	6.7(2.65)
Bispyribac-sodium + metamifop 80 g/ha	1.92(4.0)	4.0(2.12)	2.7(1.65)	5.3(2.39)
Bispyribac-sodium + metamifop 90 g/ha	2.12(4.0)	2.7(1.65)	5.3(2.39)	8.0(2.86)
Penoxsulam + cyhalofop-butyl 120 g/ha	2.12(4.0)	2.7(1.65)	4.0(2.12)	8.0(2.86)
Penoxsulam + cyhalofop-butyl 125 g/ha	1.92(4.0)	5.3(2.39)	5.3(2.39)	10.7(3.24)
Penoxsulam + cyhalofop-butyl 130 g/ha	2.39(5.3)	4.0(2.12)	5.3(2.39)	9.3(3.07)
Penoxsulam + cyhalofop-butyl 135 g/ha	2.12(4.0)	2.7(1.65)	5.3(2.39)	9.3(3.07)
Bispyribac sodium 25 g/ha	1.65(2.7)	4.0(2.12)	2.7(1.65)	6.7(2.59)
Penoxsulam 22.5 g/ha	1.65(2.7)	1.3(1.18)	2.7(1.65)	6.7(2.59)
Hand weeding twice 20 and 40 DAS	2.12(4.0)	2.7(1.65)	2.7(1.65)	5.3(2.39)
Weedy check	4.0(2.12)	2.7(1.65)	4.0(2.12)	5.3(2.39)
LSD (p=0.05)	NS	NS	NS	NS

Values in parentheses are original values, Data are subjected to square root transformation -($\sqrt{x+0.5}$), NS - non significant of the soil from second week of herbicide application. Maximum organic carbon content in the soil was observed at 60 DAS, it might be due to the vigorous crop growth at the booting stage resulting in greater root exudation (Dotanita *et al.* 2014). Organic carbon showed a reduction at harvest stage might be due to the decline in the release of root exudates into the soil by plant roots due to senescence and continuous decomposition of organic matter.

Effect on β glucosidaseenzyme activity

β glucosidase enzyme plays a major role in organic matter mineralization in the soil ecosystem. Weed management treatments significantly influenced β glucosidase enzyme activity in soil at 30 and 60 DAS and at harvest stage during both the seasons; however at 15 DAS (just before herbicide application), no significant difference was observed among the treatments (**Table 3**). During both the seasons at 30 DAS (15 DAHA), a decline in β glucosidase enzyme activity was observed in all the treatments. The decline in β glucosidase enzyme activity observed at 30 DAS might be due to changes in soil pH. β glucosidase enzyme activity is very sensitive to pHchanges and soil management practices (Martinez and Tabatabai 2000). Soil pH affects the activity of soil enzymes through its controls on microbial enzyme production, ionization-induced conformational changes of enzymes, and availability of substrates and enzymatic co-factors (Tabatabai 1994). All the herbicide treated plots recorded higher or comparable glucosidase activity at 30 and 60 DAS and at harvest stage, as that of non-herbicide treated plots. This implies that, the applied

Table 2. Effect of weed management treatments on organic carbon content of soil

Treatment	Organic carbon (%)							
	Kharif 2014				*Rabi* 2014-15			
	15 DAS (JBHA)	30 DAS (15DAHA)	60 DAS (45DAHA)	Harvest	15 DAS (JBHA)	30 DAS (1DAHA)	60 DAS (45DAHA)	Harvest
Bispyribac-sodium + metamifop 60 g/ha	1.19	1.21	1.47	1.13	1.12	1.26	1.70	1.60
Bispyribac-sodium + metamifop 70 g/ha	1.20	1.23	1.46	1.19	1.05	1.29	1.67	1.62
Bispyribac-sodium + metamifop 80 g/ha	1.20	1.27	1.48	1.20	1.04	1.32	1.70	1.79
Bispyribac-sodium + metamifop 90 g/ha	1.20	1.22	1.55	1.26	1.15	1.28	1.89	1.64
Penoxsulam + cyhalofop-butyl 120 g/ha	1.21	1.35	1.55	1.27	1.18	1.32	1.99	1.81
Penoxsulam + cyhalofop-butyl 125 g/ha	1.23	1.37	1.56	1.23	1.20	1.56	1.97	1.63
Penoxsulam + cyhalofop-butyl 130 g/ha	1.12	1.23	1.58	1.20	1.13	1.36	1.98	1.60
Penoxsulam + cyhalofop-butyl 135 g/ha	1.22	1.29	1.55	1.20	1.13	1.31	1.93	1.84
Bispyribac sodium 25 g/ha	1.18	1.23	1.46	1.09	1.15	1.28	1.75	1.48
Penoxsulam 22.5 g/ha	1.21	1.23	1.45	1.11	1.13	1.32	1.76	1.64
Hand weeding twice 20 and 40 DAS	1.18	1.26	1.51	1.10	1.16	1.37	1.82	1.54
Weedy check	1.16	1.24	1.40	1.10	1.14	1.26	1.67	1.47
LSD (p=0.05)	NS	0.066	0.083	0.122	NS	0.121	0.069	0.117

DAS - Days after sowing, JBHA - Just before herbicide application, DAHA - Days after herbicide application, NS - non significant

Table 3. Effect of weed management treatments on β glucosidase activity in soil

Treatment	β glucosidase activity (µg para nitro phenolg/soil/h)							
	Kharif 2014				*Rabi* 2014-15			
	15 DAS (JBHA)	30 DAS (15 DAHA)	60 DAS (45 DAHA)	Harvest	15 DAS (JBHA)	30 DAS (15 DAHA)	60 DAS (45 DAHA)	Harvest
Bispyribac-sodium + metamifop 60 g/ha	34.71	20.10	37.16	54.71	51.57	34.41	58.82	57.35
Bispyribac-sodium + metamifop 70 g/ha	34.71	27.31	35.88	56.27	48.76	40.59	50.88	59.80
Bispyribac-sodium + metamifop 80 g/ha	40.78	30.20	39.31	56.27	44.90	40.59	57.24	69.21
Bispyribac-sodium + metamifop 90 g/ha	36.86	27.03	39.12	62.25	51.31	39.22	59.31	68.14
Penoxsulam + cyhalofop-butyl 120 g/ha	38.63	35.26	39.31	59.41	52.94	43.83	66.89	73.45
Penoxsulam + cyhalofop-butyl 125 g/ha	40.78	40.42	41.86	57.06	54.12	46.27	65.29	59.61
Penoxsulam + cyhalofop-butyl 130 g/ha	38.63	27.48	39.51	57.16	49.41	39.51	68.72	63.53
Penoxsulam + cyhalofop-butyl 135 g/ha	40.98	31.28	38.73	58.24	44.44	42.75	64.12	75.03
Bispyribac sodium 25 g/ha	39.90	22.74	32.85	52.55	46.07	32.22	51.08	63.61
Penoxsulam 22.5 g/ha	39.51	23.33	36.27	53.82	45.49	39.41	52.45	64.51
Hand weeding twice 20 and 40 DAS	37.85	33.43	38.24	55.68	44.83	42.06	56.47	59.31
Weedy check	37.55	27.16	35.40	54.02	44.98	32.16	49.12	55.28
LSD (p=0.05)	NS	3.436	3.465	5.030	NS	3.007	4.995	5.434

DAS- Days after sowing, JBHA- Just before herbicide application, DAHA- Days after herbicide application, NS - non significant herbicide mixtures did not have any adverse impact on β glucosidase activity in soil. Trimurtulu *et al*. (2015) reported that presence of herbicides in the rhizosphere stimulates the physiological activities of the host plant root system and enhanced the release of root exudates into the rhizosphere. The organic root exudates will provide a variety of liable carbon compounds to soil which will stimulate the enzyme activity by the microorganisms (Kotroczo *et al*. 2014). Several researchers have reported the enhanced β glucosidase activity followed by herbicide application (Saha *et al*. 2012, Santric *et al*. 2014). β glucosidase enzyme activity was found to increase from 30 DAS, and reached the maximum at harvest stage. The increased root activity at 60 DAS might have stimulated the bacterial and fungal population that are likely a significant source of β glucosidase enzyme. There is considerable evidence suggesting that β glucosidase is an extra cellular enzyme secreted mainly by bacteria and fungi (Sinsabaugh and Moorhead 1994, Veena *et al*. 2011). Maximum β glucosidase enzyme activity values observed at harvest stage might be due to an increase in the amount of decomposing litter in the soil, since the crop is in the senescence stage. Larson *et al*. (2002) reported that increased inputs of soluble organic constituents' increases the β glucosidase enzyme activity in soil.

It can be concluded that application of herbicide mixtures, bispyribac-sodium + metamifop at 60, 70, 80 and 90 g/ha and penoxsulam + cyhalofop-butyl at 120, 125, 130 and 135 g/ha at 15 DAS did not have any adverse effect on non-target organism, *viz*. earth worm, organic carbon content and β glucosidase enzyme activity in soil, the biological indicators of soil fertility and biomarkers of toxicity. Post-emergence application of herbicide mixtures recorded comparable or higher number of earth worms per square meter, β glucosidase enzyme activity and organic carbon content in the soil as compared to non-herbicide treatments, *viz*. weedy check and hand weeding twice. Hence the herbicide mixtures, bispyribac sodium + metamifop at the tested doses, *i.e*. 60, 70, 80 and 90 g/ha and penoxsulam + cyhalofop butyl at 120, 125, 130 and 135 g/ha are environmentally safe.

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Fitting dose-response curve to identify herbicide efficacy and ED_{50} value in mixture

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ABSTRACT

Most of the farmers shifted to direct-seeded rice (DSR) from conventional puddled-transplanted system. One of the major challenges in DSR is weed management, which reduces the productivity of the rice system significantly. Therefore, many herbicide combinations are being tried for broad-spectrum control of weeds. In the present study, field experiments were conducted during *Kharif* 2013 and 2014 to know the herbicides efficacy when used in mixture using dose-response curve in DSR. The treatments comprised of tank-mix combinations of two herbicides *viz*. fenoxaprop (0, 30, 40, 50, 60 g/ha) and metsulfuron (0, 2.5, 3.0, 3.5, 4.0 g/ha) to control grassy and broad-leaved weeds, respectively in DSR. Among many non-linear dose-response models, hill model was found to be the best for the data. Results revealed that when fenoxaprop applied in mixture with metsulfuron, its efficacy increased/decreased 4-5% during both the years. Further, when metsulfuron was applied in mixture, its ED_{50} value was increased from 3.43 to3.62 g/ha as compared to its alone application. Thus, the study revealed the presence of antagonistic effect of fenoxaprop on metsulfuron when used in mixture, which ultimately resulted in reduced efficacy in terms of pre cent weed control.

Key words: Dose-response, Herbicide efficacy, Fenoxaprop, Hill model, Metsulfuron

In many Asian countries, rice was grown formerly in puddled-transplanted system. But nowadays, most of the farmers started to shift their rice cultivation to direct-seeded rice (DSR) from conventional puddled-transplanted rice (PTR) because puddling or repeated tillage under wet conditions need more labour, water, and energy (Mahajan *et al.* 2012; Chauhan *et al.* 2012). One of the major challenges in DSR is weed management, which reduces the productivity of the rice system significantly (Singh *et al.* 2007, Chauhan and Johnson 2010, Mahajan and Chauhan 2011). In this system, weeds germinate at the same time as rice seeds which in later stages give tough competition to the main crop. Yield losses due to weeds in DSR systems can go as high as 90% if no control measures are taken in time (Chauhan and Johnson 2011). Therefore, DSR system requires proper control of weeds to get the desired yield of the crop. Among all the methods of weed control, use of herbicides is established as a major method of weed control which led to development of many molecules for the control of broad-spectrum weeds.

Herbicides such as pendimethalin, oxadiazon, oxdiargyl, and pyrazosulfuron as pre-emergence; and bispyribac-sodium, azimsulfuron, penoxsulam, fenoxaprop, and 2,4-D as post-emergence have been reported to provide effective weed control in rice (Chauhan 2012). However, use of single herbicide is often not sufficient to control all weeds effectively in DSR systems. Further, the continuous use of a single herbicide over a long period of time may develop herbicide resistance against some weeds and shifts in weed flora (Buhler *et al.* 2000, Chauhan *et al.* 2012). Therefore, herbicide combinations are being tried for achieving broad-spectrum weed control.

Information regarding the optimum combination of two herbicide doses is of substantial significance in weed control. In the past, studies have been conducted where dose-response curves have been used to study the biological effects of herbicides for weed control, resistance of weeds, and herbicide persistence in soil (Streibig 1987, Streibig *et al.* 1993, Streibig and Jensen 2000, Price *et al.* 2012). Studies on dose-response relationship is important to know the herbicide efficacy and mode of action. In order to improve weed control efficacy and reduce the application costs, the use of herbicide mixtures has become popular in many countries (Kudsk 2002). This strategy also characterises an important means to avoid problems related to herbicide resistance

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(Friesen *et al.* 2000, Sattin *et al.* 2000), but it requires some preliminary information to assist farmers with the process of herbicide and dose selection. Keeping this in view, a field experiment was conducted to know the herbicides efficacy in mixture using dose-response curve in direct-seeded rice.

MATERIALS AND METHODS

A field experiment was conducted on direct-seeded rice (DSR) during *Kharif* 2013 and 2014 at the experimental farm of ICAR-Directorate of Weed Research, Jabalpur situated at 23.90° N latitude, 79.58° E longitude and at an altitude of 412 m above mean sea level. The climate of study area is characterized by mean annual precipitation of 1277 mm, mean annual temperature of 24.6°C, mean annual maximum temperature of 31.27°C and mean annual minimum temperature of 17.97°C.

The soil of the experimental field was clay loam, pH 6.9 and OC 0.71%, low in N, medium in available P and K. The field was prepared by giving two ploughings, one with cultivator and another with rotavator. Rice (cv. *Kranti*) was dry-seeded at 30 kg/ha with tractor mounted seed-cum-fertilizer drill. The crop was sown in rows 18.5 cm apart at a depth of 2-3 cm on mid-June and harvested in early-November. The field was surface-irrigated after seeding for uniform germination, and further, irrigation was given as per requirement of crop. Nitrogen was applied at 120 kg/ha in three splits, 1/3 each as basal, at 28 DAS (tillering) and at 60 DAS (panicle initiation). Phosphorus at 60 kg/ha as P_2O_5 was applied with the zero-till cum fertilizer drill machine during seeding. Potassium at 60 kg/ha as K_2O was broadcasted uniformly before rice seeding.

The experiment was laid out in 5^2 factorial randomized block design with 3 replications. The treatments comprised of tank-mix combinations of two herbicides *viz*. fenoxaprop and metsulfuron. Fenoxaprop was used to control grassy weeds at 0, 30, 40, 50, 60 (recommended) g/ha whilemetsulfuron was applied at 0, 2.5, 3.0, 3.5, 4.0 (recommended) g/ha to control broad-leaved weeds.

Data recording and treatment

Herbicides were tank-mixed in specified doses for making different combinations and applied to the crop at 25 DAS. Twelve days after the application of herbicides, data on per cent weed control were observed. Error assumptions (normality, randomness and homogeneity of the error variance) were confirmed with studentized residuals and Shapiro-Wilk normality test before fitting the model. Data were found non-normal, therefore arc sine transformation was applied to the data to make its distribution normal so that data meets the assumptions before analysis.

Model fitting

Non-linear models describing biologically realistic dose responses are preferred over essentially invalid models such as straight line, polynomials, and inverse polynomials. Dose-response curve are generally used to fit data on doses of herbicides and response of weeds in terms of weed control (Green 1991). The plot of curve can be easily interpreted and is immediately informative to readers. In the present study, non-linear dose-response models were fitted to the data *e.g.* logistic, log-logistic, log-probit, Hill function and variant of these models (with intercept and without intercept). These are all *S*-shaped curve and help in understanding the dose-response relationships. Among all, dose- response Hill model was found to be best for the data. Dose-Response Hill function is given by: $y = \delta + \frac{\alpha x^{\theta}}{\varphi^{\theta}+x^{\theta}}$ where, y is the % weed control, δ is intercept, α=y_{max}, x denote the dose, θ is the hill coefficient of sigmoidicity and φ denote the ED_{50} value or the dose for which 50% weed control is obtained. Hill model is very flexible and effective in fitting experimental data (Goutelle *et al.* 2008).

RESULTS AND DISCUSSION

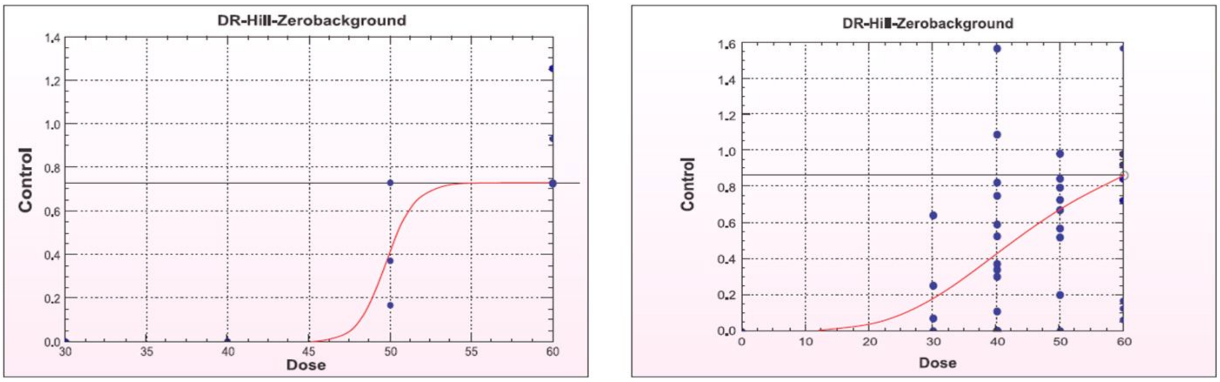
Weed flora

The field was mainly infested with *Echinochloa colona, Alternanthera sessilis, Eclipta alba, Ludwigia adscendenus, Dinebra retroflexa, Cyperus iria, Ammania baccifera* and *Commelina benghalensis* with varying density in two years. Total weed flora consisted of 73% broad-leaved species, 11% grassy and 16% sedges in 2013. In the year 2014, weed flora consisted of 46% broad-leaved, 22% grassy and 32% sedges.

Herbicde dose and plant response

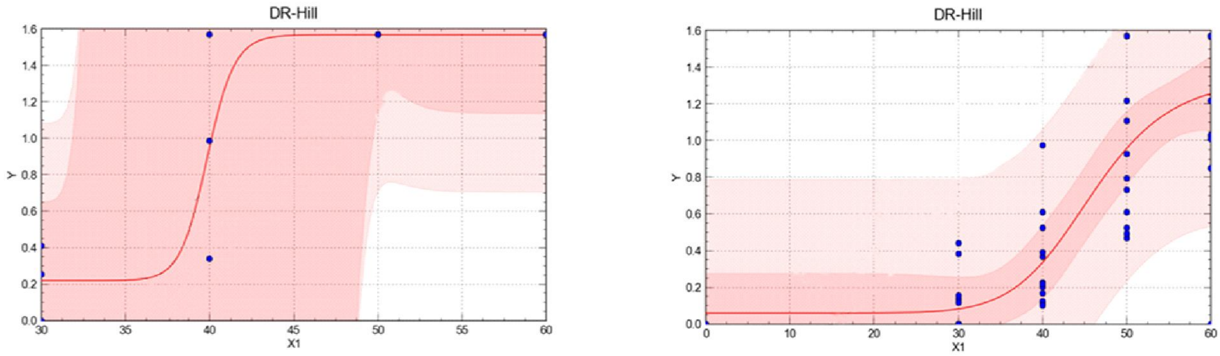
In our study, in 2013, fenoxaprop poorly controlled grassy weeds at recommended dose (60 g/ha) as well as at lower doses. However, in 2014, it controlled all grassy weeds even at lower doses. Different graphs were obtained by fitting the hill model to the data.

Figure 1(a) revealed that 68% of grassy weeds were controlled with full dose of fenoxaprop when applied alone. Its ED_{50} value was estimated as 49.7 g/ha from the fitted model. It is clear from **Figure 1(b)**



(a) $y = \frac{0.726x^{57.06}}{49.71^{57.06}+x^{57.06}}$ (b) $y = \frac{0.85x^{4.05}}{44.9^{4.05}+x^{4.05}}$

Figure 1. Dose response curve of weed control data (arc sine value) obtained from experimental plots where fenoxaprop alone (a) or in mixture (b) was used to control grassy weeds in DSR during *Kharif* 2013



(a) $y = 0.221 + \frac{1.54x^{49.4}}{39.8^{49.4}+x^{49.4}}$ (b) $y = 0.062 + \frac{1.28x^{9.58}}{45.7^{9.58}+x^{9.58}}$

Figure 2. Dose response curve of weed control data (arc sine value) obtained from experimental plots where fenoxaprop alone (a) or in mixture (b) was used to control grassy weeds in DSR during *Kharif* 2014

that when fenoxaprop was applied in combination with metsulfuron, its control efficacy increased from 68 to 73% and ED_{50} value reduced to 44.9 g/ha from 49.7 g/ha when applied alone.

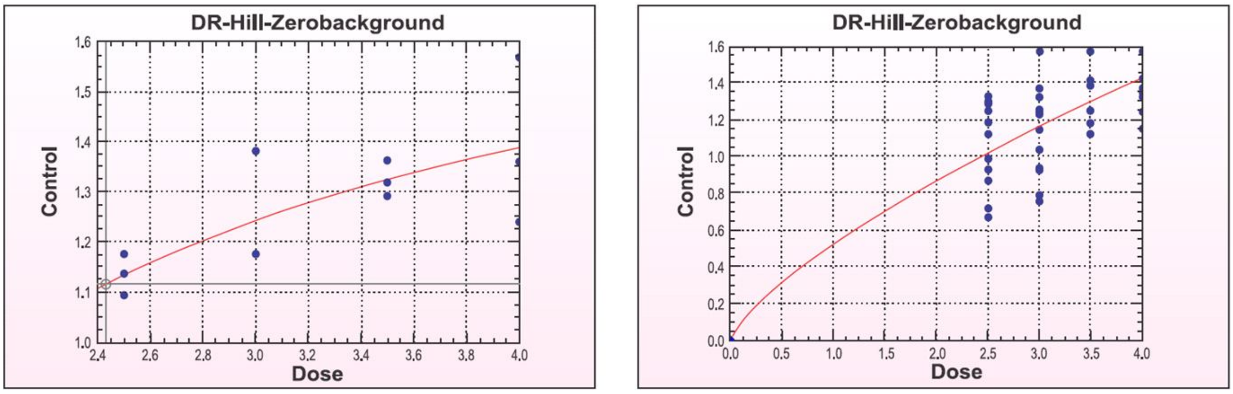
The relationship between herbicide-dose and plant-response (in terms of weed control) is of fundamental importance in understanding herbicide efficacy (Seefedlt 1995). The classical bioassay, often used to quantify the amount of herbicide in soil, employs a single 'standard' dose-response curve. This standard curve is then used to estimate the amount of herbicide in an unknown sample based on plant response in the sample (Nyffeler *et al.* 1982). The optimal herbicide dose is influenced by how much to be applied to avail an acceptable level of control. Therefore, in order to optimize herbicide usage, a knowledge of efficacy is necessary (Pannell 1990).

Analysis also revealed that almost 100% control of grassy weeds was achieved with recommended dose (60 g/ha) of fenoxaprop when applied alone during 2014 (**Figure 2a**). It has been established that under optimum weather and soil conditions, effective weed control may be obtained with doses of herbicide below that recommended by the manufacturer (Brain *et al.* 1998). But when applied in mixture its efficacy decreased to 96%. The ED_{50} value was estimated as 39.8 g/ha from the fitted model when used alone but it was increased to 45.7 g/ha when used in mixture (**Figure 2b**). Therefore, efficacy of the fenoxaprop decreased due to antagonistic effect of metsulfuron when applied in mixture.

On the other hand, metsulfuron controlled all broad-leaved weeds significantly even at the lower

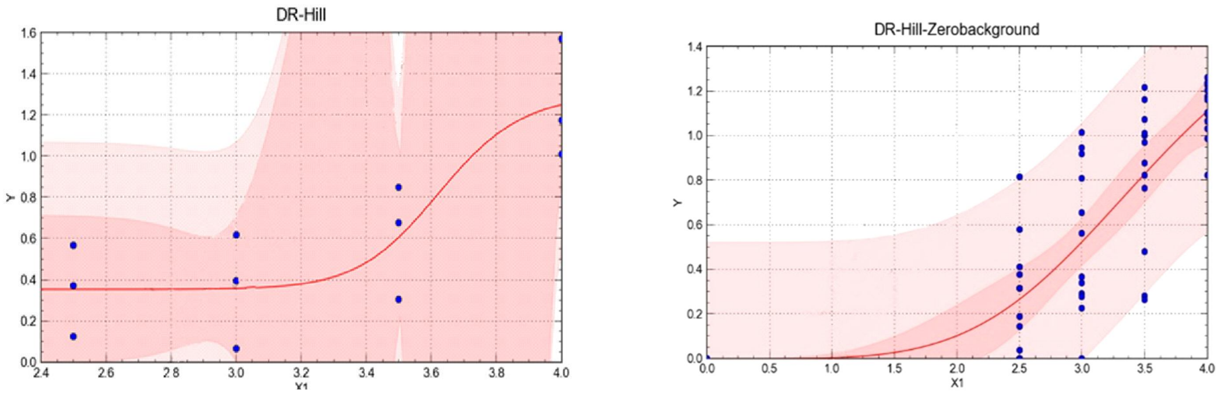
Table1. Parameters of the Hill models fitted to the data of fenoxaprop

Year	Herbicide	Parameter value			
		δ	α	θ	φ (ED_{50})
2013	Fenoxaprop (alone)	-	0.726	57.06	49.71
	Fenoxaprop (mixture)	-	0.85	4.05	44.9
2014	Fenoxaprop (alone)	0.221	1.54	49.4	39.8
	Fenoxaprop (mixture)	0.062	1.28	9.58	45.7



(a) $y = \frac{1.37x^{1.58}}{1.68^{1.58}+x^{1.58}}$ (b) $y = \frac{1.42x^{5.28}}{2.94^{5.28}+x^{5.28}}$

Figure 3. Dose response curve of weed control data (arc sine value) obtained from experimental plots where metsulfuron alone (a) or in mixture (b) was used to control broad leaved weeds in DSR during *Kharif* 2013



(a) $y = 0.335 + \frac{1.25x^{33.02}}{3.43^{33.02}+x^{33.02}}$ (b) $y = \frac{1.22x^{4.7}}{3.62^{4.7}+x^{4.7}}$

Figure 4. Dose-response curve of weed control data (arc sine value) obtained from experimental plots where metsulfuron alone (a) or in mixture (b) was used to control broad-leaved weeds in DSR during *Kharif* 2014

doses (<4 g/ha) in 2013. Hill model was also used to fit the data of metsulfuron alone as well as in mixture **(Figure 3**).

Metsulfuron applied alone, controlled all broad-leaved weeds effectively even at the lower doses than recommended (4 g/ha). Its ED_{50} value was obtained as 1.68 g/ha when applied alone but increased to 2.94 g/ha when applied in combination with fenoxaprop (**Figure 3**). Hence, it can be inferred that fenoxaprop has some antagonistic effect on metsulfuron when applied in mixture. In 2014, when metsulfuron was applied alone, it controlled 95% of broad-leaved weeds and ED_{50} value was obtained as 3.43 g/ha. But, when it was applied in mixture with fenoxaprop, its efficacy reduced to 90% with ED_{50} value as 3.62 g/ ha. These results indicated antagonistic effect of fenoxaprop on metsulfuron when used in mixture.

Table 1. Parameters of the Hill models fitted to the data of *Kharif* 2014

Year	Herbicide	Parameter value			
		δ	α	θ	φ (ED_{50})
2013	Metsulfuron (alone)	-	1.37	1.58	1.68
	Metsulfuron (mixture)	-	1.42	5.28	2.94
2014	Metsulfuron (alone)	0.335	1.25	33.02	3.43
	Metsulfuron (mixture)	-	1.22	4.7	3.62

Responses of herbicides in terms of weed control were different in 2 years. This was due to variable composition of broad-leaved, grassy weeds and sedges in soil seed bank (Anwar *et al.* 2013). During 2013, fenoxaprop failed to control all grassy weeds at lower doses but the weed control efficiency increased from 68 to 73% when used in mixture. On the other hand, it controlledall grassy weeds at recommended dose as well as at lower doses during 2014. However, when it was tank-mixed with metsulfuron, its efficacy decreased to 96% which confirmed the antagonistic effect of metsulfuron over fenoxaprop.

During both the years of experimentation, the efficacy of metsulfuron decreased when used in mixture. This further showed the presence of antagonistic effect of fenoxaprop on metsulfuron when used in mixture. In both the years, ED_{50} value of both the herbicides were different, so it was not possible to combine the results and therefore results were presented separately.

It was concluded that fenoxaprop and metsulfuron showed antagonistic effect on each other when used as tank-mix combination. These results are useful for the farmers and researchers to know about the compatibility of these two herbicides in direct-seeded rice.

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Pre-emergence herbicides are ancillary apt for annual planning of weed management in system intensification

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ABSTRACT

Field experiments were conducted at Viswavidyalaya farm, Jaguli, Nadia following system intensification (SI) package of practices during 2011-2016 on pre-*Kharif* black gram (*Vigna mungo*) and green gram (*Vigna radiata) – Kharif* direct-seeded puddled and transplanted rice (*Oryza sativa) – Rabi* potato (*Solanum tuberosum*) and onion (*Allium cepa)* crop sequences. Balance nutrition of N:P:K:Neem cake at recommended doses were used along with judicious water in critical crop growth stages and ecosafe green labelled pesticides for insect and disease management. For annual planning of weed pest management (APWPM), glyphosate 71 SG + oxyfluorfen 23.5 EC mixture at 1000 g/ha was used after pre-*Kharif* crops besides the application of selective pre-emergence (PE) organic herbicides treatment wise in different crops along with HW, post-emergence (PoE) herbicides and weedy check as standard. The results revealed that PE herbicide treatments recorded 30.5 and 10.3% more productivity over PoE herbicides treated plots and 38.4 and 60.0% over weedy check in blackgram and greengram, respectively. The corresponding values were 2.74 and 5.14% and 32.7 and 31.0% in direct seeded puddled and transplanted rice, respectively. In *Rabi* potato and onion, these figures were 21.1 and 30.4% and 42.0 and 49.0%, respectively. The soil microflora population at harvest recorded increasing in all PE herbicide used plots though an initial decreasing trend upto a month.

Key words: Annual planning of weed management, Herbicides, Pre-emergence, Productivity, Rice based crop sequences, System intensification

System Intensification using more biological inputs through best management practices of farmers' available resources, is the best alternative methodology for sustainable food, nutrition, ecological and health security (Uphoff 1999, Ghosh *et al*. 2014). Weed pest causes globally 11.5% and at national 10.9% production loss (DWR 2015). Field experiments have revealed that number of weed seeds in the anaerobic ecosystem were 477% lesser in upper surface in comparison to under surface of soil upto 0-15 cm depth. The corresponding figures for aerobic and roadside areas were 308 and 390%. Further eco-safe and eco-efficient herbicides in annual planning of weed pest management (APWPM) as pre-emergence is less costly to the farmer and create an eco-sustainable environment with improved yield. APWPM aims to diminish the weed seed bank in crop field prior to crop planting and subsequently by using pre-emergence (PE) herbicides for reducing the weed competition (Ghosh *et al.* 2016) in critical crop weed competition period (CCWCP). With this contemplation, field experiments have been undertaken in common rice based crop sequences in Inceptisol by adopting system intensification and APWPM to evaluate the efficacy of ecosafe pre-emergence herbicides in CCWCP on per cent diminution of weed pest infestation, to find out the soil microflora status for soil health improvement and to assess the concomitant improvement of crop productivity by PE in comparison to post-emergence (PoE) herbicides.

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MATERIALS AND METHODS

Eight field experiments were conducted at University farm, Jaguli, Nadia during 2011-2016 on varied combinations of rice based crop sequences involving black gram and green gram (pre-*Kharif*) – direct-seeded puddled and transplanted rice (DSPR and TR- *Kharif*) – onion and potato (*Rabi*) grown in system intensification and following annual planning of weed pest management. The experimental soil was sandy loam in nature with neutral pH. The climate of the Inceptisol is warm and humid with an average rainfall of 1700 mm/annum of which around 70% rainfall occurs during June to September. The lowest relative humidity is observed in the month of December while the maximum is in July-August.

System intensification methodology was followed for all crops grown in different sequences. The varieties were: black gram (*Vigna mungo*) *cv*. '*Sarada* (*WBU108*)'; green gram (*Vigna radiata*) *cv*. '*Sonali (B-1)*'; '*Satabdi (IET 4786)*' for both direct seeded puddled and transplanted rice (*Oryza sativa*); potato (*Solanum tuberosum*) *cv*. '*Kufri Jyoti*' and for onion (*Allium cepa*) *cv*. '*Sukhsagar*'. The crops were grown with optimum plant population and balanced fertilization of N:P:K:Neem cake at 20:40:40:2000 for black gram and green gram, 60:30:30:5000 for both direct-seeded puddled and transplanted rice, 150:100:100:10000 for potato and 80:40:40:5000 kg/ha in onion. Judicious water (3 cm/irrigation) was used in critical physiological growth stages in all crops besides keeping moist in rice field. Regarding insect and disease pest management only eco safe green labelled pesticide mixtures were used. Glyphosate 71 SG + oxyfluorfen 23.5 EC mixture 1000 g/ha was used after harvesting of pre-*kharif* crops followed by removing of *Cyperus* nuts and weed stubbles during land preparation of *Kharif* rice crop as a part of annual planning of weed management methodology. The selective herbicides used in treatments of eight crop sequences in this experiment during 2011-16 were listed (**Table 1**).

A common mechanical weeding (wheel hoe at 30 DAS in black and green gram and at 30 DAP in onion; rice weeder at 30 DAT in (DSPR) and (TR) and earthing up at 25 DAP in potato) was done in all treatments. Hand weeding (HW) in pre-*Kharif* at 20 DAS, in *Kharif* at 20 and 40 DAT, in *Rabi* potato at 15 DAP and in onion at 20 and 50 DAP were used. Weedy check is common control treatment for all six crops grown in eight varied crop sequences.

Weed (monocot and dicot) density and biomass using quadrate and average of three sites at 30 and 50 DAS/DAT/DAP were recorded from the experimental fields and from the data of total dry weed biomass, the weed control efficiency (WCE) was calculated. The biological yields (grain/tuber/bulb) and major yield attributes (number of pods/plant and number of seeds/pod of *Vigna* spp.; number of panicles/plant and number of filled grains/panicle of *Oryza sativa*; number and weight of tubers (*Solanum* spp.) and number and weight of bulbs (*Allium* spp.) /plant were recorded at harvest from the marked undisturbed areas in each plot. The population of soil microflora in the rhizosphere soil were also recorded at 5, 10, 15 and 30 DAA and at harvest (PE herbicides) and at 3, 10 and 30 DAA and at harvest (PoE herbicides). For microbial analysis by dilution plating the standard

Table 1. Name of chemical herbicides with active ingredient (a.i.), formulation, dose and time of application in crop sequences used in this experiment during 2011-16

Season	Crop	Name of herbicide with a.i. and formulation	Dose (g/ha)	Time of application
Pre-*Kharif*	Black gram	Oxyfluorfen 23.5 EC	100	Pre-emergence- 1 DAS
	Green gram	Pendimethalin 30 EC	750	
		Quizalofop-ethyl 5 EC	50	Post-emergence-20 DAS
Kharif	Direct seeded puddled rice (DSPR)	Oxyfluorfen 23.5 EC	100	Pre-emergence- 1 DAS
		Bispyribac-sodium 10 SC	20	
		Cyhalofop-butyl 10 EC	100	
		Carfentrazone-ethyl 40 DF	25	
		Almix 20 WP	4	Post-emergence-20 DAS
		Pyrazosulfuron-ethyl 10 WP	30	
	Transplanted rice (TR)	Oxyfluorfen 23.5 EC	100	Pre-emergence-1 DAT
		Bispyribac-sodium 10 SC	20	
		Pretilachlor 50 EC	500	
		Pretilachlor 30.7 EC	500	
		Butachlor 50 EC	1250	
		Oxadiargyl 80 WG	100	
		Triasulfuron 20 WG	12	
		Flucetosulfuron 10 WG	20	
		Almix 20 WP	4	Post-emergence-20 DAT
		Pyrazosulfuron-ethyl 10 WP	30	
Rabi	Potato	Oxyfluorfen 23.5 EC	100	pre-emergence-1 DAP
		Pendimethalin 30 EC	750	
		Paraquat dichloride 24 SL	2500	
		Metribuzin 70 WP	600	
		Metribuzin 70 WP	600	Post-emergence-40 DAP
	Onion	Oryzalin - XL 40 SC	6.25 (l/ha)	Pre-emergence-1 DAP
		Pendimethalin 30 EC	750	
		Quizalofop-ethyl 5 EC	50	Post-emergence-20 DAP

methods prescribed by Pramer and Schmidt (1965) were used. A soil dilution was prepared in sterile distilled water by constant shaking and plating were done separately in replicates in specific media. The Plates were incubated at 28 ± 1 ^{0}C for different durations between 5-7 days in BOD incubator and observations in terms of counting of number of colonies/plate were recorded.

RESULTS AND DISCUSSION

The dominant weed flora in all crops grown during pre-*Kharif* (black and green gram), *Kharif* (direct-seeded puddled and transplanted rice) and *Rabi* (potato and onion) seasons under these eight experiments during 2011-16 were listed (**Table 2**). In this experiment, use of PE herbicides in annual planning of weed pest management showed enhanced major yield attributes and superior productivity in comparison to standard PoE herbicides (**Table 3** and **4**, **Figure 1** and **2**).

At 30 DAS, the maximum WCE of 74.33 and 75.37% was recorded against HW treatment in black and green gram, respectively. But 19.31 and 15.28% higher WCE in black and green gram, respectively was observed against two PE herbicides over the PoE herbicide. At 50 DAS, similar trends was observed and the corresponding figures for the maximum was in HW 55.21 and 55.67% and in PE herbicides 10.72 and 11.29% higher WCE over PoE. In DSPR and TR, HW was also recorded maximum WCE of 69.57 and 75.31%, respectively at 30 DAT and 71.60 and 78.90% respectively, at 50 DAT. The four PE herbicides recorded an average WCE of 55.71 and 42.52% at 30 and 50 DAT, respectively while the corresponding figures for two PoE herbicides were 64.25 and 49.69% in DSPR. Thus in direct seeded puddled rice, PoE herbicides showed better weed management (8.54 and 7.17% more WCE at 30 and 50 DAT, respectively over PE herbicides). In transplanted rice the eight PE herbicides recorded an average of 69.08 and 53.16% WCE at 30 and 50 DAT, respectively while the corresponding figures for two PoE herbicides were 66.26 and 55.77% recording 2.82 and 2.61% lesser WCE than PE herbicides.

In potato, the four PE herbicides recorded an average of 20.03 and 24.24% more WCE (92.40 and 66.27% WCE) at 30 and 50 DAP, respectively over one PoE herbicide. HW recorded maximum WCE (69.42%) only at 50 DAP but recorded 0.02% lesser than PE herbicides (maximum WCE 92.38%) at 30 DAP. In onion HW recorded maximum WCE of 71.33 and 61.60% at 30 and 50 DAP, respectively. The two PE herbicides showed an average of 61.90 and 43.96% WCE at 30 and 50 DAP, respectively and these PE herbicides recorded 13.30 and 9.29% more WCE than that of the PoE herbicide used in this experiment (**Table 3**).

Table 2. Dominant weed flora of the experimental field in different seasons during 2011-16

Pre *Kharif* (summer)	*Kharif* (rainy)	*Rabi* (winter)
Monocot weeds	Monocot weeds	Monocot weeds
Brachiaria mutica	*Echinochloa colona, Echinochloa formosensis*	*Dactyloctaneum aegyptium*
Dactyloctaneum aegyptium	*Leersia hexendra*	*Digitaria sanguinalis*
Digitaria sanguinalis	*Leptochloa chinensis*	*Eleusine indica*
Eleusine indica	*Panicum maximum*	*Echinochloa colona*
Echinochloa colona	*Cyperus difformis*	*Setaria glauca*
Cyperus rotundus	*Cyperus iria*	*Cyperus rotundus*
Dicot weeds	*Fimbristylis littoralis*	Dicot weeds
Alternanthera sessilis	*Fimbristylis dichotoma*	*Anagallis arvensis*
Amaranthus viridis	*Scirpus juncoides*	*Argemone mexicana*
Commelina benghalensis	*Algal Anabena circinalis (BGA)*	*Blumea lacera*
Corchorus acutangulas	Dicot weeds	*Chenopodium album*
Digera arvensis	*Alternanthera philoxeroides*	*Cleome viscosa*
Euphorbia hirta	*Ammania baccifera/multiflora*	*Digera arvensis*
Melilotus alba / indicus	*Bergia capensis*	*Fumaria purviflora*
Melochia corchorifolia	*Eclipta alba*	*Gnaphalium luteoalbum*
Nasturtium indicum	*Hypericum japonicum*	*Melilotus alba / indicus*
Phyllanthus niruri	*Lindernia ciliate / procumbans*	*Nicotiana plumbiginifolia*
Physalis minima	*Ludwigia octovalvis*	*Physalis minima*
Scoparia dulcis	*Lemna minor*	*Portulaca oleracea*
Spilanthus paniculata	*Marsilea quadrifolia*	*Solanum nigrum*
Trianthema monogyne	*Oldenlandia corymbosa /diffusa*	*Sonchus arvensis*
Trianthema portulacastrum	*Stellaria media*	*Vicia sativa / indica*

The higher weed control efficiency in PE herbicides was mainly due to managing weed seeds in the soil rhizosphere zone before planting and further inhibiting the germinated weeds that emerged during critical crop weed competition period (CCWCP). This helps to create an atmosphere favourable for crop growth utilizing the maximum resources (by reducing the weed competition to minimum since establishment). Further, using mechanical weeding (wheel hoe, rice weeder or earthing up) the later germinated weeds were also managed besides creating soil aeration that helps all crops to improve health. Quizalofop-ethyl in black gram, green gram and onion, recorded more inconsistency in WCE (lower) than that observed in other PoE herbicides as it mainly controlled the monocots only. Similar findings were recorded by Teasdale (1996), Kewat *et al.* (2000), Tiwari *et al.* (2007), Chauhan and Yadav (2013), Parthipan *et al.* (2013).

During pre-*Kharif* season, application of tested PE herbicides showed enhanced numbers of dominant yield attributes over the standard PoE herbicides in both black and green gram crops experimented during 2011-16. Significantly, 3.35 and 3.45 higher number of pods by applying PE herbicides oxyfluorfen 23.5 EC and pendimetahlin 30 EC (mean 14.05 and 15.12) were recorded over PoE herbicide quizalofop-ethyl 5 EC (10.70 and 11.67) in black and green gram, respectively. HW showed highest (14.90 and 15.87) while weedy check the minimum (9.33 and 10.33) number of pods in black and green gram, respectively (**Table 4**).

During *Kharif* season in direct-seed puddled and transplanted rice twice HW at 20 and 40 DAP recorded maximum 12.87 and 16.45 number of panicles/plant while the weedy check plot showed minimum 9.90 and 12.67 number of panicles/plant, respectively (**Table 4**). The four PE herbicides in DSPR and eight PE herbicides in TR recorded a mean 12.38 and 15.37 number of panicles/plant, respectively. These figures are 12.55 and 5.85% higher than that of two PoE herbicides almix 20 WP and pyrazosulfuron-ethyl 10 WP (mean 11.00 and 14.52) used in both DSPR and TR, respectively.

During *Rabi* season in potato, four PE herbicides oxyfluorfen 23.5 EC, pendimetahlin 30 EC, paraquat dichloride 24 SL and metribuzin 70 WP (mean tuber weight 59.03 g) was recorded 10.93 g more mean tuber weight over PoE herbicide metribuzin 70 WP (48.10 g). HW showed highest mean tuber weight of 59.00 g while weedy check the minimum 40.33 g. In onion crop HW showed highest mean bulb weight of 44.7 g and weedy check the

Table 3. Weed control efficiency in black gram and green gram – direct-seeded puddled and transplanted rice – potato and onion crop sequence following APWPM during 2011-16

Treatment	Dose (g/ha)	WCE (%) 30 DAS/ DAT/ DAP	WCE (%) 50 DAS /DAT /DAP
Pre-*Kharif* season (mid March – mid June)			
Blackgram			
Oxyfluorfen 23.5 EC at 1 DAS	100	73.6	53.4
Pendimethalin 30 EC at 1 DAS	750	71.7	51.3
Quizalofop-ethyl 5 EC at 20 DAS	50	53.3	41.7
Hand weeding at 20 DAS	-	74.3	55.2
Weedy check	-	-	-
Greengram			
Oxyfluorfen 23.5 EC at 1 DAS	100	72.2	54.3
Pendimethalin 30 EC at 1 DAS	750	71.7	54.7
Quizalofop-ethyl 5 EC at 20 DAS	50	56.7	43.2
Hand weeding at 20 DAS	-	75.4	55.7
Weedy check	-	-	
Kharif season (first week of July – end October)			
Direct seeded puddled rice			
Oxyfluorfen 23.5 EC at 1 DAP	100	58.3	43.7
Bispyribac-sodium 10 SC at 1 DAP	20	56.9	44.3
Cyhalofop-butyI 10 EC at 1 DAP	100	53.3	40.4
Carfentrazone-ethyl 40 DF at 1 DAP	25	54.3	41.7
Almix 20 WP at 25 DAP	4	66.7	51.8
Pyrazosulfuron-ethyl 10 WP at 20 DAP	30	61.8	47.5
Hand weeding twice at 20 and 40 DAP	-	69.6	71.6
Weedy check	-	-	-
Transplanted rice			
Oxyfluorfen 23.5 EC at 1 DAT	100	69.6	54.7
Bispyribac-sodium 10 SC at 1 DAT	20	68.9	52.3
Pretilachlor 50 EC at 1 DAT	500	69.6	51.4
Pretilachlor 30.7 EC at 1 DAT	500	71.3	55.1
Butachlor 50 EC at 1 DAT	1250	63.3	49.7
Oxadiargyl 80 WG at 1 DAT	100	68.3	53.9
Triasulfuron 20 WG at 1 DAT	12	67.3	51.3
Flucetosulfuron 10 WG at 1 DAT	20	64.7	54.7
Almix 20 WP at 25 DAT	4	74.3	56.9
Pyrazosulfuron-ethyl 10 WP at 20 DAT	30	67.8	56.8
Hand weeding twice at 20 and 40 DAT	-	75.3	78.9
Weedy check		-	-
Rabi /Winter season (first week of November – end February)			
Potato			
Oxyfluorfen 23.5 EC at 1 DAP	100	93.2	67.4
Pendimethalin 30 EC at 1 DAP	750	89.3	62.4
Paraquat dichloride 24 SL at 1 DAP	2500	91.7	66.9
Metribuzin 70 WP at 1 DAP	600	95.4	68.3
Metribuzin 70 WP at 40 DAP	600	72.4	90.5
Hand weeding at15 DAP	-	92.4	69.4
Weedy check	-	-	-
Onion			
Oxyfluorfen 23.5 EC at 1 DAP	100	68.7	47.3
Oryzalin - XL 40 SC at 1 DAP	6.25 l/ha	60.3	41.9
Pendimethalin 30 EC at 1 DAP	750	56.7	42.6
Quizalofop-ethyl 5 EC at 20 DAP	50	48.6	34.7
Hand weeding at 20 and 50 DAP	-	71.3	61.6
Weedy check	-	-	-

A common mechanical weeding (wheel hoe at 30 DAS in black and green gram and at 30 DAP in onion; rice weeder at 30 DAT in DSPR and TR and an earthing up at 25 DAP in potato) was done in all treatments.

minimum 35.33 g mean bulb weight. Three PE herbicides, oxyfluorfen 23.5 EC, oryzalin 40 SC and pendimetahlin 30 EC (mean bulb weight 41.00 g) recorded 6.61 g more mean bulb weight over PoE herbicide quizalofop-ethyl (30.87 g bulb weight). A common mechanical weeding by wheel hoe was also done at 30 DAP with each treatment that helps to manage the resurgence weed flora (**Table 4**).

All the PE and PoE herbicides treatments and HW recorded more productivity over weedy check in all the experiments during 2011-16. In black and green gram during pre *Kharif* season, 30.5 and 10.3% (38.4 and 60.0% over weedy check) more yield was recorded in PE herbicides treated plots over PoE herbicides treatments. In direct-seeded puddled and transplanted rice, the corresponding figures for PE herbicides over PoE herbicides treatments were 2.74 and 5.14% (32.7 and 31.0% over weedy check) while in potato and onion these figures were 21.1 and 30.4% (42.0 and 49.0% over weedy check), respectively.

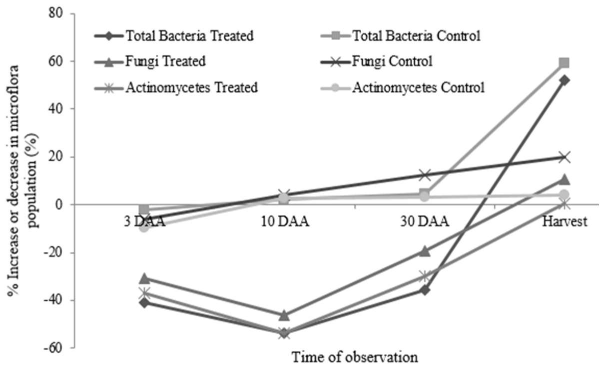
Because of following the annual planning of weed pest management (APWPM), weed seed bank was reduced prior to planting and by using HW or selected herbicides due to which weed competition to crops in their critical crop weed competition stages was further reduced that helped to improve the crop health supplemented by balance nutrition and judicious water use. Ghosh *et al.* (2016) expressed similar opinion while working with PE mixture of botanical and chemical herbicides following APWPM in transplanted rice. The soil microflora population (**Figure 1**) at harvest revealed 0.35 to 152% increase in all PE herbicides used plots in spite of an initial decrease at 30 DAA. But in case of PoE, herbicides treated plots (**Figure 2**) the increasing trend of microflora population after an initial decrease limited only 5.2- 16% at harvest.

PE herbicides treated crops established a healthier crop over PoE herbicides by minimizing weed pest competition since initial stage. Therefore, the PE herbicides treated plots recorded better productivity over PoE herbicides treated plots in all the experimented crops as the major yield attributing characters like number of pods (black and green gram), panicle numbers (rice), tuber or bulb weight (potato and onion) showed higher in PE herbicides over PoE herbicide treated plots. PoE herbicides are usually applied in the crop critical physiological growth stages like branching, nodulation, tillering, tuber or bulb formation *etc*. which ultimately affected the major yield attributes by forcing the crop plants to face an initial competition of resources with weed

Table 4. Major yield attributes and productivity of black gram/green gram – DSP rice/TR rice – potato/ onion crop sequence following APWPM during 2011-16

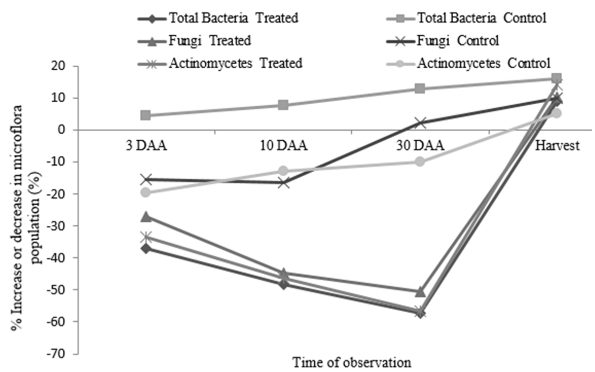
Treatment	Dose (g/ha)	Major yield attribute No. of pods/plant	Yield (t/ha) Seed yield
Pre-Kharif season (mid March – mid June)			
Blackgram			
Oxyfluorfen 23.5 EC at 1 DAS	100	14.67	1.19
Pendimethalin 30 EC at 1 DAS	750	13.43	1.08
Quizalofop-ethyl 5 EC at 20 DAS	50	10.70	0.87
Hand weeding at 20 DAS	-	14.90	1.26
Weedy check	-	9.33	0.82
LSD (p=0.05)		1.11	0.15
Greengram			
Oxyfluorfen 23.5 EC at 1 DAS	100	15.33	0.99
Pendimethalin 30 EC at 1 DAS	750	14.90	0.93
Quizalofop-ethyl 5 EC at 20 DAS	50	11.67	0.87
Hand weeding at 20 DAS	-	15.87	0.97
Weedy check	-	10.33	0.60
LSD (p=0.05)		1.24	0.09
Kharif season (first week of July – end October)		No. of panicles/ plant	Grain yield
Direct-seeded puddled rice			
Oxyfluorfen 23.5 EC at 1 DAP	100	12.82	3.23
Bispyribac sodium 10 SC at 1 DAP	20	12.67	3.19
CyhalofopbutyI 10 EC at 1 DAP	100	11.70	3.14
Carfentrazone ethyl 40 DF at 1 DAP	25	12.33	3.18
Almix 20 WP at 25 DAP	4	11.10	3.11
Pyrazosulfuron-ethyl 10 WP at 20 DAP	30	10.90	3.09
Hand weeding twice at 20 and 40 DAP	-	12.87	3.30
Weedy check	-	9.90	2.40
LSD (p=0.05)		0.82	0.13
Transplanted rice			
Oxyfluorfen 23.5 EC at 1 DAT	100	15.12	4.15
Bispyribac-sodium 10 SC at 1 DAT	20	15.47	4.19
Pretilachlor 50 EC at 1 DAT	500	15.33	4.17
Pretilachlor 30.7 EC at 1 DAT	500	16.33	4.26
Butachlor 50 EC at 1 DAT	1250	14.80	4.04
Oxadiargyl 80 WG at 1 DAT	100	15.90	4.23
Triasulfuron 20 WG at 1 DAT	12	14.97	4.06
Flucetosulfuron 10 WG at 1 DAT	20	15.00	4.12
Almix 20 WP at 25 DAT	4	14.70	3.98
Pyrazosulfuron-ethyl 10 WP at 20 DAT	30	14.33	3.92
Hand weeding twice at 20 and 40 DAT	-	16.45	4.45
Weedy check	-	12.67	3.17
LSD (p=0.05)		0.92	0.13
Rabi/winter season (first week of November – end February)		Average tuber weight (g)	Tuber yield
Potato			
Oxyfluorfen 23.5 EC at 1 DAP	100	59.60	31.86
Pendimethalin 30 EC at 1 DAP	750	56.33	27. 70
Paraquat dichloride 24 SL at 1 DAP	2500	57.20	29. 33
Metribuzin 70 WP at 1 DAP	600	63.00	33. 20
Metribuzin 70 WP at 40 DAP	600	48.10	25. 20
Hand weeding at 15 DAP	-	59.00	32.58
Weedy check	-	40.33	21.50
LSD (p=0.05)		7.39	1.06
Onion		Average bulb weight (g)	Bulb yield
Oxyfluorfen 23.5EC at 1DAP	100	43.50	29.50
Oryzalin - XL 40 SC at 1 DAP	6.25 /ha	41.33	27.67
Pendimethalin 30 EC at 1 DAP	750	41.00	26.30
Quizalofop-ethyl 5 EC at 20 DAP	50	35.33	21.33
Hand weeding at 20 and 50 DAP	-	44.70	31.56
Weedy check	-	30.87	18.67
LSD (p=0.05)		5.31	2.72

A common mechanical weeding (wheel hoe at 30 DAS in black and green gram and at 30 DAP in onion; rice weeder at 30 DAT in DSPR and TR and earthing up at 25 DAP in potato) was done in all treatments



PE Herbicides- Initial microflora population: Total bacteria 51. 00 CFU x 10 ^{6}/g Fungi: 20.25 CFU x 10 ^{4}/g and Actinomycetes 130.72 CFU x 10 ^{5}/g of soil

Figure 1. Effect of PE herbicides used in various field crops on percent increase or decrease of the average total bacteria, total fungi and total actinomycetes population in the rhizosphere soil of experimental fields during 2011-16



PoE Herbicides- Initial Microflora population: Total Bacteria 56. 50 CFU x 10 ^{6}/g Fungi: 24.00 CFU x 10 ^{4}/g and Actinomycetes 151.00 CFU x 10 ^{5}/g of soil

Figure 2. Effect of PoE herbicides used in various field crops on percent increase or decrease of the average total bacteria, total fungi and total actinomycetes population in the rhizosphere soil of experimental fields during 2011-16

plants. Further the reduced microflora population may unable to supply better resources particularly nutrients for establishing higher yield attributes in various crops and as a result the productivity was also suffered in PoE herbicides treated plots. Das *et al.* (2014) and Ghosh *et al.* (2015) expressed similar views working with PoE herbicides and PE botanicals, respectively in this inceptisol.

Therefore, for increasing sustainable productivity in crops grown in sequence with system intensification methodology, the annual planning of weed pest management including ecosafe PE herbicides with mechanical weeding may be the better option to replace the traditional costly hand weeding.

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Short communication

Herbicidal management of Chinese sprangletop (*Leptochloa chinensis)* in direct-seeded rice

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Leptochloa chinensis (L.) Nees. (Chinese sprangletop or Red sprangletop) is one of the most important invasive weeds in direct-seeded rice fields (Chin 2001). In Kerala, Chinese sprangletop was reported as a new weed specific to the alkaline soils of Chittoor taluk (Vidya *et al*. 2004). Though this weed is listed as an indicator plant for alkaline conditions, it is now seen spreading rapidly in acidic soils of Kerala also with typical example of weed shift. Continuous use of bispyribac-sodium, which is one of the most popular rice herbicides among farmers in Kerala, to control barnyard grass resulted in the dominance of Chinese sprangletop. In view of the growing menace of *Leptochloa chinensis* in the rice fields of Kerala, it is important to develop a new herbicide strategy by making use of the new molecule herbicides or the pre- and post- emergence herbicides already in use for effective control.

A field experiment in wet seeded rice was conducted during second crop season of 2012 in a farmer's field of Thrissur district ($75^0$58' latitude and $76^0$11' longitude and 1m below MSL), Kerala. The soil was clay loam with pH 5.2, organic C of 1.4%, available N of 890 kg/ha, available P of 24 kg/ha and available K of 281 kg/ha. The crop received 165.5 mm rainfall during 2012. The mean monthly minimum and maximum temperature were 33.9°C and 23.2°C. The experiment comprised 12 treatments. The herbicide oxyfluorfen 23.5 EC was sprayed as pre-emergence at 3 days after sowing (DAS), while butachlor 50 EC and pretilachlor 50 EC were applied at 6 DAS. Pyrazosulfuron-ethyl 10 WP was applied as early post-emergence at 8 DAS whereas cyhalofop butyl 10 EC, fenoxaprop-p-ethyl 6.9 EC, bispyribac- sodium 10 SC, metamifop 10 EC, azimsulfuron 50 DF and penoxsulam 24 SC were applied at 20 DAS. Hand-weeding twice at 20 and 40 DAS and weedy check were kept as controls. The treatments were applied in a randomized block design with three replications and a plot size of 20 m^2. The rice variety used was '*Jyothi (PTB 39)*'.The seed rate for sowing was 100 kg/ha. The crop was fertilized with 90, 35, 45 kg/ha of N, P_2O_5, and K_2O respectively. One third dose of N and K and half of P were applied at I5 DAS, one third dose of N and K and half of P at 35 DAS and remaining one third N and K at 55 DAS (KAU, 2011). Observations on weed density and weed dry weight for total weeds and *L.chinensis* were recorded separately with the quadrate (0.25 x 0.25 m) placed randomly in each plot at 30 DAS, 60 DAS and at harvest. The data on weed count were subjected to square root transformation ($\sqrt{x+0.5}$) to normalize the distribution. Weed control efficiency (WCE) was computed separately for *L. chinensis* and total weeds by using weed dry weight, and weed index (WI) was computed using grain yield of weed free check and yield of treated plot. Yield attributing characters like panicles/m^2, grains per panicle, fertility % and 1000 grain weight were recorded at harvest by placing the quadrate (0.25 x 0.25 m) in each plot. The cost of cultivation was worked out based on the labour and input cost incurred towards rice cultivation in different treatments. The data were analyzed using ANOVA and the least significant difference (LSD) values at 5% level of significance were calculated.

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Weed flora and density

The major weed species found in experimental plot were grasses. At 60 DAS, the relative density was highest in the grasses *Leptochloa chinensis* (31%) and *Echinochloa* sp. (8.6%), followed by the sedges *Fimbristylis miliacea* (21.3%) and *Cyperus* sp. (16.5%), and the lowest was in the broad-leaved weeds *Lindernia crustacea* (10.7%), *Ludwigia parviflora* (8.3%) and *Alternanthera* sp. (3.6%). The higher proportion of grasses compared to sedges and broad-leaf weeds in rice in *Kole* lands was also reported by Joy *et al*. (1993) and Sindhu (2008).

The weeds, especially the sedges and broad-leaved weeds, were present in all treatments except that of pretilachlor, where sedges were not recorded, and of bispyribac-sodium, where broad-leaved weeds were absent. Azimsulfuron and penoxsulam, though broad-spectrum herbicides, were found less effective compared to bispyribac-sodium in controlling broad-leaved weeds. Metamifop was seen to be the least effective against sedges, and also less effective against grasses and broad-leaf weeds. At 30 DAS, *L. chinensis* was absent in the fenoxaprop-p-ethyl, hand-weeded control, pyrazosulfuron-ethyl, oxyfluorfen, pretilachlor and butachlor treatments (**Table 2**). At 60 DAS the population increased, and so the dry weight also increased as compared to 30 DAS.

Table 1. Effect of herbicides on weed density, total weed dry weight and weed control efficiency (WCE%)

Treatment	Weed density (no./m^2) 30 DAS			60 DAS			Harvest			Total weed dry weight (kg/ha)			WCE (%)		
	G	S	B	G	S	B	G	S	B	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
Butachlor-50 EC	3.80^{f} (14)	4.06^{h} (16)	3.81^{e} (14)	9.62^{e} (92)	3.14^{h} (9.4)	2.92^{f} (8)	7.31^{e} (53)	2.92^{e} (8)	2.12^{i} (4)	60.10^{i}	993.37^{b}	764.50^{d}	64.54^{d}	6.83^{k}	30.75^{i}
Oxyfluorfen-23.5 EC	2.55^{g} (6)	3.39^{i} (11)	5.34^{b} (28)	7.52^{h} (56)	4.53^{e} (20)	2.92^{f} (8)	5.70^{g} (32)	2.34^{f} (5)	4.06^{f} (16)	136.99^{c}	809.60^{d}	704.00^{e}	19.20^{j}	24.66^{i}	36.23^{h}
Pretilachlor-50 EC	0.71^{i} (0)	0.71^{k} (0)	4.95^{c} (24)	5.34^{i} (28)	3.54^{g} (12)	6.67^{c} (44)	4.18^{h} (17)	1.60^{g} (2)	6.04^{d} (36)	88.00^{g}	578.76^{h}	527.13^{h}	48.10^{f}	46.14^{e}	52.25^{e}
Pyrazosulfuron-ethyl-10 WP	0.71^{i} (0)	4.52^{g} (20)	2.92^{f} (8)	10.22^{c} (104)	3.81^{f} (14)	2.12^{g} (4)	7.78^{c} (60)	1.22^{gh} (1)	2.92^{h} (8)	25.33^{k}	595.46^{g}	478.00^{i}	85.06^{b}	44.59^{f}	56.70^{d}
Azimsulfuron-50 DF	4.53^{d} (20)	5.70^{f} (32)	4.53^{d} (20)	10.79^{b} (116)	3.54^{g} (12)	2.92^{f} (8)	7.78^{c} (60)	0.71^{i} (0)	4.53^{e} (20)	78.40^{h}	637.80^{f}	792.50^{c}	53.76^{e}	40.65^{g}	28.21^{j}
Bispyribac sodium-10 SC	5.61^{b} (31)	6.07^{e} (36)	0.71^{h} (0)	10.12^{d} (102)	4.53^{e} (20)	2.12^{g} (4)	8.09^{b} (65)	2.92^{e} (8)	2.12^{i} (4)	110.00^{e}	652.86^{e}	614.00^{g}	35.11^{h}	39.25^{h}	44.38^{f}
Cyhalofop-butyl-10 EC	2.55^{g} (6)	8.03^{d} (64)	5.34^{b} (28)	4.95^{j} (24)	8.28^{c} (68)	5.96^{d} (36)	3.54^{i} (12)	6.67^{c} (44)	8.03^{b} (64)	94.26^{f}	436.53^{j}	406.00^{j}	44.41^{g}	59.38^{c}	63.23^{c}
Fenoxaprop-p-ethyl-6.9 EC	0.71^{i} (0)	8.27^{c} (68)	4.95^{c} (24)	0.71^{k} (0)	7.52^{d} (56)	7.97^{b} (63)	2.12^{h} (4)	7.45^{b} (55)	6.67^{c} (44)	29.30^{j}	362.35^{k}	340.12^{k}	82.72^{c}	60.70^{b}	69.19^{b}
Metamifop-10 EC	4.06^{e} (16)	9.08^{b} (82)	5.34^{b} (28)	9.41^{f} (88)	9.41^{b} (88)	6.04^{d} (36)	7.52^{d} (56)	5.79^{d} (33)	4.53^{e} (20)	144.00^{b}	903.37^{c}	880.70^{b}	15.05^{k}	7.56^{j}	11.17^{k}
Penoxsulam-24 SC	5.28^{c} (24)	3.99^{h} (15)	3.81^{e} (14)	8.51^{g} (72)	3.54^{g} (12)	3.80^{e} (14)	7.11^{f} (50)	0.71^{i} (0)	3.54^{g} (12)	115.80^{d}	448.50^{i}	685.40^{f}	31.70^{i}	58.26^{d}	37.92^{g}
Handweeded control	1.58^{h} (2)	2.74^{j} (7)	1.87^{g} (3)	0.71^{k} (0)	1.22^{i} (1)	0.71^{h} (0)	0.71^{j} (0)	0.71^{i} (0)	1.87^{j} (3)	20.17^{l}	4.80^{l}	16.22^{l}	88.11^{a}	100.0^{a}	97.0^{a}
Unweeded control	6.04^{a} (36)	10.7^{a} (115)	6.36^{a} (40)	12.66^{a} (161)	11.44^{a} (130)	8.75^{a} (76)	9.61^{a} (92)	9.87^{a} (97)	9.19^{a} (84)	169.5^{a}	1074.6^{a}	1104.0^{a}	-	-	-
LSD (P=0.05)	5.67	6.33	4.78	5.02	3.63	3.57	4.07	3.87	3.82	2.37	5.87	3.72	1.43	0.53	0.31

G - Grasses, S - Sedges, B - Broad-leaf weeds, DAS - Days after sowing. *$\sqrt{x+0.5}$ transformed values. Original values are given in the parentheses

Table 2. Effect of herbicides on *Leptochloa chinensis* count, dry weight and weed control efficiency (WCE)

Treatment	30 DAS Count (no./m^2)	Dry weight (kg/ha)	WCE %	60 DAS Count (no./m^2)	Dry weight (kg/ha)	WCE %	Harvest Count (no./m^2)	Dry weight (kg/ha)	WCE %
Butachlor-50 EC	*0.71^{g} (0)	0	100^{a}	5.06^{g} (25.7)	139.20^{h}	76.00^{d}	4.16^{f} (17.3)	186.40^{h}	69.64^{e}
Oxyfluorfen-23.5 EC	0.71^{g} (0)	0	100^{a}	5.77^{f} (33.3)	185.60^{f}	67.70^{f}	4.0^{f} (16.0)	192.22^{g}	68.70^{ef}
Pretilachlor-50 EC	0.71^{g} (0)	0	100^{a}	4.65^{h} (21.7)	116.10^{i}	79.80^{c}	2.89^{g} (8.3)	96.00^{i}	84.40^{d}
Pyrazosulfuron-ethyl-10 WP	0.71^{g} (0)	0	100^{a}	6.11^{e} (37.3)	173.03^{g}	69.90^{e}	5.06^{e} (25.7)	288.00^{f}	53.10^{f}
Azimsulfuron-50 DF	3.65^{c} (13.3)	23.30^{c}	59.81^{c}	7.98^{d} (63.7)	368.20^{d}	36.00^{h}	6.11^{d} (37.3)	336.0^{e}	45.30^{g}
Bispyribac-sodium-10 SC	4.69^{a} (22.0)	34.80^{b}	40.20^{e}	10.33^{a} (106)	417.60^{b}	27.30^{j}	7.53^{a} (56.7)	527.70^{b}	14.05^{j}
Cyhalofop-butyl-10 EC	2.36^{e} (5.7)	11.60^{d}	80.00^{b}	2.82^{i} (8.0)	23.30^{j}	96.00^{b}	2.16^{h} (4.7)	48.00^{j}	92.20^{c}
Fenoxaprop-p-ethyl-6.9 EC	0.71^{g} (0)	0	100.00^{a}	0.71^{j} (0)	0	100.00^{a}	1.38^{i} (2)	10.20^{k}	98.33^{b}
Metamifop-10 EC	2.99^{d} (9.0)	23.40^{c}	60.10^{c}	8.48^{c} (72.0)	200.80^{e}	65.03^{g}	6.73^{b} (45.3)	432.50^{d}	29.60^{h}
Penoxsulam-24 SC	3.69^{c} (13.7)	23.80^{c}	59.00^{d}	7.98^{d} (63.7)	371.40^{c}	35.32^{i}	6.43^{c} (45.3)	477.40^{c}	22.25^{i}
Hand weeded control	1.22^{f} (1)	0	100^{a}	0.71^{j} (0)	0	100^{a}	0.71 (0)	0	100^{a}
Unweeded control	4.20^{b} (17.7)	58.00^{a}	-	9.75^{b} (95.0)	574.23^{a}	-	6.81^{b} (46.3)	614.00^{a}	-
LSD (p=0.05)	1.69	3.36	2.79	1.79	3.17	1.17	2.06	3.44	0.27

DAS – Days after sowing. *Original data in parentheses are subjected to square root transformation

Table 3. Effect of treatments on yield attributes and yield of direct-seeded rice

Treatment	Height (cm)	Panicles (no./m^2)	Grains/ panicle (no.)	1000 grain weight (g)	Fertility (%)	Weed Index (%)	Grain yield (t/ha)	Straw yield (t/ha)	B:C ratio
Butachlor-50 EC	89.49^{ab}	368.0^{bcd}	85.53^{de}	27.57^{b}	81.43^{ab}	37^{d}	4.74^{h}	5.19^{de}	1.6
Oxyfluorfen-23.5 EC	88.63^{ab}	306.7^{de}	89.33^{cde}	27.00^{f}	76.53^{ef}	34de	4.76^{g}	4.99^{e}	1.6
Pretilachlor-50 EC	86.51^{bcd}	324.0^{de}	92.15^{cde}	27.33^{d}	76.30^{ef}	43^{bc}	4.53^{j}	5.20^{de}	1.5
Pyrazosulfuron-ethyl-10 WP	86.65^{bc}	374.7^{bcd}	95.40^{cd}	27.27 ^{e}	80.45^{abc}	29^{ef}	4.67^{i}	5.63^{bc}	1.5
Azimsulfuron-50 DF	90.50^{a}	341.3^{cde}	99.20^{bc}	27.87^{a}	73.13^{g}	35^{d}	4.83^{f}	4.92^{f}	1.6
Bispyribac sodium-10 SC	85.07^{cd}	372.0^{bcd}	108.50^{ab}	27.33^{d}	79.53^{bcd}	38^{cd}	5.02^{d}	5.25^{d}	1.7
Cyhalofop-butyl-10 EC	89.17^{ab}	409.3^{bc}	109.40^{ab}	27.67^{a}	82.40^{ab}	25^{fg}	5.46^{c}	5.74^{b}	1.9
Fenoxaprop-p-ethyl-6.9 EC	90.47^{a}	441.37^{ab}	112.50^{a}	27.57^{b}	83.33^{a}	20^{g}	5.88^{b}	5.74^{b}	2.1
Metamifop-10 EC	90.49^{a}	341.0^{cde}	91.30^{cde}	26.87^{g}	73.80^{fg}	46^{b}	4.48^{k}	5.37^{c}	1.4
Penoxsulam-24 SC	83.62^{d}	340.0^{cde}	72.13^{f}	27.17^{f}	76.07^{ef}	33de	4.93^{e}	5.64^{bc}	1.6
Handweeded control	86.97^{bc}	461.3^{a}	111.8^{a}	27.43^{c}	78.43^{cde}	-	6.46^{a}	5.87^{a}	1.9
Unweeded control	85.20^{cd}	272.0^{e}	81.20^{ef}	27.33^{d}	77.43^{de}	56^{a}	4.07l	5.37^{c}	1.3
LSD (p=0.05)	2.68	0.31	10.04	0.92	2.76	0.05	0.26	0.70	

In a column, means followed by same superscript do not differ significantly at 5% level of significance in DMRT

Weed dry weight and weed control efficiency

All grasses, sedges and broad-leaf weeds persisted till harvest, and dry weight (**Table 1**) was the highest in the unweeded plot. Hand-weeding resulted in the lowest total weed and *L. chinensis* dry matter production. At 30 DAS, herbicides, *viz*. cyhalofop, pretilachlor, azimsulfuron, butachlor, fenoxaprop-p-ethyl, and pyrazosulfuron ethyl showed less weed dry matter production (**Table 1**). At 60 DAS, the weed dry weight increased to the tune of six times in unweeded control and the lowest dry weight was noticed in fenoxaprop-p-ethyl treated plots followed by the treatment cyhalofop-butyl. At 30 DAS the population and dry weight of *L. chinensis* (**Table 2**) were low compared to that at 60 DAS and at harvest, indicating subsequent germination of this weed probably due to well managed water level in the plots initially. At 30 DAS, *L. chinensis* was absent in the treatment fenoxaprop-p-ethyl, and cyhalofop butyl recorded the lowest weed dry weight of 11.6 kg/ha. The highest weed control efficiency (WCE) was recorded with fenoxaprop-p-ethyl, followed by cyhalofop-butyl while lowest was in bispyribac-sodium treated plot.

Yield and economics

The highest number of panicles/m^2, filled grains per panicle , and grain yield were registered in hand-weeding (**Table 3**). The highest grain yield of 6.46 t/ha was recorded in hand-weeded control plot followed by fenoxaprop-p-ethyl (5.88 t/ha) and cyhalofop-butyl (5.46 t/ha), and the lowest yield of 4.07 t/ha was obtained in unweeded control. An analysis of the economics of rice cultivation showed that application of fenoxaprop-p-ethyl provided the highest B:C ratio (2.1), (**Table 3**).

SUMMARY

A field experiment was conducted to study the herbicidal management of *Leptochloa chinensis* (L.) Nees. during *Rabi* season in a farmer's field at Pullu in Thrissur district during the period November 2012 -March 2013. Post-emergence application of fenoxaprop-p-ethyl 60 g/ha or cyhalofop-butyl 80 g/ha can be recommended in *L. colona* infested fields. Wherever this weed is not a problem, bispyribac-sodium 30 g/ha can be recommended.

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Short communication

Allelopathic potential of rice varieties against major weeds of rice and wheat

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Key words: Allelopathy, Germination, Rice straw, Seedling vigor index, Total chlorophyll content

Rice-wheat system is the major cropping system in Northern India. Direct-seeding of rice is receiving considerable attention because of decreasing availability of water and increasing labor costs. In rice shift from transplanted to direct-seeded cultural practices, weed problems are expected to increase since crop and weeds can emerge together (Rao *et al.* 2007). Yield losses of wheat due to weeds are estimated around 25-50% and in very severe cases the losses may go up to 80% (Singh *et al.* 2005). Production of large amount of straw by rice crop is one of the most serious problems in rice producing countries like India. The majority of rice straw is burnt in the fields causing environmental pollution and health hazard to public. Incorporating the residues of rice with high allelopathic activity can reduce the herbicide usage in rice-wheat system. *Echinochloa crus-galli* and *E. colona* in rice and *Phalaris minor* in wheat are the predominant and noxious grassy weeds in rice-wheat system (Walia *et al.* 2005). The use of rice germplasm that contains high allelopathic activity, combined with incorporating straw into the soil can suppress germination of weeds. So, the present study was undertaken to assess basmati and non-basmati rice varieties for their allelopathic potential against germination of *E. crus-galli*, *E. colona* and *P. minor*.

Seeds of six rice varieties, *viz. 'PR 115, PR 124, PR 118, Pusa Punjab Basmati-1509, Punjab Basmati-3* and *Basmati-386'* were procured from Rice Section, Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana. Seeds of *E. crus-galli* and *E. colona* were collected from several rice fields and *P. minor* seeds from wheat fields of Punjab. Seeds were bulked, cleaned and stored at room temperature in a laboratory in air tight plastic containers until they were used in experiments.

Uniform sized seeds of *E. crus-galli, E. colona* and *P. minor* were surface sterilized using 0.1% mercuric chloride for two minutes followed by thorough washing with distilled water to ward off any fungal infection. Seed germination was tested on 3 replicates of twenty seeds placed evenly on Whatman No. 1 filter paper in 9 cm Petri dishes. Dishes were moistened with 5 ml of treatment solution and incubated at 30°C (optimum temperature) for *E. crus-galli* and *E. colona* and at 20°C (optimum temperature) for *P. minor* in environmental chamber (Model MAC MSW-127, Delhi, India). Seeds germinated using distilled water served as control.

Water extracts of roots and shoots (5%) were prepared from 50 days old rice plants. Paddy straw extracts (5%) were prepared from mature rice plants. For preparing aqueous extracts, samples were shade dried followed by oven drying at 65-70°C for 48 hrs. The plant samples were chopped into 2-3 cm pieces and then grounded. Aqueous extracts (5%) were prepared by soaking 5 g plant material in 100 ml distilled water for 24 hr at room temperature followed by filtration. Allelopathic potential of aqueous extracts prepared from 50 days old plants was tested against *E. crus-galli* and *E. colona*. The allelopathic potential of paddy straw aqueous extracts was tested against *P. minor*.

Germination counts were made at 24-h intervals for 15 days after start of the experiment, with the criterion for germination being visible protrusion of the radicle. Germination (%) was calculated as: (No. of seeds germinated /total number of seeds sown) × 100. Shoot and root length of seedlings was measured on 15th day of experiment using centimeter scale. Seedling vigor index (SVI) was calculated as described by Abdul-Baki and Anderson (1973) using the formula: SVI = seedling length (cm) x germination (%). Membrane leakage of 15 days old seedlings was determined as described by Fletcher and Drexlure (1980). Total chlorophyll content of seedlings was determined as described by Anderson and Boardman (1964). All the experiments were conducted in a completely randomized design with three replications and the experiment was repeated thrice. There were no significant differences between the results of the repeated experiments, so data were pooled before

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conducting analysis of variance (ANOVA) using CPCS 1 software.

Effects of aqueous extracts

Aqueous shoot extracts of all the six rice varieties significantly reduced germination of *E. crus-galli* in the range of 10-45% as compared to 86.7% germination in control. Shoot extracts of non-basmati varieties (*PR 115, PR 124* and *PR 118*) exhibited higher suppressive effect as compared to basmati varieties of rice (*Pusa Punjab Basmati-1509, Punjab Basmati-3 and Basmati-386*). Rice varieties '*PR 124*' and '*PR 118*' exhibited maximum inhibitory effect due to which germination of *E. crus-galli* was reduced to 10% (**Table 1**). Shoot extract of '*PR 124*' exhibited maximum inhibitory effect on seedling growth and seedling vigor index (SVI).

Aqueous root extracts of six rice varieties reduced germination of *E. crus-galli* to 17.5-48.3%. Aqueous root extracts of basmati varieties caused germination inhibition to greater extents as compared to non-basmati rice varieties. Maximum inhibitory effect on germination and seedling growth of *E. crus-galli* was observed due to root extract of '*Punjab Basmati-3*', which reduced germination to 17.5%; and also reduced SVI by 86.9% than control (**Table 1**). Chung *et al*. (2003) reported the inhibitory effects of rice hulls and leaf plus straw on *E. crus-galli* germination. They reported that rice variety '*CUBA 65-v-58*' caused 36.8% reduction in germination of *E. crus-galli*.

Shoot extract of '*PR118*' a non-basmati rice variety caused maximum increase in membrane leakage with 16.9% points and greatest reduction in total chlorophyll content (60.6%) as compared to their respective controls (**Table 1**).

The aqueous shoot and root extracts of rice varieties caused significantly reduced germination of *E. colona*. (**Table 2**). Swain *et al*. (2012) studied the effect of decomposing leachates of upland rice cultivar '*Vandana*' which reduced germination and seedling growth of *E. colona*. Aqueous shoot and root extracts of rice varieties caused significant increase in membrane leakage coupled with reduction in total chlorophyll content of *E. colona* seedlings (**Table 2**). Shoot extract of '*Basmati-386*' caused maximum increase in membrane leakage (26% points) and greatest reduction in total chlorophyll content (73.2%) as compared to their respective controls. Aqueous root extract of '*Punjab Basmati-3*'

Table 1. Effect of aqueous shoot and root extracts (5%) of rice varieties on germination, seedling vigor index, membrane leakage and total chlorophyll content of *Echinochloa crus-galli* seedling

Variety	Germination (%)		Seedling vigor index		Membrane leakage of seedling (%)		Total chlorophyll content of seedling (mg/g FW)	
	Shoot extract	Root extract	Shoot extract	Root extract	Shoot extract	Root extract	Shoot extract	Root extract
PR 115	23.3	44.2	93.2	269.6	41.0	52.4	0.523	0.309
PR 124	10.0	44.1	32.0	233.7	48.8	49.5	0.415	0.343
PR 118	10.0	48.3	75.0	313.9	53.3	45.8	0.316	0.381
Pusa Punjab Basmati-1509	39.2	44.2	294.0	304.9	43.3	57.8	0.631	0.325
Punjab Basmati-3	45.0	17.5	346.5	99.7	45.8	57.5	0.661	0.209
Basmati-386	39.2	24.3	219.5	140.9	51.7	55.0	0.494	0.245
Control	86.7	86.7	763.0	763.0	36.4	41.0	0.803	0.803
LSD (p=0.05)	5.5	9.07	33.2	40.2	11.5	15.5	0.036	0.100

Table 2. Effect of aqueous shoot and root extracts (5%) of rice varieties on germination, seedling vigor index, membrane leakage and total chlorophyll content of *E. colona* seedling

Variety	Germination (%)		Seedling vigor index		Membrane leakage of seedling (%)		Total chlorophyll content of seedling (mg/g FW)	
	Shoot extract	Root extract	Shoot extract	Root extract	Shoot extract	Root extract	Shoot extract	Root extract
PR 115	30.8	24.2	169.4	135.5	58.4	55.0	0.635	0.846
PR 124	35.8	40.8	211.2	269.3	56.1	49.5	0.817	1.431
PR 118	37.5	35.8	191.2	261.3	65.1	52.5	0.809	1.176
Pusa Punjab Basmati-1509	37.5	34.2	138.7	174.4	60.0	50.5	0.967	1.804
Punjab Basmati-3	31.7	17.5	142.6	63.0	51.0	59.0	0.655	0.780
Basmati-386	23.3	23.3	81.5	88.5	68.0	56.5	0.509	0.931
Control	86.7	86.7	771.6	771.6	42.0	42.0	1.897	1.897
LSD (p=0.05)	7.5	6.9	44.2	19.8	8.6	9.0	0.059	0.135

Table 3. Effect of aqueous paddy straw extracts (5%) of rice varieties on germination, seedling vigor index, membrane leakage and chlorophyll content of *Phalaris minor* seedling

Varieties	Germination (%)	Seedling vigor index	Membrane leakage of seedling (%)	Total chlorophyll content of seedling (mg/g FW)
PR 115	32.5	289.2	34.3	0.542
PR 124	57.5	500.2	28.7	0.791
PR 118	68.3	812.8	27.9	0.824
Pusa Punjab Basmati-1509	38.3	417.5	33.3	0.665
Punjab Basmati-3	47.5	560.5	27.4	0.716
Basmati-386	60.8	784.3	29.4	0.812
Control	92.5	1332.0	26.2	0.924
LSD (p=0.05)	8.6	124.7	8.1	0.096

caused greatest increase in membrane leakage (17% points); and also caused maximum decrease in total chlorophyll content of about 58.9% than control.

Aqueous rice straw extracts (5%) of rice varieties significantly reduced germination of *P. minor* in the range of 32.5-68.3% as compared to 92.5% germination in control (**Table 3**). Variety *'PR 115'* exhibited maximum inhibitory effect and reduced germination of *P. minor* to 32.5%. Rice straw extract of this variety reduced SVI by 78.3% as compared to control. Among the basmati varieties, '*Pusa Punjab Basmati-1509*' exerted maximum suppressive effect and reduced the germination to 38.3%; and caused 68.6% reduction in SVI as compared to control. Om *et al.* (2002) also reported reduced germination of *P. minor* due to rice straw extract. Aqueous rice straw extracts of rice varieties caused significant increase in membrane leakage and decreased total chlorophyll content of *P. minor* seedlings (**Table 3**).

SUMMARY

The study was conducted to assess the allelopathic potential of three basmati (*PR 115, PR 124, PR 118)* and three non-basmati (*Pusa Punjab Basmati-1509, Punjab Basmati-3 and Basmati-386*) rice varieties against germination and seedling growth of *Echinochloa crus-galli*, *E. colona* and *Phalaris minor*. Shoot extracts (5%) of non-basmati rice varieties prepared from 50 days old plants had more detrimental effect on germination and seedling growth of *E. crus-galli* as compared to basmati rice varieties. Variety '*PR 124*' reduced *E. crus-galli* germination to 10% and seedling vigor index by 95.8% as compared to control. Root extracts (5%) of basmati varieties had higher allelopathic potential against germination and seedling growth of *E. crus-galli* than non-basmati varieties. Root extracts (5%) of '*Punjab Basmati- 3*' affected germination and SVI of *E. crus-galli* most severely. Aqueous extracts of rice varieties also significantly reduced germination of E. colona and P. minor.

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Short communication

Integrated weed management in rice bean

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Key words: Herbicide, Rice bean, Seed yield, Weed control

Rice bean (*Vigna umbellata*) is an underutilized minor pulse crops which is nutritionally rich with multiple uses. In India, its distribution is mainly confined to the tribal regions of North Eastern hills and hilly tracts of Western and Eastern Ghats in North Eastern states. It is grown on a limited scale in Eastern peninsular tracts (parts of Orissa and Chotanagapur) and Western peninsular tracts of Southern hills. Though, rice bean is one of the potential crops, its benefits have not been harnessed to fuller extent. Considering the labour crisis in cultivation of any crop including rice bean, application of herbicides for weed management is gaining more importance in recent days. The potential yield losses due to weeds can be as high as about 65% depending on the crop, degree of weed infestation, weed species and management practices (Yaduraju *et al.* 2006). Weeds compete with crops for natural and applied resources besides being responsible for reducing quantity and quality of agricultural productivity (Rao and Nagamani 2013, Rao *et al.* 2015). In this context, the present study was carried out to find out an effective herbicide for weed control in rice bean.

The experiment was conducted at Main Research Station, Hebbal, University of Agricultural Sciences, Bangalore, India for three consecutive *Kharif* seasons during 2012, 2013 and 2014 in a randomized block design with 11 treatments replicated thrice. The experimental site is situated at an altitude of $12^0$58' North, longitude of 77^0 35' East and altitude of 899 meters above mean sea level. The normal annual rainfall is 862.95 mm. The soil type was red sandy loam with a pH of 6.55 and electrical conductivity of 0.26 dS/m. Among the treatments, the pre-emergence herbicides were oxyflurofen 50 g/ha, oxyflurofen 50 g/ha + one hand weeding at 5 weeks after sowing (WAS), pendimethaline at 1 kg/ha and pendimethaline1 kg/ha + one weeding at 5 WAS, post-emergence application of fenoxaprop-p-ethyl 50 g/ha, quizlofop-p-ethyl 50 g/ha and oxadiargyl at 50 g/ha. In addition, weedy check (control), weed free control, two manual weeding at 3rd and 5th week and one manual weeding at 30 days after sowing were also included. A newly developed early maturing and high yielding variety of rice bean '*KBR-1*',was used under the study. The crop was sown in 30 cm x 10 cm spacing and raised with protective irrigation. The weed count (no/m^2) and dry weight (g/m^2) were recorded by putting a quadrate of 0.25 m^2 at two random spots in each plot and working out the mean values. Weed control efficiency (WCE) was calculated by using the formula

To calculate B:C ratio, prevailing market prices for rice bean seeds, the price for different inputs and farm operations were considered.

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Effect on weeds

The predominant weeds observed were *Digitaria margineta, Cyperus rotundus, Amaranthus virdis, Commelina benghalensis, Spillanthus acmella, Parthenium hysteroporus, Ageratum conyzoides, Eleusine indica, Euphorbia* spp. Three hand weeding (weed free check) resulted in the lowest weed count (11.11/m^2), dry weight of weeds (10.6 g/m^2) and higher weed control efficiency (95.3%) (**Table 1**). Sootrakar *et al.* (1995) reported that 3 hand weeding at (25, 40 and 55 DAS) resulted in the lowest weed counts and the highest weed control efficiency (98.8%). This treatment was found at par with pre-emergence application of pendimethaline 1.0 kg/ha in combination with one hand weeding at 5 WAS in case of weed count, weed dry weight and weed control efficiency. Yadav (2004) also reported the lowest weed dry matter and the highest weed control efficiency under pre-emergence application of pendimethalin at 0.5 kg/ha + 1 hand weeding at 40 DAS.

Among integrated weed management practices, pendimethaline 1.0 kg/ha + 1 hand weeding at 5 WAS produced lower weed population which was significantly superior over remaining treatments. Weed control efficiency of treatments varied from

Table 1.Effect of weed management practices on weeds, seed yileld and economics (pooled data)

Treatment	Weed count (no./m^2)	Weed dry weight (g/m^2)	Weed control efficiency (%)	Seed yield (t/ha)	Gross returns (x10^3`/ha)	Net returns (x10^3`/ha)	B:C ratio
Fenoxaprop-p-ethyl 50 g/ha at 3 WAS	32.8	110.4	49.5	0.83	41.51	20.44	1.97
Quizlofop-p- ethyl 50 g/ha at 3 WAS	31.9	100.7	55.7	0.84	42.09	20.14	1.92
Oxyflurofen 50 g/ha as pre-emergence	31.4	113.8	49.7	0.79	39.41	18.79	1.91
Oxyflurofen 50 g/ha as pre-emergence + one hand weeding at 5WAS	25.2	55.8	74.6	1.23	61.75	38.13	2.61
Oxadiargyl 50 g/ha at 3 WAS	42.2	166.8	24.5	0.57	28.54	7.92	1.38
Pendimethaline 1 kg/ha as pre-emergence	30.2	88.2	60.6	0.89	44.37	22.43	2.02
Pendimethaline1 kg/ha as pre-emergence + one weeding at 5 WAS	23.0	36.1	83.86	1.31	65.37	40.43	2.62
Two manual weeding at 3rd and 5thWAS	28.3	53.6	75.8	1.05	52.36	26.06	1.99
One manual weeding at 30 DAS	29.1	74.6	65.3	0.88	44.16	20.86	1.90
Weedy check	58.0	221.4	-	0.38	19.04	-0.81	0.96
Weed free check	11.1	10.6	95.3	1.42	71.16	41.86	2.43
LSD (p=0.05)	0.52	1.101	-	0.18	-	-	-

24.5 to 95.3%. Weed free check resulted in higher value of weed control efficiency followed by pendimethalin + 1 hand weeding at 5 WAS (**Table 1**). Weed control treatment may be attributed to kill and check the growth of weeds due to application of herbicides resulting in reduction in dry matter and increased weed control efficiency. Similar, findings was also reported by Chauhan and Gurjar (1998).

Effect on yield

Among the integrated weed management treatments, pre-emergence application of pendimethaline 1.0 kg/ha + one weeding at 5 WAS and oxyflurofen 50 g/ha + one hand weeding at 5WAS recorded significantly higher seed yield (1.31 and 1.23 t/ha, respectively) (**Table 1**). Oxadiargyl 50 g/ha post-emergence (3 WAS) recorded the lowest seed yield (0.57 t/ha).

Economics

The higher B:C ratio of 2.62 was recorded with pendimethaline 1.0 kg/ha + hand weeding at 5 WAS followed by oxyflurofen 50 g/ha + hand weeding at 5 WAS (2.61), whereas the weed free check recorded the B:C ratio of 2.43 (**Table 1**). This might be due to increased cost of cultivation of rice bean in weed free check treatment due to higher labour wages. This cost was reduced in the pendimethaline 1.0 kg/ha + hand weeding at 5 WAS followed by oxyflurofen 50 g/ha + hand weeding at 5 WAS by using herbicides.Weedy check recorded the lowest gross monitory returns (` 19,505/ha), net monitory returns (` 811/ha) and B:C ratio of 0.96. Hand weeding treatments, though significantly reduced weed biomass and improved the grain yield, it gave less benefit: cost ratio owing to higher cost of farm labour.

SUMMARY

The experiment on weed control in rice bean was conducted at Hebbal, Bengaluru for three years 2012, 2013 and 2014 using pre- and post-emergent herbicides along with manual weeding. Results revealed that the weed free control treatment recorded the lower weed count (11.11/m^2), weed dry matter (10.6 g/m^2) with higher weed control efficiency (95.3%) and seed yield (1.42 t/ha). The higher B:C ratio of 2.62 was recorded with pre-emergence application of pendimethalin 1.0 kg/ha + one hand weeding at 5 weeks after sowing (WAS) followed by pre-emergence application of oxyflurofen 50 g/ha + one hand weeding at 5 WAS (2.61).

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Short communication

Tillage practices effects on winter crops weeds density and growth under rice based cropping system

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Key words: Rainfed ecosystem, *Rabi* crops, Tillage practices, Weed density, Weed dry matter

Rice-based cropping systems are most predominant in India. Out of 139.9 million hectare (Mha) net cropped area, about 53% is rainfed and it produces almost 45% of food grains, 75-85% of pulses and oilseeds and significant amount of important industrial crops. Weeds are considered as one of the major limiting factors for efficient crop production in rainfed areas. Changes in tillage practices can cause shifts in weed species and densities. However, very little attention was given to understand effect of tillage practices on weed populations, as such information could be used to reduce populations of troublesome weed species (Peachey *et al.* 2006). So far much emphasis has been given on studying crop yields, weed emergence pattern and seed bank dynamics comparing zero tillage (ZT) and other conservation tillage practices with conventional tillage (CT) in rice based cropping systems across the world. However, meager efforts have been made on managing weed problem and improving yields by imposing diverse crops and designed tillage sequences within a cropping system. The present study was undertaken with the aim to understand effects of tillage practices on weed population in winter (*Rabi*) crops under rainfed rice based cropping system of Chhattisgarh.

A field experiment involving 4 tillage practices and 6 different *Rabi* crops was undertaken at Research cum Instructional Farm, Indira Gandhi Krishi Vishwavidyalaya, Raipur (Chhattisgarh) during *Rabi* winter season of 2014-15. Geographically, Raipur is situated in the centre of Chhattisgarh and lies between 210 16' N latitude and 810 36' E longitudes with an altitude of 298 m above the mean sea level (msl). The climatic condition of Raipur is sub-humid to semi-arid and receives average annual rainfall of 1325 mm. Soil sampling from the experiment field were taken with the help of a tube auger from 10 different points of the plots before starting of field experiment and were subsequently processed for further analysis for soil quality parameters. The analyzed soil indicated sandy loam texture and had pH (6.6), bulk density (1.48 g/cm^3), organic carbon (0.72%) and available NPK (219.14, 16.70 and 322 kg/ha, respectively).

The experiment was laid out in strip plot design with three replications. The treatment consisted of four tillage practices *viz.* zero tillage (ZT) direct-drilling of seeds and fertilizers at 2nd days after harvesting (DAH) of rice, minimum tillage (MT) and line sowing of seeds and fertilizers at 3rd DAH of rice, MT and line sowing of seeds and fertilizers at 6th DAH of rice, farmer practice-broadcasting seeds and fertilizer at 12th DAH of rice in horizontal strips and six *Rabi* crops *viz.* buckwheat, chickpea, lathyrus, safflower, linseed and toria in vertical strips. The varieties of crops namely *Fagopyrum esculentum* (buckwheat), *Cicer aeritinum* (chickpea), *Lathyrus sativus* (lathyrus), *Carthamus tinctorius* (safflower), *Linum usitatissimum* (linseed) and toria were *JG-14*, *Prateek*, *Bhima*, *RLC-92* and *Indira Toria–1*, respectively. The sowing of crops such as buckwheat, chickpea, *Lathyrus*, safflower, linseed and *Toria* was done on 31st October, 1st, 4th and 10th November 2014, respectively. All recommended package of practices of each crop were adopted during study period. During crop growth period, the maximum temperature varied between 25 ^{0}C to 37.3 ^{0}C with bright sunshine hours of 3 to 9.8 per day while, the minimum temperature ranged between 8 ^{0}C to 21.5 ^{0}C. The maximum and minimum relative humidity during the crop period was recorded 94 and 22%, respectively. A total of 11.7 mm rainfall was also received during the crop period. Weed parameters were recorded at 30, 60, 90 days after sowing (DAS) and at harvest. Weed growth, density and biomass were recorded with the help of one m^2 quadrate and oven drying, recorded data were subjected to square root transformation *i.e.* $\sqrt{x+0.5}$

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The data obtained from various characters under study were analyzed by the method of analysis of variance as described by Gomez and Gomez (1984).

Effect on weed density and biomass

Tillage practices and crops showed significant influence on weed density at almost all the growth stages (**Table 1**). Significantly lowest weed density (41.8, 48.8, 52.5 and 49.3 at 30, 60, 90 DAS and at harvest, respectively) was recorded with ZT direct drilling of seeds and fertilizers at 2nd days after harvesting (DAH) of rice. However, highest weed density (246.7, 216.2, 191.4 and 157.2 at 30, 60, 90 DAS and at harvest, respectively) was recorded under minimum tillage (MT) and line sowing of seeds and fertilizers at 3rd DAH of rice. Sangwan *et al.* (2008) also observed higher weed emergence and density under conventional method of sowing than ZT. *Rabi* crops also significantly influenced weed density at all the growth stages except 30 DAS. Lowest weed density among the tested crops was observed under safflower (119.75, 99.23 and 73 at 60, 90 DAS and at harvest, respectively), which was at par with *Lathyrus*. Highest weed density was recorded with buckwheat (141, 144.4 and 133.3 at 60, 90 DAS and at harvest, respectively). It was also observed that maximum numbers of recorded weed species were annuals.

Tillage practices and *Rabi* crops showed significant influence on weed biomass at all the growth stages **(Table 2)**. Among the tillage practices, significantly lowest weed biomass (1.36, 3.93, 8.92 and 11.12 g/m^2 at 30, 60, 90 and harvest stage, respectively) was recorded under ZT direct-drilling of seeds and fertilizers at 2nd DAH of rice. Whereas, highest weed biomass, *viz.* 9.23, 16.6, 33.5 and 37 g/m^2 at 30, 60, 90 and harvest stage, respectively was recorded under MT and line sowing of seeds at 3rd DAH of rice. The highest weed biomass recorded under MT and line sowing of seeds at 3rd DAH of rice was due to presence of higher weed population. In contrary to our observations, Monsefi *et al.* (2014) observed higher weed biomass in ZT than conventional tillage (CT) system. Similar to tillage practices, crops also significantly influenced weed biomass across the growth stages. Significantly lowest biomass was observed with safflower (4.8, 8.52, 20.33 and 23.88 g/m^2 at 30, 60, 90 and harvest stage, respectively), which was at par with linseed and *Toria* at 30 DAS, *Lathyrus* and *Toria* at 90 DAS and *Lathyrus*, chickpea and Toria at harvest stage.

Weed growth rate (g/day/m^2)

The weed growth increased in significant proportion up to 90 DAS and thereafter decreased (**Table 2**). Among the tillage practices, significantly highest weed growth rate (0.048, 0.083 and 0.09 g/day/m^2 at 60, 90 DAS and at harvest, respectively) was noted under MT and line sowing of seeds at 3rd DAH of rice. While, lowest weed growth rate (0.037, 0.050 and 0.05 g/day/m^2 at 60, 90 DAS and at harvest, respectively) was observed under ZT direct drilling of seeds and fertilizers at 2nd DAH of rice. These results were corroborated with the findings of Malik *et al.* (2000). With respect to *Rabi* crops, highest weed growth rate was recorded under toria throughout crop growth period and lowest weed growth rate was recorded in lathyrus (0.032g/day/m^2) at 60 DAS and safflower (0.064 and 0.005 g/day/m^2) at 90 DAS and at harvest stage, respectively.

Table 1. Effect of tillage practices and *Rabi* crops on weed density in rainfed rice based cropping system of Chhattisgarh

Treatment	Weed density (no. of weed/m^2)			
	30 DAS	60 DAS	90 DAS	At harvest
Tillage practice				
ZT direct drilling of seeds and fertilizers at 2nd days after harvesting (DAH) of rice,	6.51 (41)	7.02 (49)	7.28 (52)	7.06 (49)
MT and line sowing of seeds and fertilizers at 3rd DAH of rice	15.72 (247)	14.72 (216)	13.85 (191)	12.56 (157)
MT and line sowing of seeds and fertilizers at 6th DAH of rice	13.84 (191)	12.66 (160)	12.75 (162)	11.78 (138)
Farmer practice-broadcasting seeds and fertilizers at 12th DAH of rice	10.70 (114)	9.97 (99)	10.43 (108)	10.38 (107)
LSD (p=0.05)	4.98	4.12	4.42	4.23
Rabi crop				
Fagopyrum esculentum	12.38 (152)	11.90 (141)	12.04 (144)	11.57 (133)
Cicer aeritinum	12.37 (152)	11.46 (131)	11.48 (131)	11.4 (129)
Lathyrus sativus	12 (143)	11.76 (124)	10.43 (108)	9.04 (81)
Carthamus tinctorius	11.98 (143)	10.97 (119)	9.99 (99)	8.57 (73)
Linum usitatissimum	12.06 (145)	11.45(130)	11.88 (141)	10.97 (119)
Brassica campestris	12.41 (153)	11.82 (139)	12.18 (148)	11.92 (141)
LSD (p=0.05)	NS	9.99	9.10	7.85

*Square root transformed values ($\sqrt{x+0.5}$), original values are in parentheses

Table 2. Effect of tillage practices and *Rabi* crops on weed biomass and growth rate in rainfed rice based cropping systems of Chhattisgarh

Treatment	Weed biomass (g/m^2)				Weed growth rate (g/day/m^2)		
	30 DAS	60 DAS	90 DAS	At harvest	60 DAS	90 DAS	At harvest
Tillage practice							
ZT direct drilling of seeds and fertilizers at 2nd days after harvesting (DAH) of rice	1.36 (1.36)	2.10 (3.93)	3.07 (8.92)	3.41 (11.12)	0.037	0.050	0.0055
MT and line sowing of seeds and fertilizers at 3rd DAH of rice	3.12 (9.23)	4.13 (16.58)	5.83 (33.48)	6.12 (37)	0.048	0.083	0.0090
MT and line sowing of seeds and fertilizers at 6th DAH of rice	2.57 (6.12)	3.45 (11.4)	5.42 (28.93)	5.8 (33.15)	0.039	0.078	0.0084
Farmer practice-broadcasting seeds and fertilizers at 12th DAH of rice	2.16 (4.17)	2.77 (7.18)	3.96 (15.19)	4.45 (19.31)	0.037	0.056	0.0060
LSD (P=0.05)	0.18	0.33	0.70	0.84	NS	0.008	0.0016
Rabi crop							
Fagopyrum esculentum	2.48 (5.67)	3.38 (10.94)	4.88 (23.34)	5.21 (26.65)	0.042	0.068	0.0063
Cicer aeritinum	2.49 (5.7)	3.33 (10.6)	4.74 (21.98)	5.13 (25.82)	0.040	0.067	0.0079
Lathyrus sativus	2.46 (5.54)	3.13 (9.27)	4.6 (20.65)	4.97 (24.17)	0.032	0.067	0.0076
Carthamus tinctorius	2.30 (4.8)	3 (8.52)	4.56 (20.33)	4.94 (23.88)	0.039	0.064	0.0050
Linum usitatissimum	2.31 (4.84)	3.2 (9.71)	4.72 (21.78)	5.01 (24.61)	0.042	0.065	0.0080
Brassica campestris	2.30 (4.77)	3.18 (9.61)	4.71 (21.7)	5.12 (25.75)	0.046	0.069	0.0086
LSD (p=0.05)	0.39	0.71	1.63	1.87	0.013	0.007	0.0018

*Square root transformed values ($\sqrt{x+0.5}$), original values are in parentheses; DAS - Days after sowing

SUMMARY

This study was conducted with the aim to understand the effects of tillage practices and *Rabi* crops on weeds in rainfed rice based cropping system of Chhattisgarh. Significantly lowest weed density, biomass and weed growth rate across all the growth stages under ZT direct drilling of seeds and fertilizers at 2nd days after harvesting (DAH) of rice as compare to other tillage practices. Among the *Rabi* crops, significantly lowest weed density, biomass and weed growth rate at all the growth stages except 30 DAS were observed with safflower crop. The combination of ZT direct drilling of seeds and fertilizers at 2nd DAH of rice and safflower can be used for better management of weeds in rainfed rice based cropping system.

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Short communication

Abundance, distribution and diversity of weeds in wheat in Haryana

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Wheat (*Triticum aestivum* L.) crop is infested with both grassy and broad-leaf weeds. Losses caused by weeds in wheat vary from 30-50% depending upon type of weed flora, time, and intensity of weed infestation, but in extreme cases there could be complete crop failure (Malik and Singh 1995). Weed flora has been in a state of dynamism brought about by mankind for his benefits, thus paving the way for superior competitive species to gain the foothold in changed soil conditions. Species which have same ecological demands are inclined to occupy the same habitats with much rapidity. Crop type and soil properties have greatest influence on the occurrence of weed species (Streibig *et al.* 1984, Andreasen *et al.* 1991). The type of irrigation, cropping pattern, weed control measures and environmental factors have a significant influence on the intensity and infestation of weeds (Saavedra *et al.* 1990). Abundance measures the quantitative significance of a species in its habitat. It describes the success of weed in terms of numbers. Density and frequency are the two simplest and most popular methods of measuring abundance. Whereas, the distribution of weed species denotes its natural geographic range. It is the description of where the species naturally occurs or where it has been recorded. Weed flora distribution is a dynamic phenomenon because it changes over time as the result of climatic, anthropogenic or ecological factors. Changes in a weed distribution can provide critical information regarding the weed species expansion or contraction, predictability of occurrence, effectiveness of control measures, habitat preferences and dispersal mechanisms. In contrast, weed diversity can be explored at several different scales from number of species per unit area to genetic diversity. It represents the number of species present in an area and specifies the abundance of each species in a community. Therefore, knowledge of weed species associated with crops in a region is pivotal and necessary to plan and execute a sound and economical weed management schedule depending upon various factors affecting weed distribution in different areas. The present survey was planned to study the abundance, distribution and diversity of weed flora in wheat crop in 14 wheat growing districts of Haryana state.

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To study the floristic composition of weeds in wheat in Haryana, 292 fields were surveyed in Ambala, Karnal, Kaithal, Jind, Sonepat, Rohtak, Faridabad, Rewari, Palwal, Bhiwani, Mahendragarh, Sirsa, Fatehbad and Hisar districts of state during January - March, 2012 and 2013. This period of survey depicts most appropriate representation of majority of weed species and the cumulative effects of all agronomic practices, soil type, fertilizer and irrigation application and weed control measures adopted during initial crop growth stages. The road map of Haryana state was followed and routes were planned to establish sampling localities as equidistantly as possible (about 10 kms) avoiding inhabited areas. Four observations on density of individual weeds were recorded per field at one spot by using quadrate of 0.5 x 0.5 m, 100 meters deep inside the fields. Pooled average values of observations of relative density (RD), relative frequency (RF) and importance value index (IVI) of individual weeds were thus calculated as per method suggested by Misra (1968) and Raju (1977).

North-eastern Haryana region is characteri-zed with abundant irrigation facilities and fertile alluvial soils. Wheat crop is mainly grown after rice and sugarcane ratoon in this region. In south-western districts, wheat is grown after cotton, pearl millet and rice. Soils are sandy loam to clay loam in texture and crop is raised with both tube well and canal water supply. In Bhiwani and Mahendragarh districts, soils are loamy sand in texture with sprinkler irrigation facility.

Weed flora density and diversity

Weed flora composition significantly diverged among districts due to different cropping systems, soil types, rainfall amount, fertility status, irrigation facilities, quality of underground water and weed control measures in addition to other agronomic practices.

Overall twenty one weed species were present in the surveyed wheat fields. Weed flora was more diverse in south-western districts as compared to north-eastern districts of Haryana. Out of 21 weed species, 4 grassy and 17 broad-leaf weeds were found to be highly associated with wheat crop (**Table 1** and **2**). Grassy weed *Phalaris minor* with IVI values of 43.2-97.7 was most dominant weed in all the districts surveyed except Bhiwani, Mahendragarh and Rewari. The maximum RD (78.3%) and IVI (97.7) of *P. minor* was found in Karnal district whereas minimum RD (2.4%) and IVI (7.4) were observed in Rewari and Mahendragarh districts, respectively. *Phalaris minor* dominance in rice-wheat crop rotation is largely due to its ecological requirements and development of resistance to herbicides of various mechanisms of actions (MoAs).

Another grassy weed, *Avena ludoviciana* with a RD of 0.5–21.7% and IVI values of 1.5 - 43.4% also showed its presence in south-western districts *i.e.* Hisar, Fatehabad, Rewari, Mahendragarh and Palwal whereas this weed was conspicuous by its absence in north-eastern districts of Haryana, *viz.* Ambala, Karnal, Jind, Kaithal, Sonepat and Rohtak due to unfavorable ecological conditions for its establishment in predominant rice–wheat crop rotation (**Figure 1**). Grassy weeds of moist soils *Polypogon monspliensis* and *Poa annua* showed their presence only in north-eastern districts. Greater occurrence and higher relative density of grassy weeds in north-eastern region may be on account of relatively high moisture and use of more fertilizers in rice-wheat sequence.

In north-eastern districts, among broad-leaf weeds *Chenopodium album, Rumex dentatus, Coronopus didymus, Anagallis arvensis* and *Medicago denticulata* were found to be highly aggressive and dominating whereas in south-western districts Bhiwani, Rewari, Hisar, Fatehbad, Sirsa, Faridabad and Mahendragarh in addition to *C. album* and *C. murale, T. polycerata, Melilotus indica, Rumex spinosus, Fumaria parviflora* and *Asphodelus tenuifolius* were dominating broad-leaf weeds. Abundance of these weeds in south-western Haryana may be due to light soils of low fertility, less use of herbicides and presence of underground brackish water in some part of these areas.

Chenopodium album with a relative density of 4.4 to 30.8% and IVI of 18.1 – 57.2% was the most dominant weed in all districts except Faridabad where *C. murale* with IVI value of 27.3% was found to be most aggressive weed. Slightly saline underground waters used for irrigation in south-western districts may be the reason for more prevalence of *C. murale* in these areas as this weed flourishes only under saline-sodic waters. The maximum IVI of *C. album* was recorded in Mahendragarh (57.2) followed by

Table 1. Weed flora of wheat in Ambala, Karnal, Kaithal and Jind districts of Haryana

Weed species	Family	Ambala			Karnal			Kaithal			Jind		
		RD (%)	RF (%)	IVI	RD (%)	RF (%)	IVI	RD (%)	RF (%)	IVI	RD (%)	RF (%)	IVI
Grassy													
Phalaris minor	Gramineae	56.8	20.3	77.1	78.3	19.4	97.7	60.9	13.8	74.7	67.8	19.7	87.5
Avena ludoviciana	Gramineae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Poa annua	Gramineae	2.0	5.7	7.7	1.1	5.1	6.2	0.5	1.3	1.8	2.0	4.5	6.5
Polypogon monspliensis	Gramineae	2.7	7.6	10.3	2.9	11.6	14.5	4.7	8.4	13.1	4.4	13.4	17.8
Broad-leaf													
Chenopodium album	Chenopodiaceae	11.0	15.2	26.2	4.4	14.1	18.5	8.1	13.8	21.9	11.5	17.3	28.8
Chenopodium murale	Chenopodiaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rumex dentatus	Polypogonaceae	7.8	15.2	23.0	2.3	10.3	12.6	4.7	9.8	14.5	6.3	12.6	18.9
Rumex spinosus	Polypogonaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coronopus didymus	Cruciferae	5.4	10.1	15.5	3.8	12.2	16.0	7.1	16.7	23.8	3.1	11.0	14.1
Anagallis arvensis	Primulaceae	3.6	5.1	8.7	4.1	14.2	18.3	5.5	12.5	18.0	1.1	4.7	5.8
Medicago denticulata	Leguminosae	4.2	8.8	13.0	2.0	7.7	9.7	4.7	8.4	13.1	2.4	11.0	13.4
Melilotus indica	Leguminosae	3.3	6.4	9.7	0.1	1.2	1.3	1.2	4.2	5.4	0.1	0.7	0.8
Malva parviflora	Malvaceae	2.7	5.1	7.8	0.7	3.8	4.5	1.7	4.1	5.8	0.0	0.0	0.0
Convolvulus arvensis	Convolvulaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.4	1.6	0.2	2.7	2.9
Cirsium arvense	Compositae	0.0	0.0	0.0	0.0	0.0	0.0	0.2	1.4	1.6	0.0	0.0	0.0
Vicia sativa	Leguminosae	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.3	1.8	0.0	0.0	0.0
Trigonella polycerata	Leguminosae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Asphodelus tenuifolius	Liliaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fumaria parviflora	Fumariaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pluchea lanceaolata	Compositae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Carthamus oxycantha	Compositae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 2. Weed flora of wheat in Fatehbad, Hisar, Sirsa, Sonipat and Rohtak districts of Haryana

Weed species	Fatehbad			Hisar			Sirsa			Sonipat			Rohtak		
	RD (%)	RF (%)	IVI	RD (%)	RF (%)	IVI	RD (%)	RF (%)	IVI	RD (%)	RF (%)	IVI	RD (%)	RF (%)	IVI
Grassy															
Phalaris minor	47.9	22.6	70.5	35.0	18.2	53.2	39.7	30.2	69.9	55.1	25.5	80.6	59.0	30.7	89.7
Avena ludoviciana	2.4	8.5	10.9	15.4	10.6	26.0	10.8	9.4	20.2	0.0	0.0	0.0	0.0	0.0	0.0
Poa annua	0.2	1.0	1.2	0.0	0.0	0.0	0.5	3.4	3.9	1.2	1.4	2.6	3.2	3.2	6.4
Polypogon monspliensis	1.9	9.6	11.5	0.0	0.0	0.0	0.5	7.3	7.8	5.6	8.5	14.1	7.6	12.7	20.3
Broa-leaf															
Chenopodium album	14.0	5.4	19.4	25.3	16.6	41.9	15.2	7.4	22.6	12.1	26.0	38.1	9.6	15.3	24.9
Chenopodium murale	0.7	2.1	2.8	5.3	5.7	11.0	2.7	2.1	4.8	0.0	0.0	0.0	0.0	0.0	0.0
Rumex dentatus	4.5	7.5	12.0	2.8	5.5	8.3	7.4	7.5	14.9	5.2	9.7	14.9	6.0	14.0	20.0
Rumex spinosus	9.2	5.4	14.6	1.0	3.2	4.2	8.5	5.4	13.9	0.0	0.0	0.0	0.0	0.0	0.0
Coronopus didymus	6.5	15.0	21.5	1.5	5.5	7.0	3.6	3.2	6.8	5.2	9.2	14.4	3.3	6.8	10.1
Anagallis arvensis	1.9	5.4	7.3	0.9	4.0	4.9	0.5	5.4	5.9	5.6	8.2	13.8	3.3	3.7	7.0
Medicago denticulata	5.2	9.6	14.8	0.8	4.8	5.6	3.6	3.6	7.2	3.5	2.6	6.1	4.2	6.0	10.2
Melilotus indica	1.1	5.4	6.5	2.3	7.1	9.4	3.1	3.5	6.6	3.2	4.2	7.4	1.2	1.6	2.8
Malva parviflora	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	2.0	4.0	0.6	1.2	1.8
Convolvulus arvensis	1.9	4.3	6.2	5.7	7.1	12.8	1.6	4.3	5.9	0.3	1.4	1.7	0.3	3.3	3.6
Cirsium arvense	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Vicia sativa	0.0	0.0	0.0	1.5	3.1	4.6	0.0	0.0	0.0	1.2	1.4	2.6	1.2	1.0	2.2
Trigonella polycerata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Asphodelus tenuifolius	0.0	0.0	0.0	3.2	7.4	10.6	2.5	7.4	9.9	0.0	0.0	0.0	0.0	0.0	0.0
Fumaria parviflora	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pluchea lanceaolata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Carthamus oxycantha	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 3. Weed flora of wheat in Faridabad, Rewari, Palwal, Mahendragarh and Bhiwani districts of Haryana

Weed species	Faridabad			Rewari			Palwal			M. Garh			Bhiwani		
	RD (%)	RF (%)	IVI	RD (%)	RF (%)	IVI	RD (%)	RF (%)	IVI	RD (%)	RF (%)	IVI	RD (%)	RF (%)	IVI
Grassy															
Phalaris minor	29.4	13.8	43.2	2.4	6.4	8.8	52.7	29.7	82.4	3.2	4.2	7.4	8.4	7.4	15.8
Avena ludoviciana	16.7	12.7	29.4	21.7	21.7	43.4	2.1	0.6	2.7	7.2	14.6	21.8	0.5	1.0	1.5
Poa annua	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Polypogon monspliensis	1.2	8.4	9.6	0.0	0.0	0.0	3.5	2.3	5.8	0.0	0.0	0.0	0.0	0.0	0.0
Broad-leaf															
Chenopodium album	13.0	5.1	18.1	23.4	24.6	48.0	10.4	16.9	27.3	30.8	26.4	57.2	29.7	27.0	56.7
Chenopodium murale	14.1	13.2	27.3	14.9	21.8	36.7	1.5	1.6	3.1	22.7	14.3	37.0	20.7	12.0	32.7
Rumex dentatus	7.9	9.7	17.6	0.0	0.0	0.0	12.5	20.5	33.0	0.0	0.0	0.0	0.0	0.0	0.0
Rumex spinosus	0.7	2.5	3.2	8.4	3.8	12.2	0.0	0.0	0.0	4.2	3.4	7.6	2.9	3.0	5.9
Coronopus didymus	2.5	5.7	8.2	0.0	0.0	0.0	2.1	5.0	7.1	0.0	0.0	0.0	0.0	0.0	0.0
Anagallis arvensis	0.5	8.5	9.0	0.0	0.0	0.0	3.1	4.7	7.8	0.0	0.0	0.0	0.0	0.0	0.0
Medicago denticulata	2.3	8.3	10.6	0.0	0.0	0.0	4.5	9.0	13.5	0.0	0.0	0.0	0.0	0.0	0.0
Melilotus indica	7.2	4.2	11.4	6.5	3.1	9.6	0.1	1.5	1.6	3.6	3.4	7.0	1.6	3.0	4.6
Malva parviflora	1.7	4.1	5.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Convolvulus arvensis	0.2	1.4	1.6	2.5	3.1	5.6	0.2	2.4	2.6	1.3	2.4	3.7	0.7	2.0	2.7
Cirsium arvense	0.2	1.4	1.6	0.0	0.0	0.0	3.2	0.5	3.7	0.0	0.0	0.0	0.0	0.0	0.0
Vicia sativa	2.5	1.3	3.8	0.5	3.1	3.6	1.4	0.5	1.9	2.6	0.0	2.6	0.6	0.0	0.6
Trigonella polycerata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.4	12.4	23.8	9.7	11.0	20.7
Asphodelus tenuifolius	0.0	0.0	0.0	5.5	3.5	9.0	0.0	0.0	0.0	7.6	15.7	23.3	19.6	33.0	52.6
Fumaria parviflora	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.4	3.4	8.8	3.4	3.0	6.4
Pluchea lanceaolata	0.0	0.0	0.0	11.4	3.6	15.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Carthamus oxycantha	0.0	0.0	0.0	2.8	5.5	8.3	2.4	2.5	4.9	0.0	0.0	0.0	0.0	0.0	0.0

Bhiwani (56.7), Rewari (48.0) and Hisar (41.9). Robust dicotyledonous weed *Malva parviflora* habitant of heavy textured soils and zero till planted wheat was found only in Ambala, Karnal, Kurukshetra, Rohtak, Sonepat and Fardiabad districts. *Medicago denticualta* broad-leaf weed of *leguminosae* family was present in all rice growing districts whereas weed of same family *Trigonella* *polycerata* was found in light textured soils of south-western districts *viz.* Singh *et al.* (1995) also reported the occurrence of this weed in light textured soil. *Phalaris minor* was the single most dominating weed under rice-wheat cropping system, whereas *Phalaris minor, Chenopodium album* and *Avena ludoviciana* had higher relative densities under cotton-wheat cropping system (**Figure 1**).

The survey indicates that distribution and diversity of weed species could be directly correlated to the soil type, rainfall, irrigation facilities, quality of underground water, fertility status and cropping patterns as varied in different districts of Haryana. Therefore, the present survey could be of much practical value in formulating local management

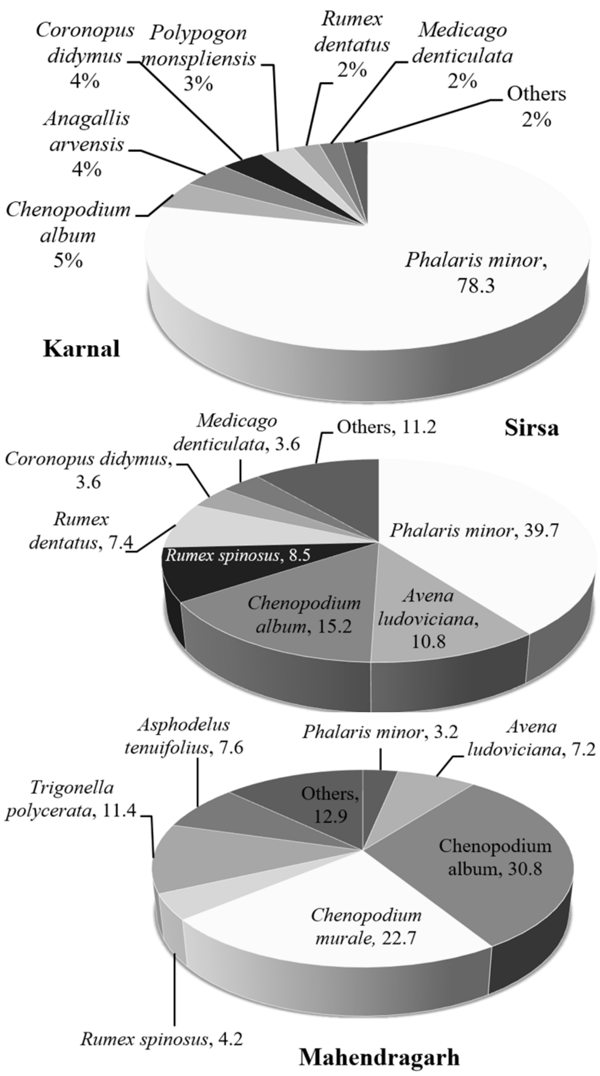

Figure 1. Relative density (%) of most dominated weed species in wheat under rice-wheat (Karnal), cotton-wheat (Sirsa) and pearlmillet-wheat (Mahendragarh) cropping systems

strategies depending upon types of weed species, their abundance and distribution to sustain wheat productivity.

SUMMARY

To study the floristic composition of weeds in wheat, 292 fields were surveyed in fourteen wheat growing districts of Haryana state during January–March 2012 and 2013. In all, 21 weed species (4 grassy and 17 broad-leaf) were found to infest wheat fields in Haryana. Grassy weed *Phalaris minor* was most dominant weed with IVI values of 43.2-97.7 in all the surveyed districts except Bhiwani, Mahendragarh and Rewari. Another grassy weed, *Avena ludoviciana* showed its presence with a RD of 0.5-21.7% and IVI values of 1.5-43.4% in south-western districts of Haryana. Grassy weeds of moist soils *Polypogon monspliensis* and *Poa annua* showed their presence only in north-eastern districts. *Chenopodium album* and *Chenopodium murale, Trigonella polycerata, Melilotus indica, Rumex spinosus, Fumaria parviflora* and *Asphodelus tenuifolius* were dominating broad-leaf weeds in south-western districts. Robust dicotyledonous weed *Malva parviflora*, adherent to heavy textured soils and zero till planted wheat, was mainly confined in Ambala, Karnal, Kurukshetra, Rohtak, Sonepat and Fardiabad districts. *Convolvulus arvensis*- a broad-leaf climber in all districts except Ambala and Karnal.

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Short communication

Rigid ryegrass problem in wheat and its management in Tunisia

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Key words: Density, Herbicide, Loss, Ryegrass, Tunisia, Yield

In Tunisia, cereals are important crops and occupy about 1.2 to 1.5 million hectares, of which about 70% is planted with wheat (ONAGRI 2015). Among the weeds, the ryegrass (*Loluim rigidum*) is very competitive in crops especially cereals (Lemerle *et al.* 1996). In Tunisia, ryegrass infested fields was 32%, representing about 1/3 of the total cereal-cropped areas. The weed was found infesting several crops growing on different soil types (clay, loam and sandy). These included wheat, barley, faba bean (*Vicia faba*), chickpea (*Cicer arietinum*), fenugreek (*Trigonella foenumgraecum*), canola (*Brassica napus*), sugar beet (*Beta vulgaris*) and oat (*Avena sativa*) (Khammassi *et al.* 2016). Losses caused by rigid ryegrass varied and became increasingly important under the Mediterranean climate (Gonzalez-Andujar and Saavedra 2003). Rigid ryegrass control in cereal crops relies mainly on selective grass herbicides of the groups of acetyl Coenzyme A carboxylase (ACCase) and acetolactate synthase (ALS) inhibitors. Ryegrass (*Lolium* spp.) is one of the weeds that has developed resistance against eleven grass herbicides products in different countries of the world including France, England, Spain, the USA, Australia including Tunisia (Souissi *et al.* 2004). This study aims to determine the density of rigid ryegrass (*Lolium rigidum* Gaud.) in three climatic regions (sub-humid, superior and lower semi-arid), the correlation between density of ryegrass and losses wheat yields and evaluate the efficacy of grass herbicides, the most used by farmers, on ryegrass.

Surveys were conducted in cereal area of the North and North-West of Tunisia during the 2013-14. All the surveyed regions belonged to the sub-humid and superior and lower semi-arid climatic regions. The areas surveyed were between 36 and 37 degrees to the North and between 9 and 10 degrees to the East and with altitudes that ranged from 7 to 908 m. In each field, 10 samples with one m² quadrate were taken. The density of ryegrass (*Lolium rigidum*) was determined by counting in each sample and was classified according to the climate regions. Field experiment was conducted at 10 locations in the North of Tunisia with different levels of infestation of ryegrass to evaluate the efficacy of 14 herbicides at recommended doses. Experiment was conducted in randomized complete block design (RCBD) with four replications (**Table 1**). The plot area was 40 m² (4 m × 10 m). Wheat variety '*Durum'* was sown in second half of November 2013. Azote fertilizer (33.5%) with three applications of ammonitrate (120, 150 and 100 kg/ha) was applied over three stages of development at 3 leaves of wheat, at tillering and before heading. Fungal diseases were controlled by application of epoxiconazole at 125 g/ha. The spraying of herbicides was done with sprayer calibrated to discharge 200 l/ha at 3 kpa. The efficacy was assessed by percentage of damaged plants of ryegrass compared to an untreated control at 30 days after spray. Experimental data were subjected to analysis of variance (ANOVA) and analysis of the Pearson correlations using SAS statistical package (SAS® 2000).

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Density of rigid ryegrass

The rigid ryegrass (*Loluim rigidum* Gaud.) was recorded in all the climatic regions (sub-humid, superior and lower semi-arid) and in all crops along with other weeds and in different soil types (clayey, loam and sandy). In sub-humid climatic regions, the infestation with rigid ryegrass varied from 4 to 657 plants/m² with an average of 158 plants/m². In the superior semi-arid climatic regions, the infestation varied from 3 to 23 plants/m² with an average of 9 plants/m². The lowest average of 3 plants/m² of ryegrass infestation was recorded in the lower semi-arid climatic regions (infestation from 0 to 9 plants/m²). So, the density of rigid ryegrass increased to the lower semi-arid to the sub-humid climate regions. However, the maximum density (657 plants/m²) of ryegrass was recorded in sub-humid against 9 plants/m² in the lower semi arid. The density of ryegrass increased with increase annual rainfall (**Table 2**). High weed infestations (> 300 plants/m²) were observed in the Northern regions of Tunisia where weather conditions, mainly the rainfall, was more favorable.

Table 1. List of herbicides used in field trials

Trade name	Active substance	Concent. (a.i.)	Recommande rate (ha)
Amilcar OD	Mesosulfuron-methyl + iodosulfuron-methyl-sodium	7.5 g/l + 7.5 g/l	1 l
Amilcar WG	Mesosulfuron-methyl + iodosulfuron-	30 g/kg + 30 g/kg	330 g
Apyros	Sulfosulfuron	75%	26.6 g
Axial	Pinoxaden	45 g/l	1 l
Tolurex	Chlortoluron	500 g/l	4.8 l
Dopler plus	Diclofop-methyl + fénoxapropo-p-ethyl	250 g/l + 20 g/l	2.5 l
Evrest	Flucarbazone sodium	70 %	43 g
Grasp	Tralkoxydim	400 g/l	0.8 l
Illoxan CE	Diclofop-methyl	360 g/l	2 l
Pallas OD	Pyroxsulam	46.6 g/l	0.5 l
Puma Evolution	Fenoxaprop-p-ethyl + iodosulfuron-methyl-sodium	64 g/l + 8 g/l	1 l
Puma Super	Fenoxaprop-p-ethyl	69 g/l	1 l
Topik	Clodinafop-propargyl	100 g/l	0.5 l
Traxos	Pinoxaden + clodinafop-propargyl	22.5 g/l + 22.5 g/l	1.2 l

Densities as low as 10 plants/m² were found in semi-arid regions with an average rainfall of 300 mm. Surveys conducted in Southern Australia revealed the occurrence of rigid ryegrass in 86% of canola crops and 69% of cereal crops (Lemerle *et al.* 1996). As rigid ryegrass originated from the temperate regions of Europe and Asia, temperate climate is very suitable for weed survival thus, explaining its predominance in regions with a Mediterranean climate such as in Tunisia.

Table 2. Density of rigid ryegrass in different climate stages and the average of rainfall

Climatique stages	Density of rigid ryegrass (plants/m²)			Interval of rainfall (mm)
	Minima	Maxima	Average	
Sub-humide	4	657	157.7	600-800
Superior semi-arid	3	23	9	500-600
Lower semi-arid	0	9	2.6	400-500

Effect of density of rigid ryegrass on yield of wheat

Wheat yield loss increased with increase of the density of rigid ryegrass. Correlation study showed a highly significant correlation between losses in yield and the density of rigid ryegrass ($r = 0.92847$ and $p = 0.0001$) and an exponential equation $y = 109, 56\ e^{-0,001x}$ was determinate. When the density was 300 plants/m², the losses in yields were in order of 20 to 30%, but when density exceeded 1000 plants/m², the losses in yields were in the order of 70% (**Figure 1**). Reeves (1976) reported that losses in the yield due to rigid ryegrass may vary with density, sowing date and seed stock. In the field, density with 200 plants/m² may cause losses in wheat yield ranging from 20 to 50% (Porter and Gawith 1999). Moreover, when the density of Italian ryegrass increased from 0.7 to 93 plants/m², the yield loss increased from 0 to 4.1 t/ha (Appleby *et al.* 1976). Thus, with high densities (1500 plants/m²), yield reductions in wheat may ranged from 23.1 to 47.8% (Reeves and Brooke 1977). These high densities of ryegrass can contribute, in addition to crop yield losses (Appleby *et al.* 1976, Palta and Peltzer 2001), to increase the seed stock (Hopfensperger 2007) and to reduce the efficacies of herbicides (El-Sebai *et al.* 2005).

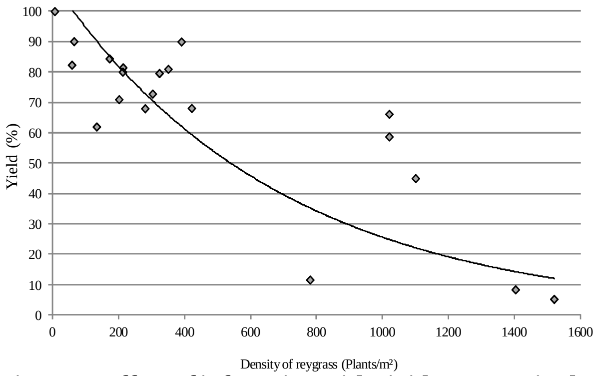

Figure 1. Effect of infestation with rigid ryegrass in the yield of wheat

Efficacy of herbicides on rigid ryegrass

Herbicides (mesosulfuron-methyl 7.5 g/ha + iodosulfuron-methyl-sodium 7.5 g/ha, pyroxsulam 23.3 g/ha, fenoxaprop-p-ethyl 64 g/ha + iodosulfuron-methyl-sodium 8 g/ha and chlortoluron 2400 g/ha) had good control on rigid ryegrass in some locations, but other herbicides showed low to medium effect (mesosulfuron-methyl 9.9 g/ha + iodosulfuron-methyl-sodium 9.9 g/ha, diclofop-methyl 720 g/ha, clodinafop-propargyl 50 g/ha, pinoxaden 27 g/ha + clodinafop-propargyl 27 g/ha, pinoxaden 45 g/ha, diclofop-méthyl 625 g/ha + fénoxapropo-p-ethyl 50 g/ha, tralkoxydim 320 g/ha, sulfosulfuron 75% 26.6 g/ha and flucarbazone-sodium 70% 43 g/ha). At one location (212 plants/m²) all tested herbicides showed lower efficacy except chlortoluron (83.6%). In all locations, herbicides (mesosulfuron-methyl 7.5 g/ha + iodosulfuron-methyl-sodium 7.5 g/ha, pyroxsualm 23.3 g/ha and fenoxaprop-p-ethyl 64 g/ha + iodosulfuron-methyl-sodium 8 g/ha) showed best effect. The best efficacy (97%) was registered with mesosulfuron-methyl 7.5 g/ha + iodosulfuron-methyl-sodium 7.5 g/ha in the location 8, although infestation of rigid ryegrass was high enough (123 plants/m²). However, the efficacies of herbicides were varied from one location to another location and depending on the rate of the infestation with ryegrass and the presence or not of resistance in this weed. The average herbicides efficacies showed good efficacies with chlortoluron

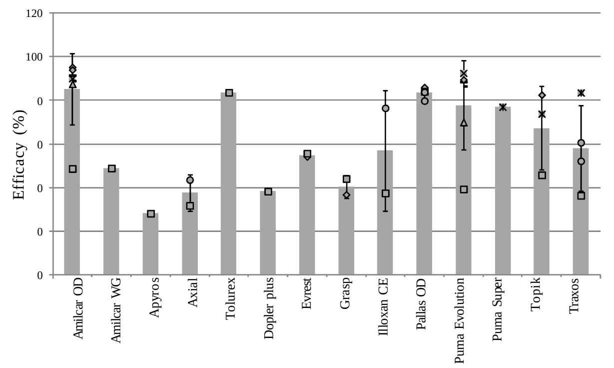

Figure 2. Efficacy of herbicides on rigid ryegrass in 10 locations

2400 g/ha. Factors influencing herbicide efficacy have been documented. These include weed and crop densities (Scursoni *et al.* 2012), which can further be influenced by other factors such as soil type, period of weed emergence and weed growth stage (O'Donovan *et al.* 1985). Low efficacy of herbicides on rigid ryegrass were registered with sulfosulfuron 75% at 26.6 g/ha, pinoxaden at 45 g/ha, diclofop-méthyl at 625 g/ha +fénoxapropo-p-ethyl at 50 g/ha, flucarbazone sodium 70% at 43 g/ha and tralkoxydim at 320 g/ha (ACCase and ALS herbicides inhibitors). Certain herbicides such as mesosulfuron-methyl 9.9 g/ha + iodosulfuron-methyl-sodium 9.9 g/ha, diclofop-methyl 720 g/ha, clodinafop-propargyl 50 g/ha and pinoxaden 27 g/ha + clodinafop-propargyl 27 g/ha have limited the ryegrass populations up to 50%, but this was insufficient to have better yield (**Figure 2**). These results were confirmed with the work of Souissi *et al.* (2004).

SUMMARY

Rigid ryegrass (*Lolium rigidum* Gaud.) is a weed that caused significant losses in yields. The results showed that the density of ryegrass varied depending with the climatic regions and increased with increasing of rain. However, the density of this weed increased to the lower semi-arid to the sub-humid climate regions. Maximum infestation (657 plants/m²) of ryegrass was recorded in sub-humid against 9 plants/m² in the lower semi-arid climatic regions. Study of the correlation showed that the yield losses were highly correlated with density (r = 0.92847 and p=0.0001) with an exponential equation $y = 109{,}56\ e^{-0{,}001x}$. The results of the field trials showed that pre-mix mesosulfuron-methyl 7.5 g/ha + iodosulfuron-methyl-sodium 7.5 g/ha, pyroxsulam 23.3 g/ha and fenoxaprop-p-ethyl 64 g/ha + iodosulfuron-methyl-sodium 8 g/ha and chlortoluron 2400 g/ha controlled ryegrass effectively. At some locations, herbicides ACCase inhibitors (pinoxaden at 45 g/ha, diclofop-méthyl at 625 g/ha + fénoxapropo-p-ethyl at 50 g/ha and tralkoxydim at 320 g/ha) and ALS inhibitors (sulfosulfuron75% at 26.6 g/ha and flucarbazone sodium 70% at 43 g/ha) showed poor efficacy which may be due to the development of resistance in rigid ryegrass in many locations of Tunisia.

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Short communication

Inhibitory effects of rice straw on the germination and seedling growth of some major weeds of wheat

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Wheat [*Triticum aestivum* (L.) emend. Fiori and Paol.] faces severe competition from weeds leading to yield losses up to 34.3% which is more than the combined losses caused by insects, pests and disease (Dangwal *et al*. 2010). The rice-wheat cropping system, which is the backbone of India's food security, produces a huge quantity of rice straw. Management of this bulk of rice straw is a major challenge as it is considered to be a poor feed for the animals owing to high silica content. Aqueous extract of rice residue suppressed the growth of lettuce and *Phalaris minor* (Khan *et al*. 2001) while both aqueous and organic solvent extracts of rice plants inhibited the growth of several plant species (Das and Goswami 2001). Phenols such as *p*-salicylic acid, *p*-coumaric acid, vanillic acid, syringic acid, ferulic acid, and mandelic acid present in the rice straw are reported to be responsible for its inhibitory influences (El- Shahawy *et al*. 2006).Therefore, the present work was conned out to study the effect of rice straw on the germination and seedling growth of four major weed species of wheat crop.

A laboratory experiment was conducted in the Department of Plant Physiology, G.B. Pant University of Agriculture & Technology, Pantnagar, India. Straw of three rice genotypes *viz. 'Pant Dhan 16, UPR 2962-6-2-1* and *UPR 2992-17-3-1'* were used in the experiment, because these are allelopathic varieties of rice. The straw was dried and ground in a grinder separately for each genotype. This straw powder was added on to germination paper laid in Petri dishes. The treatments consisted of supplementing one and two grams of powdered straw of each genotype in separate Petri dishes. Pure distilled water served as control. The germination paper was wetted by 10 ml of distilled water. Seeds of four weed species such as *Phalaris minor*, *Vicia sativa*, *Medicago denticulata* and *Lathyrus aphaca* were surface sterilized in 10% (v/v) hydrogen peroxide solution for 10 minutes, followed by their rinsing with deionized water and subsequent washing with distilled water for 4-5 times. Ten seeds of each species were laid over the wet rice straw and allowed to germinate at room temperature. The Petri dishes were watered intermittently to keep them moist. Data on germination (%) and shoot and root length of the weed seedlings were recorded at 21 days after incubation (DAI).

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The phenolics in rice straw were analyzed by HPLC by following the method of Tarnawski *et al.* (2006). The dried phenolic residue was dissolved in 2 ml of water: methanol (75: 25, v/v). Prior to analysis, the samples were filtered through 0.22 mm flouropore filters (Millipore) before injecting into the HPLC column. Twenty ml samples were injected using a micro Hamilton syringe into the HPLC column (C18) for analysis. Absorbance was recorded at 280 nm with the help of a UV- Vis detector. Standards of phenolics acids such as ferulic acid, gallic acid and p-hydroxybenzoic acid were used for detecting the compounds in rice straw.

The data was analyzed statistically by using completely randomized design (CRD). Standard error of means (SEm ±) and critical difference (CD) was evaluated at 5% level of significance.

Effect of rice straw on weeds germination

***Phalaris minor**:* The germination of *Phalaris minor* seeds was about 50% under control condition. Upon addition of rice straw in the medium, the germination per cent was reduced significantly except for the treatment '*Pant Dhan 16*' (1 g straw). It ranged from 13.3% to 46.7% in the presence of rice straw. The lowest germination (13.3%) was observed in the treatment '*Pant Dhan 16*' (2 g) followed by 16.67% in the presence of '*UPR 2992 17-3-1*' (2 g) (**Figure 1a**).

***Vicia sativa**: Vicia sativa* seeds recorded about 60% germination under control condition (**Figure 1b**). Addition of rice straw to the germination medium significantly reduced the germination except for the treatments '*UPR 2962 6-2-1*' (2 g) and 'UPR 2992

17-3-1' (1 g). The lowest germination rates of about 26.7% to 33.3% were observed in the treatments *'Pant Dhan 16'* (1 and 2 g) and *'UPR 2962 6-2-1'* (1 g).

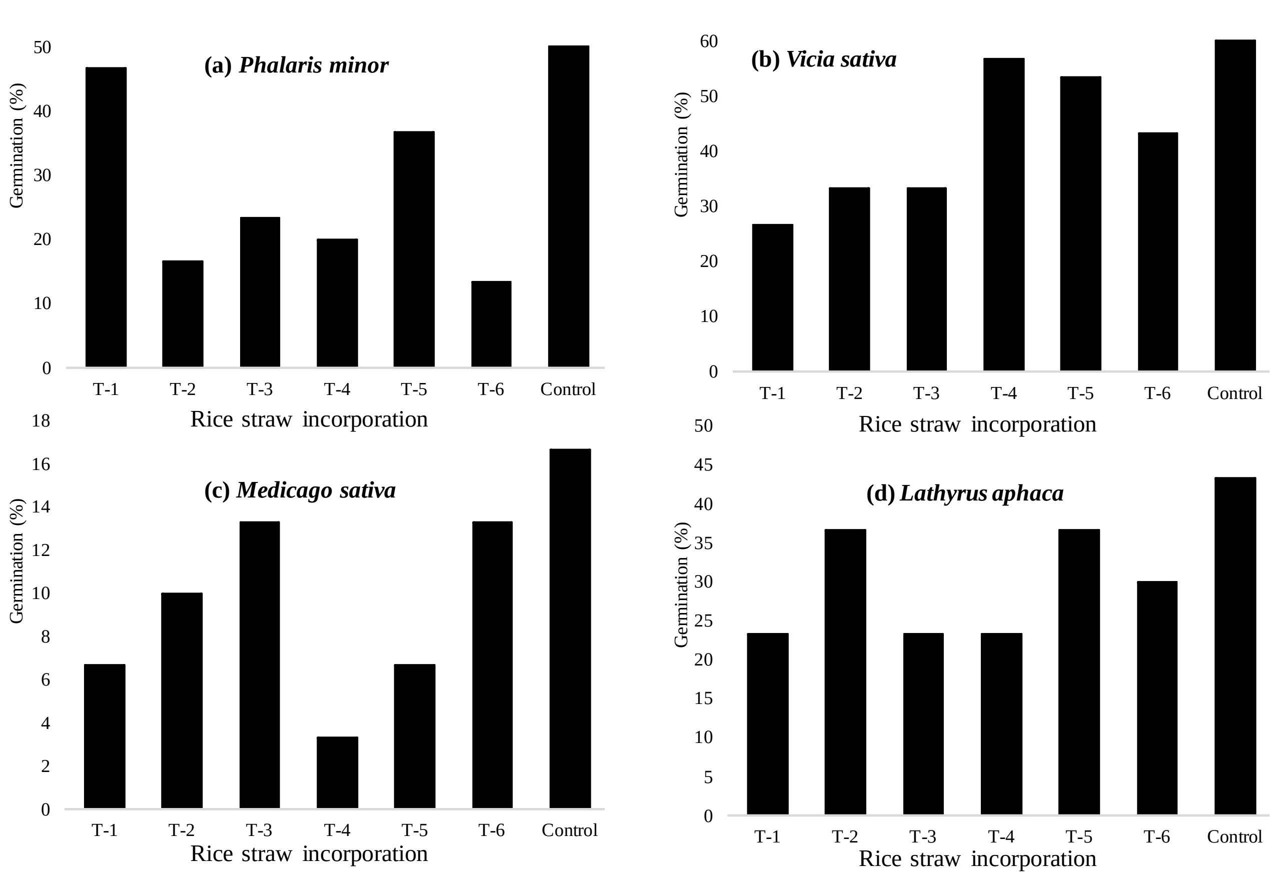
Medicago denticulata: In the control, the germination of *Medicago denticulata* seeds was very poor. It was about 16.7% (**Figure 1c**).Significant reductions in germination were observed in the treatment '*UPR 2962 6-2-1'* (2 g) followed by that in Pant Dhan 16 (1g) and '*UPR 2992 17-3-1'* (1 g).

Lathyrus aphaca: The germination of *Lathyrus aphaca* seeds was about 43.3% under control condition. '*Pant Dhan 16*' (1 g) and '*UPR 2962 6-2-1* (1 and 2 g) recorded significantly lowest germination (23.3%) as compared to all other treatments. The germination per cent in rest of the treatments ranged from 30 to 36.7% (**Figure 1d**).

Among the weed species, *Phalaris minor* recorded 60.0 to 73.3% reduction in germination in the presence of 2 g straw of all the three rice genotypes. *Vicia sativa* recorded maximum reductions in germination when straw of Pant Dhan 16 was added to the medium. *Medicago denticulata* recorded 60 to 80% reductions in germination due to straw of all the three genotypes. *Lathyrus aphaca* was more sensitive to the straws of the genotypes '*Pant Dhan 16* and *UPR2962 6-2-1*' with about 46.6 % inhibition in germination. Among the weed species, *Phalaris minor* and *Medicago denticulata* were more sensitive to rice straw. Thus, it is evident that incorporation of rice straw in the medium reduces germination of problematic weed species, both grasses and BLWs. Differential sensitivity of weed species to plants extracts (Perez 1990, Koloren 2007) further support the current findings.

Effect of rice straw on seedling growth of weed

Seedling growth of all the four weed species was reduced in presence of rice straw (**Table 1**). '*Pant Dhan 16*' (2 g) had maximum inhibitory effect on shoot length of *Phalaris minor* while '*Pant Dhan 16*' (2 g) followed by '*Pant Dhan 16*' (1 g) had maximum inhibitory effect on shoot and root length of *Vicia sativa*. It has been reported that the rice straw inhibited the germination and seedling growth



T-1 - *Pant Dhan 16* (1 g); T-2 - *Pant Dhan 16* (2 g); T-3 - *UPR 2962 6-2-1* (1 g); T-4 - *UPR 2962 6-2-1* (2 g); T-5 - *UPR 2992 17-3-1* (1 g); T-6 - *UPR 2992 17-3-1* (2 g)

Figure 1. Effect of rice straw incorporation in the germination medium on the germination (%) of four weed species (a. *Phalaris minor*, b. *Vicia sativa*, c. *Medicago denticulate*, d. *Lathyrus aphaca*)

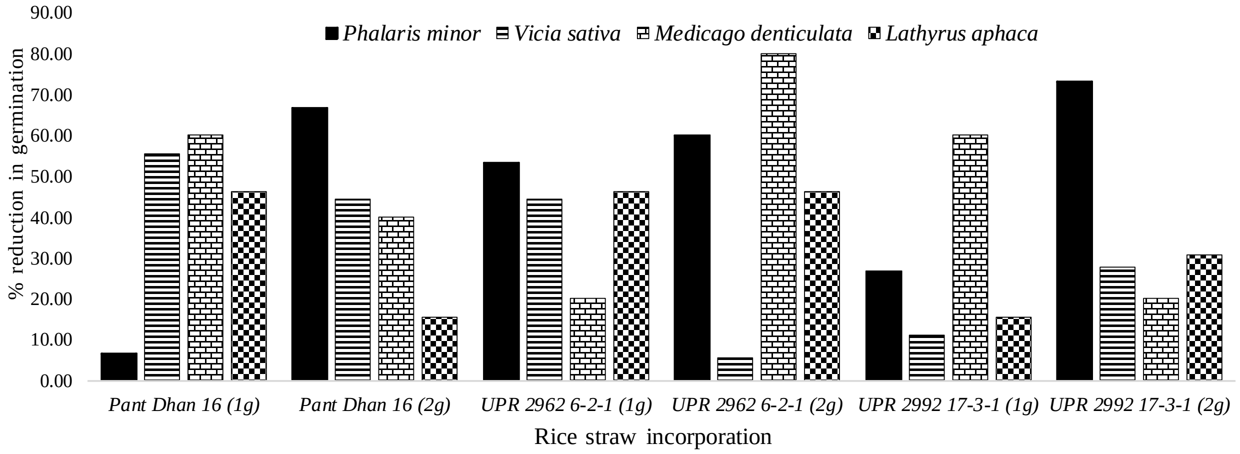


Figure 2. Effect of rice straw incorporation on per cent reduction in germination of four weed species

Table 1. Effect of rice straw on shoot length and root length of seedlings of four weed species at 21 days after incubation

Treatment (Rice straw, g/Petri plate)	*Phalaris minor* Shoot length (cm)	*Phalaris minor* Root length (cm)	*Vicia sativa* Shoot length (cm)	*Vicia sativa* Root length (cm)	*Medicago sativa* Shoot length (cm)	*Medicago sativa* Root length (cm)	*Lathyrus aphaca* Shoot length (cm)	*Lathyrus aphaca* Root length (cm)
Pant Dhan 16 (1g)	3.96	1.06	0.78	0.40	0.00	0.002	3.68	1.12
Pant Dhan 16 (2g)	0.83	0.33	0.67	0.51	0.48	0.250	1.95	0.54
UPR 2962 6-2-1 (1g)	1.93	0.51	1.86	1.43	0.76	0.330	1.51	0.68
UPR 2962 6-2-1 (2g)	1.14	0.36	2.14	1.39	0.00	0.001	1.56	0.44
UPR 2992 17-3-1 (1g)	3.73	1.12	1.86	1.18	0.00	0.002	3.51	0.87
UPR 2992 17-3-1 (2g)	0.96	0.32	1.14	1.10	0.56	0.220	1.78	0.59
Control	4.23	1.73	2.84	1.66	0.89	0.380	5.34	1.13
LSD (p=0.05)	0.65	0.25	0.16	0.09	0.23	0.010	0.50	0.13

of weed plants by 70% and increased crop yield by 20% (Xuan *et al.* 2005). The water extract of rice husk have suppressive effects on germination and seedlings growth of barnyard grass (Ko *et al.* 2005). The rice root exudates and rice leachate contain water-soluble allelochemicals which could inhibit the seed germination and reduce seedling growth of *Sisybrium officinale* (Mahmoodzadeh *et al.* 2011).

Total phenol and phenolic acid content in straw of three rice varieties

Total phenol content differed significantly among the rice varieties (**Table 2**). *'UPR 2962 6-2-1'* had the highest total phenol content (25.97 µg/g FW) followed by that in *'UPR 2992-17-3-1'*while it was the lowest in the genotype '*Pant Dhan 16*' (19.40 µg/g FW).

In the present investigation, profiling of phenolic acids through HPLC revealed three phenolic compounds such as caffeic acid, p-hydroxybenzoic acid and gallic acid in the straw of the three rice genotypes. While both '*Pant Dhan 16* and *UPR 2962 6-2-1*' had all the three phenolics acids, the genotype 'UPR 2992 17-3-1' had only two phenolic acids such as p-hydroxybenzoic acid and gallic acid (**Figure 3**).

Table 2. Phenol content (mg/g FW) in the straw of three rice genotypes

Genotype	Phenol content (µg/g FW)
Pant Dhan 16	19.40
UPR 2962-6-2-1	25.97
UPR 2992-17-3-1	21.85
LSD (p=0.05)	0.61

Among the phenolics, the concentration of gallic acid was highest in all the three genotypes, which ranged between 18.2 to 24.0 ppm. In the genotype '*UPR 2962- 6-2-1*', para-hydroxy benzoic acid was present in highest concentration (26.4 ppm). The concentration of caffeic acid was very low as compared to the other phenolics (**Figure 3**).

Extensive studies of allelochemicals in rice plants have led to identification of a range of phenolic compounds, including p-hydroxybenzoic, vanillic, p-coumeric and syringic acids (Kong *et al.* 2004). Certain phytotoxins are released by rice during their growth or even after dying via straw degradation (Chung *et al.* 2001). It was reported that p-coumaric acid was released in the greatest amount from decomposition of rice straw (Kuwatsuka and Shindo

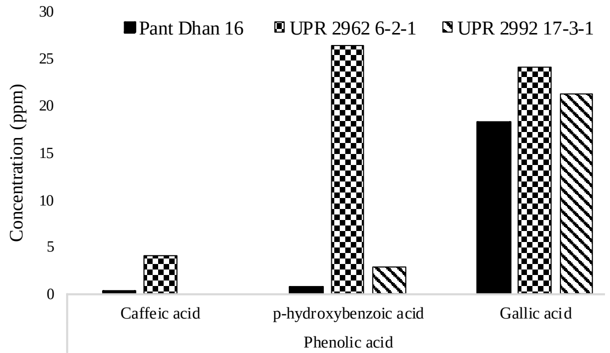


Figure 3. Concentration of caffeic acid, p-hydroxybenzoic acid and gallic acid in the straw of three rice genotypes

1973). Six simple phenols e.g. p-salicylic acid, p-coumaric acid, vanillic acid, syringic acid, ferulic acid, and mandelic acid were responsible for the inhibitory influences in rice straw (Chou 1980). In the present study, the inhibitory effects of rice straw on germination and seedling growth of weed species is attributed to gallic acid and p-hydroxybenzoic acids, which were present in higher levels in the straw. Genotypes, '*UPR 2962-6-2-1*' was found having maximum inhibitory effects on the germination of the weed seeds due its phenolic acid profile.

SUMMARY

A laboratory experiment was conducted to study the effect of rice straw on the germination and seedling growth of four major weed species of wheat *viz*. *Phalaris minor*, *Vicia sativa*, *Medicago denticulata* and *Lathyrus aphaca*. Straw of three rice genotypes, Pant Dhan 16, UPR 2962-6-2-1 and UPR 2992-17-3-1, was added to petri dishes at two different doses (1g and 2g) on which weed seeds were allowed to germinate. It was observed that germination and seedling growth of all the four weed species was adversely affected by rice straw. Straw of the rice genotype UPR 2962-6-2-1 had maximum inhibitory effect and among the weed species *Phalaris minor* and *Medicago denticulata* were more sensitive to rice straw. Analysis of phenolics content of rice straw revealed maximum phenolics in the genotype UPR 2962- 6-2-1. This shows the potential of rice straw incorporation in soil for weed management.

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Short communication

Zero-till sowing and residue mulching in rainy season maize: Effect on weeds, crop productivity and profitability

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Weeds pose serious problems in *Kharif* maize owing to its wide spacing, slow early vegetative growth, vagaries of monsoon which favour weeds due to congenial growing conditions like high temperature and humidity. Weeds emerge fast and grow rapidly thus competing with the crop severely for growth resources, *viz*. nutrients, moisture, sunlight and space during entire vegetative phase; and early reproductive stages and reduce the photosynthetic efficiency leads to lower dry matter production and grain yield of maize. Hence, managing weeds is very critical for higher yields and therefore, their effective management is needed to realize higher yields. Raised bed sowing is the conventional method of establishment for maize crop. No tillage with residue retention and herbicide use can be the alternative technologies for weed management (Dahal and Karki 2014). Information on weed dynamics under different planting methods and residue management are lacking. In this regard, the present experiment was planned to study the effect of zero-tillage sowing and residue mulching on weeds, crop productivity and profitability of *Kharif* maize.

A field experiment was conducted at Regional Research Station, Karnal of CCS Haryana Agricultural University during *Kharif* 2015. The experiment was laid out in split plot design with three replications. Main plot treatments comprised of four planting methods *viz*., raised bed with residue (RB+R), raised bed without residue (RB-R), zero tillage with residue (ZT+R) and zero tillage without residue (ZT-R). Three maize hybrids, *viz*. *HQPM-1, HM-4* and *HM-10* in combination with two weed control treatments, *viz*. atrazine 750 g/ha pre-emergence (PRE) followed by (*fb*) 1 hand weeding (HW) at 30 days after sowing (DAS) and unweeded check were kept as sub-plots. The soil of experimental field was clay loam in texture with medium in organic carbon (0.41%), low in available N (123.0 kg/ha); and medium in available P (11.0 kg/ha) and K (185.9 kg/ha) with slightly alkaline pH (8.4) and EC of 0.31 dS/m. Sowing in raised bed was done with bed planter and in flat bed with zero-till seed drill keeping row to row spacing of 75 cm using seed rate of 20 kg/ha on June 25, 2015. All the recommended package of practices was adopted to raise the crop. Atrazine was applied as pre-emergence spray to the soil surface as per treatments at 0-3 DAS through knapsack sprayer fitted with flat-fan nozzles delivering water 500 l/ha. Data on weed density and weed biomass were recorded at 60 DAS using quadrate of 0.5 m × 0.5 m twice in a plot and converted into number of weeds/m^2 and g/m^2, respectively. Data on weed density were subjected to square root transformation ($\sqrt{x+1}$) before statistical analysis. Harvesting of maize hybrid *HM-4* was done manually on September 22, 2015; and *HQPM-1* and *HM-10* on September 29, 2015 from each plot manually.

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Density and dry weight of weeds

The most dominating weed species observed in the experimental plots were *Dactyloctenium aegyptium*, *Brachiaria reptans* and *Eragrostis tenella* among grassy weeds, *Portulaca oleracea*, *Ammania baccifera* among broad-leaf weeds (BLW) and *Cyperus rotundus* among sedges. The lowest density and dry weight of grassy weeds and dry weight of sedges were recorded under ZT+R *fb* RB+R, ZT-R and highest in RB-R; however, dry weight of sedges in RB+R and ZT+R were at par with each other (**Table 1** and **2**). The lowest density and dry weight of BLW was recorded under ZT+R *fb* RB+R, RB-R and highest in ZT-R. In sedges, the lowest density was recorded in RB+R *fb* ZT+R, RB-R and highest in ZT-R. In general, residue retention resulted in lower density and reduced biomass of all type of weeds under both methods of planting. The density of grassy weeds was lower under ZT than raised bed, while BLW and sedges were less under raised bed; however, the differences in the case of sedges were not always significant (**Table 1**). In general, dry weight of weeds was lower under ZT as compared to raised bed except for BLW which was slightly higher under ZT (**Table 2**). The lower density of grassy weeds in ZT might be due to the killing of weeds with glyphosate before sowing of crop and non-disturbance of the soil surface. However, slightly higher sedges under ZT, particularly at initial stages, might be due to the regeneration of some of the weeds even after spray; but at later stages, ZT and raised bed became at par with each other. Dahal and Karki (2014) has also reported that ZT+R and atrazine applied at 1.5 kg/ha as pre-emergence had significantly lowered density and dry weight of grassy weeds and BLW as compared to conventional tillage, residue removed and manual weeding at 30 DAS.

Among maize hybrids, the lowest density and dry weight of grassy weeds and sedges was recorded under *HM-10 fb HM-4* and *HQPM-1* (**Table 1** and **2**). Lower density and dry weight of BLW was recorded with *HM-4 fb HM-10* and higher in *HQPM-1*. The faster initial growth of *HM-10* than the other hybrids could be the reason for lower weed infestation and dry weight of weeds as compared to other hybrids. In general, the crop growth is inversely related to weed infestation. The dry weight of weeds exhibited an increasing trend from crop germination to harvest in unweeded check, whereas the density of weeds did not increase that much. It might be due to early germination and establishment of weeds which kept on growing with time. Significantly lower density and dry weight of all type of grassy weeds, BLW and sedges were recorded under atrazine 750 g/ha (PE) *fb* 1 HW at 30 DAS than unweeded check (**Table 1**). Higher total weed density and dry weight under unweeded check mainly was due to higher and uninterrupted growth of weeds which made the best use of the growth resources. Two HW and pre-emergence application of atrazine 1.5 kg/ha recorded lower weed density and dry weight in maize (Rao *et al.* 2009).

Grain yield and economics

Maize sown in ZT+R recorded highest grain yield (7.32 t/ha) and net returns (` 59958/ha) as compared to other establishment methods. ZT observed to be a suitable planting method with numerically higher but statistically similar grain yield to raised bed. The increase in grain yield of maize under ZT+R maize could be attributed to higher yield attributes, lesser weed infestation and to some extent better soil environment. There was less stagnation of

Table 1. Effect of planting methods, residue and weed management on density of different weeds at 60 DAS of different maize hybrids

Treatment	Density of weeds (no./m^2)*								
	Grassy weeds				Broad-leaf weeds				Sedges
	D. aegyptium	*B. reptans*	*E. tenella*	Total	*P. oleracea*	*A. baccifera*	Other	Total	*C. rotundus*
Planting method									
Raised bed with residue	2.69 (6.7)	1.46 (1.2)	1.21 (0.6)	2.97 (8.4)	1.16 (0.4)	1.09 (0.2)	8.72 (85.6)	8.75 (86.2)	5.50 (30.2)
Raised bed without residue	3.01 (8.6)	1.92 (3.1)	2.45 (5.7)	4.12 (17.3)	1.20 (0.5)	1.27 (1.0)	12.82 (180.9)	12.86 (182.4)	8.80 (79.1)
Zero tillage with residue	2.02 (3.1)	1.31 (0.9)	1.61 (0.4)	2.28 (4.4)	1.14 (0.3)	1.24 (0.7)	5.86 (43.9)	5.94 (44.9)	5.57 (33.4)
Zero tillage without residue	2.72 (6.6)	1.78 (2.3)	1.33 (0.9)	3.23 (9.72)	1.17 (0.4)	1.44 (1.3)	12.78 (183.9)	12.85 (185.7)	10.67 (119.7)
LSD (p=0.05)	0.18	0.19	0.11	0.20	NS	0.10	0.10	0.10	0.15
Maize hybrids									
HQPM-1	2.72 (6.9)	1.75 (2.5)	1.66 (2.5)	3.39 (11.9)	1.30 (0.8)	1.35 (1.1)	11.43 (140.1)	8.17 (77.0)	8.17 (77.0)
HM-4	2.73 (6.9)	1.57 (1.6)	1.54 (1.9)	3.22 (10.3)	1.07 (0.2)	1.07 (0.2)	8.98 (104.0)	7.16 (61.8)	7.59 (61.8)
HM-10	2.38 (4.9)	1.53 (1.6)	1.41 (1.3)	2.83 (7.7)	1.14 (0.3)	1.36 (0.2)	9.72 (126.6)	7.59 (58.0)	7.16 (58.0)
LSD (p= 0.05)	0.10	0.16	0.11	0.15	0.08	0.07	0.09	0.08	0.08
Weed management									
Atrazine 750 g/ha (PE) *fb* 1 HW at 30 DAS	2.23 (4.1)	1.36 (1.0)	1.23 (0.8)	2.54 (5.8)	1.04 (0.1)	1.10 (0.2)	6.97 (55.4)	7.54 (67.6)	7.52 (67.3)
Unweeded check	2.99 (8.4)	1.88 (2.8)	1.85 (3.0)	3.76 (14.1)	1.30 (0.8)	1.44 (1.4)	8.30 (75.8)	12.66 (182.0)	12.57 (179.8)
LSD (p=0.05)	0.08	0.13	0.09	0.12	0.07	0.06	0.06	0.07	0.07

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

Table 2. Effect of planting methods, residue and weed management on dry weight of weeds at 60 DAS, grain yield and economics of different maize hybrids

Treatment	Dry weight of weeds (g/m^2)				Grain yield (t/ha)	Net returns ($x10^3$ `/ha)	Benefit-cost ratio
	Grassy weeds	Broad-leaf weeds	Sedges	Total weeds			
Planting method							
Raised bed with residue	24.81	4.37	2.87	32.05	7.00	50.87	1.88
Raised bed without residue	43.90	5.89	5.56	55.36	6.29	50.79	2.08
Zero tillage with residue	20.84	3.20	3.24	27.28	7.32	59.96	2.13
Zero tillage without residue	31.49	7.39	9.41	48.29	6.42	57.47	2.35
LSD (p=0.05)	1.83	0.36	0.78	2.40	0.43	-	-
Maize hybrids							
HQPM-1	42.15	6.02	7.00	55.17	6.40	49.23	2.01
HM-4	27.38	4.46	5.11	36.96	7.04	58.75	2.18
HM-10	21.24	5.16	3.70	30.10	6.83	56.39	2.14
LSD (p=0.05)	1.10	0.27	0.38	1.26	0.18	-	-
Weed management							
Atrazine 750 g/ha (PE) *fb* 1 HW at 30 DAS	3.84	3.24	3.72	10.81	7.70	66.59	2.29
Unweeded check	56.68	7.18	6.82	70.68	5.81	42.95	1.93
LSD (p=0.05)	0.90	0.22	0.31	1.03	0.15	-	-

water after higher downpour. Higher grain yield under flat sowing ZT also might be due to a longer grain filling duration resulting in bolder grains (Ram *et al.* 2010). However, the benefit-cost ratio (B: C) was maximum under ZT-R (2.35) *fb* ZT+R (2.13), RB-R (2.08) and RB+R (1.88). In general, B: C was more under ZT than raised bed, but less under residue (**Table 2**). This was due to the counting of the cost of wheat residue used in this experiment. However, if we opt for some other crop residue having less economic value then ZT+R may be superior in B: C as well. Jat *et al.* (2013) also found that the no-till flat and no-till bed systems provided similar net returns in the maize-wheat system as compared to conventional till flat system.

Residue mulch resulted in improved grain yield (7.00-7.32 t/ha) and net returns as compared to without residues under both methods of planting, *viz.* ZT and raised bed. *HM-4* provided maximum grain yield (7.04 t/ha), net returns (` 58749/ha) and B: C (2.18) *fb HM-10* and *HQPM-1*. Significantly higher grain yield (7.70 t/ha), net returns (` 66593/ha) and B: C (2.29) were observed under atrazine 750 g/ha (PRE) *fb* 1 HW at 30 DAS than unweeded check (**Table 2**). Higher grain yield, net returns and B: C of maize were recorded with two HW and PRE application of atrazine 1.5 kg/ha *fb* HW at 30 DAS in maize (Rao *et al.* 2009).

SUMMARY

Zero tillage sowing of maize with residue mulching was found a viable alternatives method of crop establishment as compared to conventional raised bed sowing without residue. Thus, zero tillage sowing of maize with residue mulching resulted in lower weed infestation, higher productivity and economics returns. Atrazine 750 g/ha (as pre-emergence) *fb* 1 HW was effective in controlling weeds in maize crop.

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Short communication

Response of black gram to integrated weed management with varying levels of phosphorus and potassium

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Key words: Black gram, Hand weeding, Integrated weed managment, Phosphorus, Potassium

Weed infestation is one of the major constraints greatly affecting the production of blackgram. Frequent irrigations during summer and monsoon rains during *Kharif* season result in high weed population and weed growth in this crop. Unchecked weeds have been reported to cause a considerable reduction in the grain yield of blackgram. Therefore, removal of weeds at appropriate time using suitable method is essential to obtain high yields. Among production inputs, fertilization plays a key role in enhancing productivity levels. Being a leguminous crop, blackgram can fix atmospheric nitrogen. Hence, nitrogen application is not that necessary except on those soils which are poor in organic matter where application of a small quantity of nitrogen as a starter dose is required. However, it responds well to phosphorus and potassium application for proper growth and production. Adequate supply of phosphorus in soil results in rapid growth, maturity and enhances quality of vegetative crop growth while supply of potassium has been proved to increase seed and grain quality by reducing the number of infected and shrivelled seeds. Hence, proper and adequate supply of P and K with good weed management practice can bring up the potential yield of blackgram.

A field experiment was carried out at School of Agricultural Sciences and Rural Development (SASRD), Nagaland University during the *Kharif* season 2015. The experimental site was located at an altitude of $25^0 45' 43''$ N latitude and $95^0 53' 04''$ E longitude at an elevation of 310 m above mean sea level. The climate of the experimental area is broadly classified as subtropical humid. The experiment comprised of four weed management treatments, *viz.* weedy check (control), hand weeding at 25 DAS and 45 DAS. pendimethalin 0.75 kg/ha *fb* 1 hand weeding at 25 DAS and pendimethalin 0.75 kg/ha *fb* imazethapyr 0.5 kg/ha at 25 DAS with three levels of phosphorus and potassium, *viz.* 30 kg/ha P_2O_5 and 30 kg/ha K_2O, 40 kg/ha P_2O_5 and 40 kg/ha K_2O and 50 kg/ha P_2O_5 and 50 kg/ha K_2O. The experiment was laid out in a factorial randomised block design with three replications. Black gram variety '*KU-301*' was sown at a spacing of 30 x 10 cm. The soil was sandy loam and acidic in reaction (pH 4.6). The soil contained 1.1% oxidizable organic carbon, 263.9 kg/ha available nitrogen, 12.4 kg/ha available phosphorus and 190.2 kg/ha available potassium. The data related to each character were analysed statistically by applying the techniques of analysis of variance as described by Cochran and Cox (1957) and the significant of different source of variations was tested using Fisher Snedecor 'F' test at 5% level of significance.

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Effect on weeds

Weed population differed significantly due to different weed management treatments. The data (**Table 1**) showed that the lowest population of broad-leaf weeds, sedge and grassy weeds at 25 DAS was found in all weed management treatments except weedy check. At 45 DAS, hand weeding at 25 and 45 DAS and pendimethalin 0.75 kg/ha *fb* 1 hand weeding at 25 DAS showed lowest weed population in all the categories of weeds. At harvest, lowest population of all the categories of weeds was recorded in hand weeding at 25 and 45 DAS. The findings are in conformity with those of Patel *et al.* (2015). Application of varying levels of P and K gave significant effect where application of 50 kg/ha P_2O_5 + 50 kg/ha K_2O recorded maximum weed density at 45 DAS and at harvest while application of 30 kg/ha P_2O_5 + 30 kg/ha K_2O recorded the lowest value which was statistically at par with application of 40 kg/ha P_2O_5 + 40 kg/ha K_2O in all the categories of weeds.

The lowest plant height, leaf area index and crop growth rate were recorded in weedy check (control) while hand weeding at 25 and 45 DAS gave the highest values which was followed by pendimethalin 0.75 kg/ha *fb* 1 hand weeding at 25 DAS. Weed free condition maintained with two hand weeding might have eliminated the crop weed competition for space, nutrient, moisture and light and thus the crop in this treatment gave better results (Rao *et al.* 2015). Hand weeded plots improved leaf area index (LAI) in black gram and this could be due to the lack of weed competition which improved the growth of crop. Absence of early weed competition increased the crop growth rate, which also increased the leaf area index (Tamang *et al.* 2015). There was significant difference in plant height, leaf area index and crop growth rate due to application of varying doses of phosphorus and potassium where 30 kg/ha P_2O_5 + 30 kg/ha K_2O gave the lowest plant height, leaf area index and crop growth rate while application of 40 kg/ha P_2O_5 + 40 kg/ha K_2O gave significantly the highest values.

Weedy check gave the least number of nodules/ plant, pods/plant and seed/pod while hand weeding at 25 and 45 DAS gave the highest values, which was statistically at par with pendimethalin 0.75 kg/ha *fb* 1 hand weeding at 25 DAS. The results are in close agreement with the findings of Jakhar *et al.* (2015). Kumar *et al.* (2015) also reported similar results in case of pods/plant and seed/pod. Application of 30 kg/ha P_2O_5 + 30 kg/ha K_2O gave the least values while 40 kg/ha P_2O_5 + 40 kg/ha K_2O gave the highest values followed by 50 kg/ha P_2O_5 + 50 kg/ha K_2O. Increased number of nodules could be due to the application of phosphorus and potassium in adequate amount, as they have been attributed to increase the activity of rhizobia and in the formation of root nodules and thereby helps in fixing more of atmospheric nitrogen in root nodule (Singh *et al.* 2008). Kokani *et al.*(2014)

Table 1. Effect of treatments on population of weeds (no./m^2)

Treatment	Broad-leaved			Sedges			Grasses		
	25 DAS	45 DAS	At harvest	25 DAS	45 DAS	At harvest	25 DAS	45 DAS	At harvest
Weed management									
Pendimethalin 0.75 kg/ha *fb* 1 hand weeding at 25 DAS	0.71 (0)	0.71 (0.0)	9.90 (97.5)	0.71 (0)	0.71 (0)	3.29 (10.3)	0.71 (0)	0.71 (0)	2.77 (7.1)
Pendimethalin 0.75 kg/ha *fb* Imazethapyr 0.5 kg/ha at 25 DAS	0.71 (0)	5.29 (28.2)	12.81 (164)	0.71 (0)	4.45 (20.3)	4.74 (21.3)	0.71 (0)	4.49 (19.7)	4.73 (21.9)
Hand weeding at 25 DAS and 45 DAS	0.71 (0)	0.71 (0.0)	5.88 (34.1)	0.71 (0)	0.71 (0)	3.16 (9.5)	0.71 (0)	0.71 (0)	2.20 (4.3)
Weedy check (control)	9.41 (88.1)	11.45 (140)	15.71 (246)	6.39 (40.3)	7.66 (58.1)	9.57 (92.6)	8.75 (76.1)	10.52 (111)	11.54 (132)
LSD (p=0.05)	0.27	0.57	0.30	0.53	0.37	0.24	0.13	0.35	0.38
Nutrient management									
30 kg/ha P_2O_5 and 30 kg/ha K_2O	2.85 (7.6)	4.45 (19.3)	10.92 (119)	2.02 (3.6)	3.21 (9.8)	5.02 (24.7)	2.69 (6.7)	3.95 (15.1)	5.11 (25.6)
40 kg/ha P_2O_5 and 40 kg/ha K_2O	2.87 (7.7)	4.48 (19.6)	10.97 (120)	2.02 (3.56)	3.31 (10.5)	5.15 (26.0)	2.72 (6.9)	3.99 (15.4)	5.19 (26.4)
50 kg/ha P_2O_5 and 50 kg/ha K_2O	2.93 (8.11)	5.03 (24.8)	11.25 (126)	2.34 (5.0)	3.62 (12.6)	5.46 (29.3)	2.75 (7.0	4.49 (19.7)	5.63 (32.2)
LSD (p=0.05)	NS	0.50	0.26	NS	0.32	0.21	NS	0.31	0.33

Figures in the parentheses are the original values which are subjected to square root transformation

Table 2. Effect of treatments on growth indices, yield attributes and yield of black gram

Treatment	Plant height	Leaf area index	CGR (g/m^2/d)	No. of root nodules/ plant	No. of pods/ plant	No. of seeds/ pod	Seed yield (t/ha)	Stover yield (t/ha)
Weed management								
Pendimethalin 0.75 kg/ha *fb* one hand weeding at 25 DAS	42.45	0.99	1.88	79.81	26.45	5.99	1.39	2.64
Pendimethalin 0.75 kg/ha *fb* imazethapyr 0.5 kg/ha at 25 DAS	36.51	0.75	1.21	71.08	22	5.36	1.29	2.50
Hand weeding at 25 DAS and 45 DAS	46.21	1.13	2.28	79.90	30.15	6.23	1.49	2.68
Weedy check (control)	29.51	0.67	0.74	50.99	14.87	4.80	0.53	2.03
LSD (p=0.05)	1.40	0.09	0.12	4.14	1.20	0.70	0.06	0.06
Nutrient management								
P_2O_5 30 kg/ha and K_2O 30 kg/ha	36.98	0.84	1.39	63.89	22.80	5.05	1.12	2.43
P_2O_5 40 kg/ha and K_2O 40 kg/ha	40.36	0.93	1.70	76.72	24.00	5.99	1.21	2.50
$P_2O_5$50 kg/ha and K_2O 50 kg/ha	38.66	0.88	1.50	70.72	23.31	5.75	1.18	2.47
LSD(p=0.05)	1.21	0.08	0.10	3.59	1.04	0.61	0.05	0.05

also observed relatively higher number of seeds in treatment with 40 kg/ha P_2O_5 and 40 kg/ha K_2O.

The highest seed and stover yield was recorded in plots with hand weeding at 25 and 45 DAS followed by pendimethalin 0.75 kg/ha *fb* 1 hand weeding at 25 DAS. It might be due to lesser crop-weed competition in these treatments as they control weeds more effectively than other treatments (Singh 2011). The lowest seed and stover yield was obtained under weedy check (control). Application of 40 kg/ha P_2O_5 + 40 kg/ha K_2O gave highest seed and stover yields which were statistically at par with 50 kg/ha P + 50 kg/ha K_2O while the lowest values were recorded under 30 kg/ha P_2O_5 + 30 kg/ha K_2O.

The results of the experiment indicated that hand weeding at 25 and 45 DAS can be recommended for high yield of blackgram where there is no scarcity of labour, but in case of labour scarcity pendimethalin 0.75 kg/ha *fb* one hand weeding at 25 DAS can be a better substitute. Application of 40 kg/ha P_2O_5 + 40 kg/ha K_2O in blackgram was found to be the optimum dose for higher yield.

SUMMARY

The dominant broad-leaf weeds in the experiment field were *Ageratum conyzoides*, *Amarantus viridis*,*Chromalaena odorata*,*Commelina bengalensis*, *Phyllanthus niruri* and *Mimosa spinosa*. *Cyperus rotundus* and *Cyperus iria* were dominant among sedges. Among grassy weeds, *Cynadon dactylon*,*Digitaria sanguinalis*, *Eleusine indica*, *Echinochloa colona* were most dominant in blackgram. Hand weeding at 25 and 45 DAS gave maximum decrease in weed density, dry weight of weeds and recorded the highest growth and yield of blackgram; followed by application of pendimethalin 0.75 kg/ha *fb* 1 hand weeding at 25 DAS. Among the fertilizer doses, application of 40 kg/ha P_2O_5 + 40 kg/ ha K_2O recorded the highest seed and stover yields.

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Short communication

Pseudocercospora sp. new leaf spot disease on *Parthenium*

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Key words: Fasciculate conidiophores, Hyaline conidia, *Parthenium*, *Pseudocercospora*

Parthenium hysterophorus L. has become one of the worst weed of India, invaded of about 35 million hectare of land (Shushilkumar and Varshney 2010). It is known to cause skin allergies in men and animals besides causing losses to crop productivity and biodiversity (Shushilkumar 2014).

This article describes a new leaf spot disease of *Parthenium hysterophorus* L. caused by *Pseudocercospora* sp. recorded for the first time from the world.

Surveys were conducted between 2004 to 2014 in Haryana, parts of Punjab, Uttar Pradesh and Delhi in different seasons of the year *i.e.* summer, rainy and winter. A new leaf spot disease was observed on *Parthenium* from Kurukshetra (Haryana).The pathogen was frequently present during rainy season but it was absent in summers. Infected leaves with a new spot disease were collected in sterilized polythene bags and brought to the laboratory. Isolation of the pathogen was done. Diseased specimens were processed and sent to International Mycological Institute (IMI), Egham, UK for confirmation of the pathogen/ disease identification.

The symptoms were characterized as circular to irregular, light yellow spots at the centre as well as on margins (**Figure 1A**). The isolated fungus was identified as a species of *Pseudocercospora* having similarities with *Cercospora partheniphila* previously recorded on this weed from Mexico, Cuba and India (Chupp 1954). Microscopic observations of the fungus revealed that conidiophores are fasciculate and arise from stomata (1-7 conidiophores per stoma). Conidiogenous cells tretic, 38 µm long, 4-5 µm thick. Conidia are hyaline, septate, short with blunt ends, 11-16 x 3.0-3.9 µm (**Figure 1B**). Differences between these two pathogens are that in *Cercospora partheniphila*, the conidiophores are long, thin with 1-4 scars, and conidia are very long with tapering ends; whereas in *Pseudocercospora* sp. the condiophores are short, thick and without any scar; conidia are also short, thick with blunt ends. A survey of available literature (Bilgrami *et al.* 1991, Evans 1997, Gnanavel 2013) revealed that *Pseudocercosopra* sp. has been recorded for the first time on *Parthenium* from the world.

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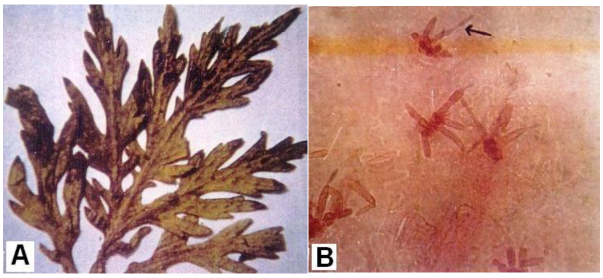

Figure 1. A- Leaf spot of *Pseudocercospora* sp. on *Parthenium* leaf. B- Condiophores having conidia

ACKNOWLEDGEMENT

Authors are thankful to CABI International Mycological Institute (IMI), UK for the identification of the pathogen.

SUMMARY

A leaf spot disease caused by *Pseudocercospora* sp. on *Parthenium hysterophorus* L. has been recorded for the first time from the world during the surveys conducted between 2004 to2014.

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Short communication

Allelopathic influence of aqueous stem extract of *Parthenium* on growth of maize

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Received: 4 March 2017; Revised: 2 May 2017

Key words: Aqueous extract, *Parthenium*, Seed germination, Seedling growth, *Zea mays*

Since 1956 *Parthenium hysterophorus* has spread like wildfire throughout India. It occupies over 35 million hectares of land in the country and has become naturalized and is spreading at an alarming rate all over India (Sushilkumar and Varshney 2010). The easy establishment of *Parthenium* in any ecosystem is attributed to several reasons, such as high growth rate, high reproductive potential, adaptive nature and above all interference by resource depletion and allelopathy. Allelochemicals isolated from *Parthenium* could be used for weed management directly or their chemistry could be used to develop new herbicides. Maize (*Zea mays* L.) is one of the most important cereal crops of India. Hence, the main objective of this study was to determine the allelopathic effects of aqueous extract of stem of *P. hysterophorus* on seed germination and seedling growth of maize under laboratory condition.

A study was conducted to evaluate the allelopathic effect of *P. hysterophorus* on maize in Department of Botany, J. P. University, Chhapra (25^0 36' - 26^0 15' N latitude and 84^0 25' - 85^0 15' E longitude), Bihar in the month of May 2016. *P. hysterophorus* plants were collected and stem was cut into 2 - 4 cm pieces and air dried for two weeks. The dried stem was ground into powder using a mixer grinder, and 10 g powder was weighed separately and soaked in 100 ml of distilled water and was mixed thoroughly by glass rod and kept overnight at room temperature to dissolve allelochemicals contents into the solution. After 24 hrs of soaking, extracts were collected by plastic funnel through the filter paper and solution was kept in a conical flask. The stock solution was adjusted accordingly to obtain five different levels of concentrations *ie*. 15, 25, 50, 75 and 100%; and a control was maintained using only distilled water. Healthy seeds of maize (180) were pre- soaked in tap water for 10 hrs. Ten seeds in each Petri dishes of 10 cm diameter with three replicates were used for each concentration. The distilled water was used regularly for moistening the seeds. The germination of seeds, radicle and plumule length and fresh weight of seedlings were recorded after seven days.

The rate of seed germination, root: shoot ratio, inhibition in rate of seed germination, relation elongation of root and shoot and seed vigour index (SVI) were calculated. Mean±SE values were calculated. T-test was performed to compare the values of root and shoot length between the values for control condition with different concentrations of stem extract of *P. hysterophorus* such as 15, 25, 50, 75 and 100%. Linear regression equations were developed between values for control condition and in different treatments for root and shoot length. Correlation coefficient values were calculated between shoot and root length values of control condition with the values of different concentrations of stem extract of *Parthenium.*

The per cent seed germination values ranged from 3.33% to 96.7% in different concentrations and 100% in control condition. The values of radicle growth of maize ranged from 0.50 to 9.81 cm in different concentrations compared to 10.5 cm in control treatment. The values of plumule length ranged from 1.5 to 4.15 cm in different concentrations and 6.63 in control condition. The fresh weight of seedlings were 2.4 g in control condition and the maximum value 2.1 g was recorded for 15% and minimum value for 100% treatment (**Table 1**). The dry weight of seedlings was 0.75 g in control condition and the maximum value 0.66 g was recorded for 25% and minimum value 0 for 100% treatment. R:S ratio values ranged from 0.33 to 3.04 in different concentrations compared to 1.58 in control condition. The minimum value 0.33 was recorded for 100% and maximum value 3.04 for 25% concentrations. The inhibitory effect on seed germination ranged from -3.33 to - 96.7% in different concentrations of stem extract. The minimum value was observed -3.33% in 15% and maximum value

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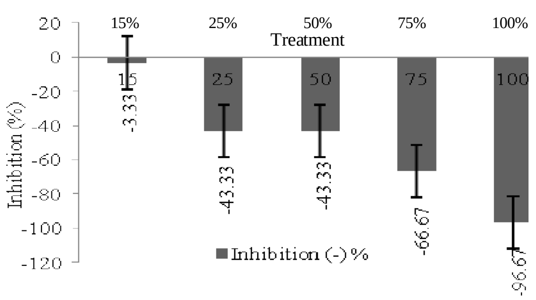

Figure 1. Inhibition (%) of maize

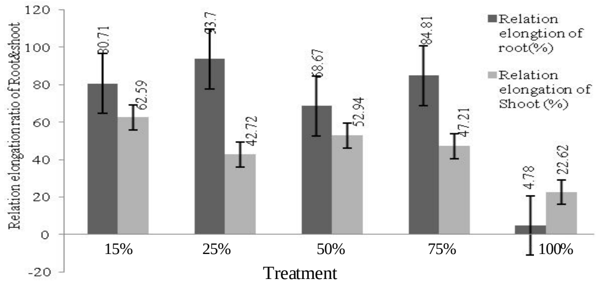

Figure 2. Relation elongation ratio of root and shoot of maize

Table 1. Effect of aqueous extract of *Parthenium hysterophorus* on germination, seedling length, fresh wt., dry wt., r:s ratio and SVI values of maize seeds

Treatment	Germination (%)	Radicle length (cm)	Plumule length (cm)	Fresh wt. (g)	Dry wt. (g)	Root:Shoot ratio	SVI
15%	96.67	8.45 ±1.43	4.15 ± 1.02	2.07	0.61	2.04	409.63
25%	56.67	9.81 ± 1.4	3.23 ± 0.83	1.9	0.66	3.04	192.85
50%	56.67	7.19 ± 1.36	3.51 ± 0.97	1.40	0.25	2.05	206.10
75%	33.33	8.88 ± 2.54	3.13 ± 1.56	0.53	0.26	2.84	113.20
100%	3.33	0.5 ± 0	1.5 ± 1	0	0	0.33	5.49
Control	100.00	10.47 ± 1.41	6.63 ± 0.49	2.39	0.75	1.58	673.47

Table 2. Linear regression equations for different concentrations of stem extract and shoot and root length

Stem extract concentrations of *P. hysterophorus*	Root Y= a + bX	Shoot Y= a + bX
15%	8.39 -0.03x	4.86 - 0.13x
25%	7 + 0.16x	3.62 - 0.11x
50%	2.53 + 0.16x	1.92 - 0x
75%	1.52 +0.15x	1.23 – 0.07x
100%	-	-0.06 + 0.02x

-96.67% in 100% treatment (**Figure 1**). The relation elongation ratios of root and shoot were recorded in different concentrations which ranged from 4.78 to 93.70 and 22.62 to 62.59, respectively (**Figure 2**). The SVI values ranged from 5.49 to 409.63 in 15% to 100% treatments and 673.47 for control condition (**Table 1**).

The t-test values for root length between control and 15, 25, 50, 75 and 100% were 1.823, 6.01, 6.79 and 13.90, respectively. The values for 50, 75 and 100% were positively highly significant (p=0.001) but other values were not significantly related. The t-test values for shoot length between control condition and different concentrations (15, 25, 50, 75 and 100%) were 2.98, 4.723, 6.70, 8.44 and 11.90, respectively.

In the present study there were strong inhibition in seed germination and seedling growth of maize by stem extracts of *P. hysterophorus* (**Table 2**). Bajwa *et al.* (2003) have reported that germination of maize was reduced by 20-25% due to aqueous extract of *P. hysterophorus*. Devi *et al.* (2014) have shown the seed germination and seedling growth of maize were significantly decreased by leaf and stem extract of *Parthenium*.

SUMMARY

An experiment was done to see the allelopathic effect of *Parthenium hysterophorus* on the seed germination and seedling growth of maize (*Zea mays*) in laboratory conditions. The results showed that seed germination was negatively affected by the aqueous stem extract of *Parthenium* in different concentrations (15, 25, 50, 75 and 100%) when compared to control condition. Seed germination in control was 100% whereas this value was 3.33% in 100% of stem extract. Stem extract of *P. hysterophorus* on shoot length was more affected than the root length. T-test values for root length between control and 50, 75 and 100% were positively and significantly different at $p<0.001$; and for shoot length these values for different treatments were significantly different at $p<0.001$.

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Short communication

Enzymatic activities of pathogenic species of *Alternaria*, isolated from *Parthenium*

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Parthenium hysterophorus L. an exotic, pernicious weed has been considered as one of the most troublesome weeds for agricultural sector by virtue of its high ecological amplitude and adaptability (Kaur *et al*. 2014) besides environmental degradation, biodiversity depletion, yield loss and health related issue (Sushilkumar 2014). It is estimated that it has invaded about 35 million hectares of land in India (Sushilkumar and Varshney 2010). *P. hysterophorus* harbours a diversity of pathogenic fungi, as shown recently by Aggarwal *et al.* (2014). Enzymes play a fundamental role in host-parasite interaction and are involved not only in the initial entry of the pathogen and its spread within the plant tissue but also in the degradation of host tissue into metabolites which the parasite can utilise (Sarkar 2009). The characteristic feature of many phytopathogenic organisms is their ability to produce a variety of enzymes capable of degrading the complex polysaccharides of the plant cell wall and membrane constituents. Pathogenic organisms either continually secrete enzymes or upon contact with the host plant. The host cell walls are penetrated, tissues are colonized and permeability of host cells is altered. During the survey it was observed that isolates of *Alternaria* infected the *Parthenium* weed and caused leaf spot and leaf blight diseases. In virtue of the shortage of information about enzymatic activity of pathogenic fungi, this present study evaluated the potential of six isolates of *Alternaria* fungi for amylolytic, ligninolytic, pectinolytic and cellulolytic production.

The fungal pathogens were isolated from the infected leaf portion of the *Parthenium* weed. The leaves were cut into small portions and sterilized in 70% ethanol then washed in sterile distilled water for four to five times. Leaf portions were then placed on PDA medium plates supplemented with streptomycin sulphate. These were then incubated at ±25 ^{o}C for 7 days. Isolated fungi were aseptically transferred to PDA plates and the pure cultures were incubated at above conditions. The pure culture was maintained on PDA slants. Lacto phenol cotton blue mount was used to study the morphological characteristics of the mycelium, conidia and perithecia of fungal strain and preliminarily identification was done with the help of standard literature (Ellis 1976).

Fungal pathogen was molecularly characterized by using the commercial service provided by Macrogen Inc., Advancing through Genomics, Korea. Fungus genomic DNA samples were extracted using a InstaGenetm Matrix (BIO-RAD.) The primers ITS1 primer (5- TCCGTAGGTGAACCTGCGG-3) and ITS5 (5–GGAAGTAAAAGTCGTAACAAGG–3) and ITS4 primer (5- TCCTCCGCTTATTGATATGC-3) were used for the PCR. The PCR reaction was performed with 20 ng of genomic DNA as the template in a 30 µl reaction mixture by using a EF-Taq (SolGent, Korea) as follows: activation of Taq polymerase at 95°C for 2 minutes, 35 cycles of 95°C for 1 minutes, 55°C, and 72°C for 1 minute each were performed, finishing with a 10-minutes step at 72°C. The amplification products were purified with a multiscreen filter plate (Millipore Corp., Bedford, MA, USA). The purified PCR products of approximately 600 bp were sequenced by using 2 universal primers (ITS1 and ITS4). Sequencing reaction was performed using a PRISM BigDye Terminator v3.1 Cycle sequencing Kit. The DNA samples containing the extension products were added to Hi-Di formamide (applied biosystems, Foster City, CA). The mixture was incubated at 95 °C for 5 min, followed by 5 min on ice and then analyzed by ABI Prism 3730XL DNA analyzer (Applied Biosystems, Foster City, CA) (Satou *et al.* 2001).

The pathogenicity was determined *in vitro* and *in vivo* conditions. For *in vitro* pathogenicity test, healthy leaves of *Parthenium* were used for inoculation. The leaves were washed with sterile distilled water and wiped with a cotton swab dipped in 70% alcohol. Mycelial discs taken from 5 days old colony were placed on leaves. The inoculated leaves were kept in sterilized moist chambers and incubated at 25 °C. Regular observations were made for the

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appearance of symptoms after 3 days of incubation as described by Aneja *et al.* (2000). For *in vivo* pathogenicity test, *Parthenium* plants were grown in earthen pots. Inoculum was prepared by growing the fungus on PDA plates, and mycelial and conidial mass was harvested by flooding the plates with sterile distilled water and then scraping the mass with a sterilized spatula. Inoculum concentration was adjusted to 6×10^4 spores/mL using hemocytometer and applied to the plants within two hours of sunset to avoid drying and to allow for a natural dew period shortly afterwards. Plants were observed weekly for the development of disease symptoms as described by Aneja *et al.* (2000).

For detection of extracellular enzyme production isolates from *P. hysterophorus* (4 isolates of *Alternaria macrospora* and two isolates of *Alternaria* sp.) were screened qualitatively for cellulase, pectinase, ligninolytic enzymes (laccase, lignin peroxidase, manganese peroxidase) and amylase production.

Screening of fungal extracellular enzymes was done by qualitative method *i.e.* agar plate method. The functional role of extracellular enzymes by fungal pathogens was assessed by growing them on PDA for 6-7 days, incubated at 25 °C and placing 5 mm mycelial plugs on the solid media. After incubation, at room temperature, the zone of enzyme activity surrounding the fungal colony was measured as described by Patil *et al.* (2015). Procedure followed for the qualitative estimation of amylolytic, Proteolytic, Cellulolytic and Ligninolytic activity is given below.

Amylase activity was assessed by growing the fungi on Glucose yeast extract peptone agar (GYP) medium with 0.2% soluble starch at pH 6.0. After incubation, the plates were flooded with 1% iodine in 2% potassium iodide (Sunitha *et al.* 2013).

A qualitative determination of cellulolytic activity, Yeast Extract Peptone Agar medium containing 0.5% Carboxy-methylcellulose (CMC) was used. After 3-5 days of fungal colony growth, the plates were flooded with 0.2% aqueous Congo red solution and destained with 1M NaCl for 15 minutes. Appearance of yellow areas around the fungal colony in an otherwise red medium indicated cellulose activity (Sunitha *et al.* 2013).

Pectinolytic activity was determined by growing the fungi in pectin agar medium (Pectin -5g, yeast extract-1g, agar- 15g pH 5.0 in 1L distilled water). After the incubation period, the plates were flooded with 1% aqueous solution of hexadecyl trimethylammonoium. A clear zone formed around the fungal colony indicated pectinolytic activity (Sunitha *et al.* 2013).

For Ligninolytic activity one cm diameter plug cut from the growing edge of PDA cultures of selected isolates, was centrally inoculated on the surface of azure B agar. The medium containing (g/L) glucose-0.2%, KH_2P0_4-1, yeast Extract- 0.01, diammonium tartarate-0.5, $CuS0_4.5H_2O$-0.001, $MgSO_4{\cdot}7H_2O$-0.5, $FeSO_4$- 0.001, $CaCl_2{\cdot}2H_2O$-0.01, $MnSO_4.H_2O$-0.001and agar agar-20; was supplemented with 0.01 % w/v Azure B. The plates were incubated at 30 °C for 7 day. The uninoculated plate served as a control. The production of lignin peroxidase and Mn peroxidase was recorded as clearance of blue coloured medium.

Laccase activity was also assessed by growing the fungi on solid medium with guaiacol as indicator. 0.01% guaiacol was added to the solid medium (PDA) and incubated at 25ºC. Guaiacol positive reaction was indicated by the formation of a reddish brown halo.

Morphological examination of pathogen

During the extensive surveys *Parthenium* was recorded in crops, uncultivated areas and roadsides which was found affected by various leaf spots and leaf blight diseases at different parts of Kurukshetra. The infected part on PDA yielded a fungal pathogens and microscopic study revealed that the pathogen belong to the genus *Alternaria*. Morphological examination by lacto phenol cotton blue mount and molecular analysis of the ITS1-5.8S-ITS2 rDNA region was carried out to confirm the species identity of the pathogen. The morphological examination (Ellis 1971) and molecular identification (ITS rDNA sequence analysis) confirmed its identity as *A. macrospora* strain MKP1, *Alternaria macrospora* strain MKP2, *A. macrospora* strain MKP3, *A. macrospora* strain MKP4, *Alternaria* sp. PMK1 and *Alternaria* sp. PMK2, which gene sequence of all the pathogens has been deposited to the NCBI gene bank with accession number KM186140, KM213867, KM514668, KM514669, KT192437 and KT192438, respectively. *In vitro* and *in vivo,* pathogenicity of the isolated pathogens was determined and the typical disease symptoms were observed on leaves in lab and in potted *Parthenium* plants. The inoculated pathogens were re-isolated, thus confirming the pathogenicity of *A. macrospora* to *Parthenium* by usual Koch's postulates.

***Alternaria macrospora* MKP1**: Colonies were grey in colour on PDA. The mycelium was septate, hyaline and branched. Conidia were solitary, dark brown, straight or slightly flexous, muriform and ellipsoidal with tapering long beak. The size of conidia ranged from 25-57.5×12.5-25 µm with 1-6 transverse septa and 0-2 longitudinal septa. Size of the beak ranged from 5-15×5-7.5 µm. The conidial morphology of *Alternaria macrospora* MKP1 is in agreement with those described by Ellis (1976). Culture has been identified from the Macrogen Inc., Advancing through Genomics, Korea and the sequence has been deposited to the NCBI gene bank with accession number KM186140.

***Alternaria macrospora* MKP2**: A pathogen was isolated on PDA media from infected leaves and it yielded grey colonies on PDA (Aneja *et al*. 2000). The identification of the pathogen has been confirmed from the CABI International Mycological Institute, UK with reference No. 503549 and the results showed that the top matches at 100% identity to two sequences of *Alternaria* species neither of which relate to published strains.

***Alternaria macrospora* MKP3:** Colonies were dark grey in colour on PDA. Conidia were solitary, dark brown, straight or slightly flexous, muriform and ellipsoidal with tapering long beak. The size of conidia ranged from 25-32.5×10-15 µm with 1-6 transverse septa and 0-2 longitudinal septa. Size of the beak ranged from 7.5-22.5×7.5 µm. Size of the conidiophore ranged from 25-67.5 µm.

***Alternaria macrospora* MKP4:** Colonies were grey green in colour on PDA. Culture has been identified from the Macrogen Inc., Advancing through Genomics, Korea and the sequence has been deposited to the NCBI gene bank with accession number KM514669.

***Alternaria* sp. PMK1**: Leaf spot yielded a greenish grey fungal colony with abundant aerial mycelium on PDA and PeDA (Aneja *et al.* 2000). The identification of the pathogen has been confirmed from CABI, International Mycological Institute, UK (IMI accession No. 504470) and Macrogen Inc., Advancing through Genomics, Korea. Molecular analysis of the ITS1-5.8S-ITS2 rDNA region carried out at CABI UK confirmed the pathogen as *Alternaria* sp. Subsequently, however on submitting the pathogen isolate to Macrogen Inc., Korea sequence analysis did not show any similarity with published strains and the best match (99%) was with unpublished strain of *Alternaria alternata* strain S-f6 (HM165489). The Sequence has been submitted to NCBI with GenBank accession number KT192437.

Alternaria sp. PMK2: Leaf spot yielded a dark grey fungal colony with abundant aerial mycelium on PDA. The conidial morphology of *Alternaria* sp. PMK2 is in agreement with those described by (Ellis 1976). Conidiophores were dark brown, straight to geniculate, arises in clusters, scar present at the point of bearing conidia. Based on these characteristics, the fungus was identified as *Alternaria* sp.

Production of cell wall degrading enzymes

The use of simpler solid media permits the rapid screening of large populations of fungi for the presence or absence of specific enzymes. The six pathogenic *Alternaria* fungi were isolated from *Parthenium* plants. All isolates were sub-cultured routinely and maintained in the department. The isolates of filamentous fungi were screened for production of cellulose, starch, pectin and lignin degrading enzymes qualitatively on agar media containing specific substrates. Each isolate was able to produce one or the other extracellular enzymes (**Table 1**). Some of the pathogens were able to produce all the enzymes.

Table 1. Enzyme activities of fungal pathogens isolated from *Parthenium* weed

Pathogens	Qualitative enzymatic activities				
	Cellulase	Amylase	Pectinase	Laccase	LiP and Mn peroxidase
A. macrospora MKP1	+	+	+	+	+
A. macrospora MKP2	+	+	+	+	+
A. macrospora MKP3	-	+	+	+	+
A. macrospora MKP4	+	+	+	+	+
Alternaria sp. PMK1	+	+	+	-	+
Alternaria sp. PMK2	+	+	+	+	+

LiP: Lignin peroxidase; MnP: Manganese peroxidase; +: Positive; -: Negative

Cellulolytic enzyme assay was performed to test the cellulolytic activity of six pathogenic *Alternaria*. Zone production by the tested fungi indicate the presence of cellulase enzyme. All the test fungi showed positive result for the production of cellulolytic enzymes except *Alternaria macrospora* MKP3.

Results showed that all the fungal isolated except *Alternaria* sp. PMK1 exhibited an ability to oxidize guaiacol, halo of intense brown colour was formed under and around the fungal colonies (positive for guaiacol oxidation), indicating the presence of ligninolytic enzymes (laccase).

Lignin peroxidase and manganese peroxidase assay revealed decolourization of the dye Azure-B by fungi which was positively correlated with production of lignin peroxidase and Mn dependent peroxidase. In solid plate screening all the six pathogens decolorized the Azure B dye and exhibited an ability of producing lignin peroxidase and Manganese peroxidase enzymes.

All the tested fungi showed the positive results for amylase production by halo zone formation on starch agar plates. The amylolytic potential of these pathogenic fungi may help them to degrade starch which is available in the host plant.

After 72 h of incubation, cultures of the tested fungi on pectin agar plates showed clear zones on treatment with iodine-potassium iodide solution indicating the pectinolytic ability of these fungi. The pectinolytic enzyme of these pathogenic fungi may help them to cause infection in the *Parthenium* plant.

In the present study, the fungal pathogens of *Parthenium* were screened qualitatively for cellulase, pectinase, amylase and lignin degrading enzymes production. The elaboration of an array of cell wall splitting enzymes helps the pathogen for easy penetration of the host cell wall and subsequent colonization. Cellulose is a major structural constituent of the cell wall of host plants. Many phytopathogenic fungi produce cellulases in culture adaptively which hydrolyse cellulose and its derivatives (Muthulakshmi 1990). The results obtained in the present study indicate that all the six isolates of *Alternaria* produced cellulase except *Alternaria macrospora* MKP3.

Several pathogenic ascomycetes and deutromycetes are known to produce lignin degrading enzymes. In our study the screened pathogens were able to produce one or the other ligninolytic enzyme which may contribute in the pathogenesis against *Parthenium*. A numbers of cell wall degrading enzymes have been shown to be produced by plant pathogens (Chenglin *et al.* 1996), which are known to facilitate cell wall penetration and tissue maceration in host plants. Since all the species of *Alternaria* are intercellular in the host, the productions of these enzymes appears to facilitate the dissolution of host cell wall and middle lamella and help entry and establishment of the pathogen in the host and are possibly responsible for playing a vital role in pathogenesis through cell wall degradation and disintegration of tissues.

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SUMMARAY

A common feature of pathogenic fungi to cause disease in plant is the necessity to pass through the plant cell wall, an important barrier against pathogen attack. To this end, fungi possess a diverse array of secreted enzymes to depolymerize the main structural polysaccharide components of the plant cell wall, *i.e.* cellulose, lignin and pectin. In the present investigation, six pathogenic fungal species such as *Alternaria* sp. PMK1, *Alternaria* sp. PMK2, *Alternaria macrospora* MKP1, *Alternaria macrospora* MKP2, *Alternaria macrospora* MKP3 and *Alternaria macrospora* MKP4 were isolated from diseased leaves of *Parthenium* plant and found to be pathogenic to this weed. Isolated fungi were examined for the presence of cellulolytic, pectinolytic, amylolytic and ligninolytic activity. Presence of enzymatic activities of these fungal indicating the importance of the cell wall degrading enzymes in pathogenicity against *Parthenium* weed.

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