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Sequential application of pre- and post-emergence herbicides for the control of weeds in transplanted rice at Hirakud command areas of Odisha

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ABSTRACT

A field experiment was conducted during rainy *(Kharif)* seasons of 2018 and 2019 to assess the efficacy of the sequential application of pre- and post-emergence herbicides for managing complex weed flora in transplanted rice at Hirakud command areas of Odisha. The weed free maintained by hand weeding twice recorded the highest values of growth parameters and rice grain yield (6.4 t/ha). The weeds in weedy check caused 50% rice grain yield reduction. The sequential application of pre-emergence herbicide (PE) pretilachlor + bensulfuron-methyl (ready-mix) 660 g/ha followed by (*fb*) post-emergence application (PoE) of bispyribac-sodium 25 g/ha recorded the highest weed control efficiency (93%), rice grain yield (6.1 t/ha), net return (₹ 63720 /ha) and benefit cost ratio (2.4) with 72.8% reduction in weed biomass and 24.6% yield advantages over recommended practice of pendimethalin 1000 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE.

INTRODUCTION

In India, rice (*Oryza sativa* L.) is grown in an area of 43.8 million ha, with a production of 116.4 million tons, and productivity of 2.7 t/ha in 2020 - 2021 (GOI 2021). In Odisha, area under rice crop is 3.86 million ha with a production of 7.7 million tons and productivity of 2.0 t/ha in 2018-2019 (RBI 2020). The advent of capital intensive technology like high yielding varieties tailored to respond to external inputs like fertilizers, irrigation and new intensive cropping systems aggravated the problem of weeds (Yaduraju and Mishra 2002). Weed infestation has been established as one of the important factors responsible for lower productivity in Odisha, as the weed flora under transplanted conditions cause a yield reduction up to 45% (Manhas *et al.* 2012).

Herbicide use is an effective method of selective and economical control of weeds immediately after rice transplanting for giving rice an advantageous initial vigorous growth and competitive superiority. Several pre- and post-emergence herbicides were identified for effective control of weeds in transplanted rice (Rajkhowa *et al.* 2006, Rao *et al.* 2017). Thus, the sequential application of pre- followed by post-emergence application of broad-spectrum herbicides was found essential for season-long effective weed control as it also helps in avoiding shifts toward problematic weed species or evolution of herbicide-resistant weed biotypes (Chauhan 2012). Adjusting the time of application, reducing the dose of the herbicide or use of herbicide in sequence can improve selectivity and adequate weed control in transplanted rice (Mallikarjun *et al.* 2014). The cultivation of two rice crops during a year in the same field in the command areas creates congenial environment for weed growth. Under such situations, the pre-emergence herbicide works up to 20 days after transplanting (DAT) and after application of 1st top dressing of fertilizer, the second flush of weeds emerge in the field which needs to be controlled. Thus the use of sequential application of pre-emergence herbicides followed by post-emergence herbicides could be more effective in managing the weed menace. With this background, the present study was undertaken.

MATERIALS AND METHODS

A field experiment was conducted during rainy *(Kharif)* seasons of 2018 and 2019 at the Regional Research and Technology Transfer Station, Chiplima of Orissa University of Agriculture and Technology under West Central Table Land Zone Odisha, India. The soil of experimental field was clay loam with porosity 39.28%, infiltration rate 0.26 cm/hr, water holding capacity 25.56% on weight basis, field capacity 19.7% on weight basis, permanent wilting point 10%, acidic (pH 5.65), low in organic carbon content (0.47%) and available N, P and K content were 242, 9.2 and 155 kg/ha, respectively. The experiment was laid out in randomized block design with 3 replications. The individual plot size was 6.1 x 2.4 m. Sixteen weed control treatments were tested (Table 1). Pre-emergence application of herbicides was done by broadcasting the herbicide mixed with 25 kg sand/ha at 3 DAT and the post-emergence application of bispyribac-sodium was done by spraying it at 20 DAT with knapsack sprayer fitted with flat fan nozzle using 375 liters water per hectare. A thin film of water was maintained in the field at the time of application of herbicides. The land was prepared by giving two ploughings each followed by planking with the help of a tractor – drawn cultivator. The puddling was done at the time of transplanting. Rice variety '*Hasant'* was transplanted in July and harvested in November during each of the year. Two rice seedlings per hill were transplanted at 20 × 15 cm spacing. A common fertilizer dose of 80, 40 and 40 kg of N, P and K/ha, respectively was applied to the crop. Full dose of P and K and half dose of N were applied as basal and remaining N was top-dressed in 2 equal splits, at maximum tillering and panicle-initiation stages of the crop.

Weed density (no./m^2), weed biomass (g/m^2) were measured by randomly placing at two places the 0.25 m^2 quadrat at 50 DAT. Weeds were separated in to three broad categories of grass, sedge and broad-leaved weeds (BLW) before drying. The weed samples collected from quadrats were kept at 85^0C for 16 hour in hot air oven and dry weight of the weeds (biomass) was measured (Klingman 1971). Weed density data was analyzed after subjecting to square root transformation. Weed control efficiency was also calculated on the basis of weed biomass using formula suggested by Mani *et al.* (1973).

$$\text{Weed control efficiency} = \frac{(\text{WDc} - \text{WDt})}{\text{WDc}} \times 100$$

Where, WDc is the biomass (g) of weeds in weedy plots, WDt is the biomass (g) of weeds in treated plots

Data on rice plant height and yield attributes like tillers/m^2, panicle length, grains/panicle, 1000 grain weight and grain yield of rice were recorded at harvest. Economics was computed using the prevailing market prices for inputs and outputs such as rice grain (₹ 17500/t), rice straw (₹ 800/t), manual labour (₹ 280/day), pretilachlor + bensulfuron 6.6 GR (₹ 982/4 kg), pyrazosulfuron +pretilachlor 6.15 GR (₹ 795/4 kg), butachlor + penoxsulam 41 SE (₹ 800/1l), oxadiargyl 80 WP (₹ 190/35 g), pretilachlor 50 EC (₹ 300/1l.), butachlor 50 EC (₹ 200/l), pendimethalin 30 EC (₹ 477/1l), bispyribac-sodium 10 EC (₹ 835/100 ml). All data were subjected to analysis of variance as described by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Effect on weeds

Major weed species infesting the field were: *Echinocloa crus-galli* (L.) Beauv., *Echinocloa colona* (L.) Link., *Paspalum distichum* L., *Cyperus iria* L., *Cyperus difformis* L., *Fimbristylis miliacea* (L.) Vahl; *Scirpus acutus Muehl. ex Bigelow.*, *Marsilia quadrifolia* L., *Ammania baccifera* L., *Alternanthera sessilis* (L.) R.Br. ex DC., and *Ludwigia parviflora* L. On an average of two years, the total weed density of 104.5/m^2 (average of two years) was observed in weedy plots at 50 DAT among which grass, sedge and broad-leaved weeds constituted 16.3, 43.1 and 40.7%, respectively (**Table 1**)

All the weed control treatments significantly reduced the density and biomass of grasses, sedges, BLW and total weeds as compared to weedy check (**Table 1 and 2**). Two hand weeding at 20 and 40 DAT provided weed free condition with 100% weed control. The pretilachlor + bensulfuron (ready-mix) PE showed lower weed biomass (8.8 g/m^2), which was at par with pretilachlor + pyrazosulfuron (ready-mix) PE (10.3 g/m^2) compared with other pre-emergence herbicides. The pretilachlor + bensulfuron (ready mix) caused a reduction of 35.7 and 72.8% in weed biomass (**Table 2**) when compared to pretilachlor PE and weedy check, respectively. Similar observations were made by Teja *et al.* (2015). Likewise, pretilachlor + pyrazosulfuron PE reduced weed biomass by 24.8 and 68.2% compared to commonly used pretilachlor and weedy check, respectively.

The sequential application of PE *fb* PoE was proved to be more effective in managing grass, sedge and broad-leaved weeds density, biomass and total weed density and biomass (**Table 1** and **2**). Maximum weed biomass reduction (93.2%) was observed with the sequential application of pretilachlor + bensulfuron (ready-mix) PE *fb* bispyribac-sodium PoE in comparison to weedy check due to effective control of all grasses, sedges and BLWs population at all growth stages as observed earlier by Maity and Mukherjee (2008), Sunil *et al*. (2010) and Bhat *et al. (*2017).

The highest weed control efficiency (WCE) at 50 DAT was recorded with pretilachlor + bensulfuron

PE *fb* bispyribac-sodium PoE (93%) followed by pretilachlor + pyrazosulfuron PE (92%) (**Table 2**). The application of pre-emergence herbicide alone showed poor weed control efficiency (48-75%). Similar results were reported by Sanodiya and Singh (2017).

Effect on rice

Pooled mean data of both years showed that sequential application of pre- and post-emergence herbicides resulted in greater rice plant height, more-number of tillers/m^2, maximum numbers of effective tillers and more grains/panicle when compared with the application of pre-emergence herbicides alone and weedy check. (**Table 3**).

The pooled mean data of both years showed that the highest grain yield of 6.4 t/ha was recorded with the weed free treatment with hand weeding twice. Among the herbicide treated plots, the sequential application of pretilachlor + bensulfuron PE *fb* bispyribac-sodium PoE with the grain yield of 6.1 t/ha followed by pretilachlor + pyrazosulfuron (ready-mix) PE *fb* bispyribac- sodium PoE with 6.0 t/ha were statistically comparable with that obtained with weed free plot (**Table 3**). This may be due to their broad spectrum weed control for a longer period resulting in minimum crop-weed competition and better growth and development of the crop. These results are in conformity with the findings of Walia *et al.* (2009), Bhat *et al.* (2017), Dhanapal *et al.* (2018) and Mahajan and Timsina (2011). The rice yield was reduced by 26.2-28.5%, without application of post-emergence herbicide. Walia *et al.* (2008) opined that it is difficult to raise weed-free rice with the application of only one herbicide. The season long uncontrolled weed growth reduced the yield of transplanted rice to an extent of 50% in weedy check in comparison to weed free plot.

The correlation and regression analysis revealed negative correlation between weed biomass and grain yield (R^2 = -0.81) and every unit increase in weed biomass, the grain yield of rice was expected to fall by 0.09 t/ha.

Table 1. Effect of weed control treatments on weed density at 50 days after transplanting (DAT) in transplanted rice

Treatment	Weed density (no./m^2) at 50 DAT											
	2018				2019				Mean			
	Grasses	Sedges	BLW	Total	Grasses	Sedges	BLW	Total	Grasses	Sedges	BLW	Total
Pretilachlor + bensulfuron 660 g/ha as PE	3.6 (12.0)	3.2 (9.0)	3.2 (9.0)	5.6 (30.0)	3.2 (9.0)	2.8 (7.0)	2.8 (7.0)	4.9 (23.0)	3.4 (10.5)	3.0 (8.0)	3.0 (8.0)	5.2 (26.5)
Pretilachlor + pyrazosulfuron 615 g/ha PE	3.7 (13.0)	3.7 (13.0)	3.3 (10.0)	6.1 (36.0)	3.3 (10.0)	3.0 (8.0)	3.0 (8.0)	5.2 (26.0)	3.5 (11.5)	3.2 (10.5)	3.2 (9.0)	5.7 (31.0)
Butachlor + penoxsulam 820 g/ha PE	4.1 (16.0)	4.7 (21.0)	2.8 (7.0)	6.7 (44.0)	3.6 (12.0)	3.6 (12.0)	2.6 (6.0)	5.6 (30.0)	3.9 (14.0)	2.7 (16.5)	2.7 (6.5)	6.2 (37.0)
Oxadiargyl 90 g/ha PE	3.7 (13.0)	5.1 (25.0)	2.8 (7.0)	6.8 (45.0)	3.5 (11.0)	3.9 (14.0)	2.6 (6.0)	5.7 (31.0)	3.6 (12.0)	2.7 (19.5)	2.7 (6.5)	6.2 (38.0)
Pretilachlor 750 g/ha PE	3.6 (12.0)	3.7 (13.0)	4.8 (22.0)	6.9 (47.0)	3.6 (12.0)	3.5 (11.0)	3.5 (11.0)	5.9 (34.0)	3.6 (12.0)	4.2 (12.0)	4.2 (16.5)	6.4 (40.5)
Butachlor 1500 g/ha PE	3.9 (14.0)	5.4 (28.0)	4.0 (15.0)	7.6 (57.0)	3.5 (11.0)	3.9 (14.0)	3.7 (13.0)	6.2 (38.0)	3.7 (12.5)	3.9 (21.0)	3.9 (14.0)	7.0 (47.5)
Pendimethalin 1000 g/ha PE	3.7 (13.0)	4.8 (22.0)	5.4 (28.0)	8.0 (63.0)	3.3 (10.0)	4.1 (16.0)	4.0 (15.0)	6.5 (41.0)	3.5 (11.5)	4.7 (19.0)	4.7 (21.5)	7.3 (52.0)
Pretilachlor + bensulfuron-methyl 660 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	1.4 (1.0)	1.4 (1.0)	1.5 (1.3)	1.7 (2.0)	3.0 (8.0)	1.9 (3.3)	1.9 (3.3)	2.6 (8.7)	2.3 (4.5)	1.8 (2.2)	1.8 (2.3)	2.2 (5.3)
Pretilachlor + pyrazosulfuron 615 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	2.4 (5.0)	1.4 (1.0)	1.7 (2.0)	3.0 (8.0)	3.6 (12.0)	2.6 (6.0)	2.8 (7.0)	5.1 (25.0)	3.1 (8.5)	2.3 (3.5)	2.3 (4.5)	4.2 (16.5)
Butachlor + penoxsulam 820 g/ha *fb* bispyribac-sodium 25 g/ha PoE	2.0 (3.0)	2.2 (4.0)	1.4 (1.0)	3.0 (8.0)	3.6 (12.0)	3.7 (13.0)	2.6 (6.0)	5.7 (31.0)	2.9 (7.5)	2.1 (8.5)	2.1 (3.5)	4.5 (19.5)
Oxadiargyl 90 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	2.0 (3.0)	2.4 (5.0)	1.4 (1.0)	3.2 (9.0)	3.3 (10.0)	3.7 (13.0)	2.8 (7.0)	5.6 (30.0)	2.7 (6.5)	2.2 (9.0)	2.2 (4.0)	4.5 (19.5)
Pretilachlor 750 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	2.2 (4.0)	2.2 (4.0)	3.0 (8.0)	4.1 (16.0)	3.2 (9.0)	3.2 (9.0)	3.5 (11.0)	5.5 (29.0)	2.7 (6.5)	3.2 (6.5)	3.2 (9.5)	4.8 (22.5)
Butachlor 1500 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	2.8 (7.0)	2.6 (6.0)	3.0 (8.0)	4.7 (21.0)	3.0 (8.0)	3.3 (10.0)	3.3 (10.0)	5.4 (28.0)	2.9 (7.5)	3.0 (8.0)	3.2 (9.0)	5.0 (24.5)
Pendimethalin 1000 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	2.0 (3.0)	2.8 (7.0)	3.3 (10.0)	4.6 (20.0)	3.2 (9.0)	3.5 (11.0)	3.5 (11.0)	5.7 (31.0)	2.6 (6.0)	3.2 (9.0)	3.4 (10.5)	5.1 (25.5)
Weed free by hand weeding twice	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)
Weedy check	4.5 (19.0)	7.4 (54.0)	6.9 (47.0)	11.0 (120.0)	4.0 (15.0)	6.1 (36.0)	6.2 (38.0)	9.5 (89.0)	4.2 (17.0)	6.6 (45.0)	6.6 (42.5)	10.3 (104.5)
LSD (p=0.05)	0.3	0.2	0.3	0.3	0.1	0.4	0.4	0.9	0.1	0.3	0.3	0.6

Square root $(\sqrt{x+1})$ transformed values, values in the parentheses are original values

Table 2. Effect of weed control treatments on weed biomass and weed control efficiency (WCE) at 50 days after transplanting (DAT) in transplanted rice

Treatment	Weed biomass (g/m^2) at 50 DAT														
	2018				2019				Mean				WCE (%)		
	Grasses	Sedges	BLW	Total	Grasses	Sedges	BLW	Total	Grasses	Sedges	BLW	Total	2018	2019	Mean
Pretilachlor + bensulfuron-methyl 660 g/ha	2.4	2.0	2.0	3.4	1.9	1.7	1.7	2.8	2.2	1.9	1.9	3.1	75	75	75
as PE	(4.9)	(2.9)	(2.9)	(10.7)	(2.8)	(2.0)	(2.0)	(6.8)	(3.8)	(2.5)	(2.5)	(8.8)			
Pretilachlor + pyrazosulfuron 615 g/ha PE	2.5	2.3	2.0	3.7	2.1	1.8	1.8	3.0	2.3	2.0	1.9	3.4	70	71	71
	(5.3)	(4.2)	(3.2)	(12.7)	(3.3)	(2.3)	(2.3)	(7.9)	(4.3)	(3.2)	(2.8)	(10.3)			
Butachlor + penoxsulam 820g/ha PE	2.8	2.8	1.8	4.1	2.3	2.1	1.6	3.2	2.5	2.5	1.7	3.7	64	66	65
	(6.6)	(6.8)	(2.3)	(15.6)	(4.3)	(3.4)	(1.7)	(9.4)	(5.4)	(5.1)	(2.0)	(12.5)			
Oxadiargyl 90 g/ha PE	2.6	3.0	1.8	4.2	2.2	2.2	1.6	3.2	2.4	2.6	1.7	3.7	62	66	64
	(6.0)	(8.1)	(2.3)	(16.3)	(3.7)	(4.0)	(1.7)	(9.4)	(4.8)	(6.0)	(2.0)	(12.9)			
Pretilachlor 750 g/ha PE	2.5	2.3	2.8	4.2	2.3	2.0	2.0	3.4	2.4	2.2	2.5	3.8	61	61	61
	(5.4)	(4.2)	(7.1)	(16.7)	(4.3)	(3.1)	(3.1)	(10.6)	(4.9)	(3.7)	(5.1)	(13.7)			
Butachlor 1500 g/ha PE	2.7	3.2	2.4	4.6	2.3	2.2	2.2	3.6	2.5	2.7	2.3	4.1	52	56	54
	(6.5)	(9.0)	(4.8)	(20.4)	(4.2)	(4.0)	(3.7)	(11.9)	(5.4)	(6.5)	(4.3)	(16.2)			
Pendimethalin 1000 g/ha PE	2.7	2.8	3.2	4.8	2.4	2.4	2.3	3.9	2.6	2.6	2.8	4.4	48	49	48
	(6.2)	(7.1)	(9.0)	(22.3)	(5.0)	(4.6)	(4.3)	(13.9)	(5.6)	(5.8)	(6.7)	(18.1)			
Pretilachlor + bensulfuron-methyl 660 g/ha	1.2	1.1	1.3	1.6	1.4	1.4	1.4	2.0	1.3	1.3	1.3	1.8	96	89	93
PE *fb* bispyribac-sodium 25 g/ha PoE	(0.5)	(0.3)	(0.6)	(1.5)	(1.1)	(0.9)	(0.9)	(2.9)	(0.8)	(0.6)	(0.8)	(2.2)			
Pretilachlor + pyrazosulfuron 615 g/ha PE	1.5	1.1	1.3	1.8	1.6	1.3	1.3	2.0	1.5	1.2	1.3	1.9	95	89	92
fb bispyribac-sodium 25 g/ha PoE	(1.2)	(0.3)	(0.6)	(2.2)	(1.6)	(0.7)	(0.8)	(3.0)	(1.4)	(0.5)	(0.7)	(2.6)			
Butachlor + penoxsulam 820 g/ha *fb*	1.3	1.5	1.1	1.8	1.6	1.6	1.3	2.2	1.5	1.5	1.2	2.0	95	86	90
bispyribac-sodium 25 g/ha PoE	(0.7)	(1.3)	(0.3)	(2.3)	(1.6)	(1.5)	(0.7)	(3.8)	(1.1)	(1.4)	(0.5)	(3.0)			
Oxadiargyl 90 g/ha PE *fb* bispyribac-	1.3	1.6	1.1	1.9	1.5	1.6	1.3	2.2	1.4	1.6	1.2	2.0	94	87	90
sodium 25 g/ha PoE	(0.8)	(1.6)	(0.3)	(2.7)	(1.4)	(1.5)	(0.8)	(3.6)	(1.1)	(1.5)	(0.6)	(3.2)			
Pretilachlor 750 g/ha PE *fb* bispyribac-	1.7	1.5	1.9	2.6	1.7	1.4	1.5	2.3	1.7	1.5	1.7	2.5	86	84	85
sodium 25 g/ha PoE	(1.9)	(1.3)	(2.6)	(5.8)	(2.0)	(1.0)	(1.3)	(4.3)	(2.0)	(1.2)	(1.9)	(5.1)			
Butachlor 1500 g/ha PE *fb* bispyribac-	2.0	2.0	2.0	3.3	1.8	1.6	1.6	2.5	1.9	1.9	1.8	2.9	78	80	79
sodium 25 g/ha PoE	(3.1)	(3.2)	(3.2)	(9.6)	(2.1)	(1.7)	(1.6)	(5.4)	(2.6)	(2.5)	(2.4)	(7.5)			
Pendimethalin 1000 g/ha PE *fb* bispyribac-	1.6	2.5	2.0	3.3	1.8	1.7	1.6	2.7	1.7	2.1	1.8	3.0	76	78	77
sodium 25 g/ha PoE	(1.7)	(5.2)	(3.2)	(10.1)	(2.4)	(2.1)	(1.6)	(6.0)	(2.0)	(3.6)	(2.4)	(8.1)			
Weed free by hand weeding twice	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	100	100	100
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)			
Weedy check	3.3	4.3	4.0	6.6	2.7	3.4	3.5	5.3	3.0	3.9	3.7	5.8	0	0	0
	(10.2)	(17.4)	(15.2)	(42.8)	(6.2)	(10.3)	(10.9)	(27.3)	(8.2)	(13.9)	(13.0)	(32.4)			
LSD (p=0.05)	0.1	0.04	0.04	0.02	0.02	0.03	0.04	0.03	0.03	0.03	0.03	0.4	-	-	-

Square root $(\sqrt{x+1})$ transformed values, values in the parentheses are original values

Table 3. Effect of weed control treatments on yield attributes, yield and economics of transplanted rice (mean data of 2 years)

Treatment	Plant height (cm)	Panicle length (cm)	Tillers/ m^2	Grains/ panicle	1000 grain wt. (g)	Grain yield (t/ha)			Straw yield (t/ha)	Cost ($x10^3$ `/ha)	Net returns ($x10^3$ `/ha)	B:C ratio
						2018	2019	Mean				
Pretilachlor + bensulfuron 660 g/ha as PE	108	25	306	141	22.9	4.2	4.8	4.5	5.3	46.01	32.68	1.7
Pretilachlor + pyrazosulfuron 615 g/ha PE	107	25	302	141	22.5	4.2	4.6	4.4	5.1	45.53	28.76	1.6
Butachlor + penoxsulam 820 g/ha PE	106	24	289	140	21.9	4.1	4.5	4.3	4.7	45.55	29.49	1.7
Oxadiargyl 90 g/ha PE	105	24	283	138	21.9	3.7	4.3	4	4.6	45.37	22.52	1.5
Pretilachlor 750 g/ha PE	104	24	265	132	21.6	3.2	4.2	3.7	4.4	44.25	17.77	1.4
Butachlor 1500 g/ha PE	104	24	258	127	21.5	3.4	3.8	3.6	4.3	44.12	12.75	1.3
Pendimethalin 1000 g/ha PE	103	24	248	125	21.3	3.6	3.4	3.5	4.2	45.12	13.19	1.3
Pretilachlor + bensulfuron-methyl 660 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	118	26	418	164	23.6	6.2	6.0	6.1	6.6	48.09	63.72	2.4
Pretilachlor + pyrazosulfuron 615 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	114	25	379	161	23.5	6.2	5.8	6.0	6.5	47.62	62.34	2.4
Butachlor + penoxsulam 820 g/ha *fb* bispyribac-sodium 25 g/ha PoE	113	25	373	160	23.2	5.9	5.7	5.8	6.4	47.63	58.68	2.2
Oxadiargyl 90 g/ha PE *fb* bispyribac-sodium25 g/ha PoE	112	25	358	151	23.4	5.3	5.5	5.4	6.2	47.45	51.04	2.2
Pretilachlor 750 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	112	25	347	150	22.9	5.1	5.3	5.2	6.2	47.45	41.63	1.9
Butachlor 1500 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	109	25	326	149	22.7	4.5	5.1	4.8	5.5	46.21	39.05	1.9
Pendimethalin 1000 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	109	24	319	141	22.5	4.2	5	4.6	5.4	47.21	31.47	1.7
Weed free by hand weeding twice	120	26	454	170	24	6.6	6.2	6.4	6.9	58.65	56.64	2
Weedy check	102	23	238	122	21.2	3.1	3.3	3.2	3	43.55	5.86	1.1
LSD (p=0.05)	9.7	NS	39.7	6.6	NS	0.7	0.5	0.7	1.2	-	0.03	0.4

Economics

All weed control treatments provided significantly higher return and B: C ratio compared to weedy check (**Table 3**). The net return was reduced by 9.7 times due to weeds (₹ 5860/ha) as compared to weed free (₹ 56640/ha). The sequential application of herbicides proved superior to herbicides pre-emergence application alone. The highest net return (₹ 63720/ha) was obtained with sequential application of pretilachlor + bensulfuron PE *fb* bispyribac-sodium PoE with benefit: cost ratio of 2.4. The hand weeding twice effectively controlled weeds and resulted in higher yields but it's B: C ratio was lower due to higher cost of cultivation (₹ 58600/ha) on account of higher human labour use as reported by Dhanapal *et al.* (2018).

The pre-emergence application of pretilachlor 6% + bensulfuron-methyl 0.6% GR at 660 g/ha *fb* post-emergence application of bispyribac-sodium 25 g/ha at 20 DAT gave effective control of all types of weeds, higher rice yield (6.1 t/ha), net return (₹ 63700 /ha) and benefit cost ratio (2.4).

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