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Bio-efficacy of sequential herbicide application for weed management in dry direct seeded rice

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ABSTRACT

Weeds are the major biotic constraint in dry-direct seeded rice (DDSR), mainly due to the concurrent emergence and absence of water layer to suppress weeds. Therefore, strategy needs to be developed to get broad-spectrum weed control in DDSR. Experiments were conducted in rice (var. MTU 1010) during 2015–16 where sequential applications of pre- and post-emergence herbicides were evaluated for providing broad-spectrum weed management options in DDSR. Both the years, employing two-hand weedings at 15 and 30 DAS provided the lowest weed densities and weed dry weight at 75 DAS, whereas the maximum values of weeds were recorded in un-weeded plots. Among the herbicide-based weed management practices, application of pendimethalin 1000 g/ha *fb* bispyribac sodium 25 g/ha *fb* fenoxaprop 60 g/ha + chlorimuron + metsulfuron 4 g/ha at 30 DAS provided excellent weed control at 75 DAS, with 4.3% higher rice grain yield than two hand weedings at 15 and 30 DAS, pendimethalin 1000 g/ha *fb* bispyribac sodium 25 g/ha also provided good weed control and higher grain yield. Un-weeded plots noticed with considerable yield reduction of 79.5–83.3% over two hand weedings. Therefore, sequential application of pendimethalin 1000 g/ha *fb* bispyribac sodium 25 g/ha is recommended along with need-based application of post-emergence herbicides (fenoxaprop 60 g/ha + chlorimuron + metsulfuron 4 g/ha) or one hand weeding to improve the weed control efficiency and provides economically higher productivity in DDSR.

Key words: Benefit-cost ratio, Dry direct-seeded rice, Pre- and post-emergence herbicides, Weed management

Rice (*Oryza sativa* L.) is a principal staple food crop for the world population; it is being cultivated in 158 million ha with the production of 759.6 million tonnes (FAO 2018). In India, it occupies about 44 million ha with the production of 116 million tonnes. Rice is predominantly transplanted in puddled field which consumes 150 ha-cm of water and also deteriorates the physicochemical properties of soil (Choudhary *et al.* 2017). In coming days, the availability of water for agriculture may reduce and puddled transplanted rice may be vulnerable (Mekonnen and Hoekstra 2016, Choudhary 2017). Under the situation, dry direct seeded rice (DDSR) is being suggested as water and labour-saving production system, wherein rice is established by direct seeding in the non-puddled and non-flooded field. The DDSR saves 67% labour, 35–57% water and 29% production cost over transplanted rice (Rana *et al.* 2016). However, weeds are major biological constraints as dry tillage and aerobic condition are conducive for better establishment and prolific growth of weeds. The simultaneous emergence of rice and weed seedling in DDSR makes weed management more difficult and yield reduction has been noticed up to 95% (Naresh *et al.* 2011) and sometimes it may lead to complete crop failure.

In DDSR, the appearance of more than one flush of weeds with heterogeneous species enhances the period for crop-weed competition. In these conditions, none of the herbicides or weed management practices provides season-long effective weed control. Manual hand weeding is the most common and effective weed control methods; however, it is tedious and costly. Moreover, seedlings of some of the grassy weeds such as *Echinochloa colona* (L) and *Echinochloa crus-galli* (L) look similar to rice seedlings, making hand weeding more difficult and less effective (Singh *et al.* 2016, Choudhary and Dixit 2018). Therefore, suitable weed management is essentially required in order to minimize yield loss and making DDSR production system attractive to practising farmers. Consequently, the present investigation was formulated to find suitable weed management comprising sequential application of pre- and post-emergence herbicides or a mixture of post-emergence herbicides to optimize the weed control, and DDSR system more productive and economically viable.

MATERIALS AND METHODS

The field experiment was conducted during 2015–16 at

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the research farm of the ICAR-National Institute of Biotic Stress Management, Raipur, Chhattisgarh (extends 21°22'N 81°49'E, 289 m amsl). The average annual rainfall was 1250 mm with a sub-tropical climate. The soil of the experimental site was loamy in texture (sand: 35%, silt: 45% and clay 20%) with 0.34% organic carbon and *p*H of 6.8. Available nitrogen (N), phosphorus (P_2O_5) and potash (K_2O) content in the soil were 209.3, 14.1 and 328.5 kg/ha, respectively. The experiment consisted of 10 treatments pendimethalin followed by (*fb*) bispyribac sodium (1000 and 25 g/ha) at 2 and 15 days after sowing (DAS), pendimethalin *fb* chlorimuron + metsulfuron (1000 and 4 g/ha) at 2 and 30 DAS, pendimethalin *fb* fenoxaprop (1000 and 60 g/ha) at 2 and 25 DAS, pendimethalin (1000 g/ha, 2 DAS) *fb* hand weeding (HW) 30 DAS, bispyribac sodium *fb* chlorimuron + metsulfuron (25 and 4 g/ha) at 15 and 30 DAS, bispyribac sodium *fb* fenoxaprop (25 and 60 g/ha) at 15 and 25 DAS, bispyribac sodium (25 g/ha, 15 DAS) *fb* HW 30 DAS, pendimethalin *fb* bispyribac sodium *fb* fenoxaprop + chlorimuron + metsulfuron (1000 and 25 and 60+ 4 g/ha), two HW at 15 and 30 DAS, and un-weeded (control) laid out in a randomized block design and replicated thrice in both the years with gross plot area of 8 m × 5 m and net plot of 6 m × 3 m. Seeds of high yielding rice cv MTU-1010 (duration of 122–125 days) were sown by seed drill with spacing of 20 cm × 5–7 cm, at a seed rate of 80 kg/ha on 16 June, 2015 and 20 June, 2016. Fertilizer, 100 kg N (Urea), 60 kg P_2O_5 (single super phosphate) and 40 kg K_2O (muriate of potash) were applied. Urea was applied in four equal splits, 8–10 days after sowing (DAS), 30 DAS (at tillering), 60 DAS (at panicle initiation) and 85 DAS (at flowering). Full of P_2O_5 and ¾ K_2O were applied with multi-crop seed-cum-fertilizer planter while planting. Remaining ¼ K_2O was applied at 85 DAS. The herbicides were sprayed with Knapsack sprayer fitted with a flat fan nozzle using water of 500 l/ha for pre-emergence and 375 l/ha for post-emergence herbicides.

Different weed species were measured at 75 DAS with a quadrate of 50 cm × 50 cm placed at two places in each plot. After counting, each group of weeds was placed separately in brown paper bags and dried in a hot air oven at 70°C for 48 h and group-wise weed dry weight was recorded. Weed control efficiency (WCE) was recorded at 75 DAS based on weed dry weight as suggested by Choudhary (2017). Panicles/m^2 was counted from two sites of each plot, whereas grains/panicle were counted from 10 panicles of each plot. The rice crop was harvested at physiological maturity in both the seasons on October 17, 2015 and October 22, 2016. The grain yield was adjusted to t/ha at 14% moisture content. The cost of cultivation as per the inputs used (common cost and variable cost) during 2015 was calculated and net return and benefit cost ratio was calculated. Data from the experiments were analyzed using the PROC GLM with Duncun Multiple Range Test using SAS software (version 9.3) at 5% level of significance. Weed density and dry weight were square root transformed [$\sqrt{(x+0.5)}$], before analysis to normalize their distribution.

RESULTS AND DISCUSSION

The common weed species found at the study site comprised sedges, for instance, *Cyperus iria* (L.), *C. compressus* (L.), *C. rotundus* (L.), *Fimbristylis miliacea* (L.), and important grasses such as *Digitaria ciliaris* (Retz.) Koel, *Echinochloa colona* (L.) Link., *Dactyloctenium aegyptium* (L.) Willd., *Eleusine indica* (L.) Gaertn. *Leptochloa chinensis* and major broad-leaved weeds like *Celosia argentea*, *Alternanthera sessilis*, *Physalis minima*, *Ageratum conyzoids*, *Ludwigia octavalis*, *Partulaca oleracea*, *Phyllanthus niruri* (L.). However, it was noticed that *Celosia argentea* was more dominant in the second year, mainly due to its appearance in later flush.

Weed density, dry weight and weed control efficiency: The relative density of weeds in study area comprised dominated 37.6–44.4% of broadleaf weeds followed by grasses (30.3–32.4%) and the lowest with sedges (25.2–30.1%). The highest total weed density (318.3 and 305.3 weeds/m^2 in 2015 and 2016, respectively) and weed dry weight (36.6 and 40.1 g/m^2 in 2015 and 2016, respectively) were recorded in un-weeded plots followed by pendimethalin *fb* fenoxaprop (Table 1). However, the lowest weed density (44.3 and 29.3 weeds/m^2 in 2015 and 2016, respectively) and weed dry weight (4.7 and 5.8 g/m^2 in 2015 and 2016, respectively) were measured in the plots imposed with two-hand weeding at 15 and 30 DAS. Among the herbicide-based weed management practices, the plots that received pendimethalin *fb* bispyribac sodium *fb* fenoxaprop + chlorimuron + metsulfuron, and bispyribac sodium *fb* HW had considerably lower density and dry weight of weeds.

Two hand weedings at 15 and 30 DAS had fewer weed density by 86-90% and lesser weed dry weight by 87.2–91.5% followed by pendimethalin *fb* bispyribac sodium *fb* fenoxaprop + chlorimuron + metsulfuron (86–88 and 85.5–89.1%, respectively) and bispyribac sodium and pendimethalin *fb* HW (83–86 and 84.0–84.4%, respectively) than that of un-weeded plots. Application of pendimethalin *fb* HW also recorded considerable reduction in weed density by 81% and weed dry weight by 78.6–81.4% (Table 1). Overall bispyribac sodium treated plots had a better response than pendimethalin applied plots and it was further improved with the imposition of HW. Among the sequential application of pre- or post-emergence herbicides, chlorimuron + metsulfuron was better than fenoxaprop in controlling weeds, but the effect of pendimethalin *fb* bispyribac sodium was superior to others. Similar to our findings, Mahajan and Chauhan (2013) and Awan *et al.* (2015) also found that bispyribac sodium was poor on controlling *Digera* spp., *Leptochloa chinensis*, *Eragrostis* spp. and some of the perennial sedges in DDSR.

Among the different groups of weeds, grassy weed density and dry weight was influenced by weed management practices, pendimethalin *fb* bispyribac sodium *fb* fenoxaprop + chlorimuron + metsulfuron had 91.6% lower density and 94.9% of lesser dry weight in 2015, whereas two HW had 88.1% lower density and 89.3% lesser weed dry weight in

Table 1 Effect of weed management practices on grass, broadleaf, sedges, total weed density (no./m^2) and weed dry weight (g/m^2) at 75 day after sowing in direct seeded rice in 2015 and 2016

Treatment	Grass		Broadleaf		Sedges		Total	
	2015	2016	2015	2016	2015	2016	2015	2016
Weed density (no./m^2)								
Pendimethalin followed by (*fb*) bispyribac sodium	5.8d(33)*	6.1bc(37)	6.1c(36)	5.8c(34)	5.8c(33)	5.2bc(27)	10.1d(102)	9.9c(97)
Pendimethalin *fb* chlorimuron + metsulfuron	7.5b(56)	6.9b(47)	5.0d(24)	5.2d(27)	6.1c(37)	5.5b(30)	10.9c(118)	10.2c(103)
Pendimethalin *fb* fenoxaprop	5.1e(26)	4.6d(21)	9.0b(81)	9.4b(88)	9.0b(82)	8.4a(70)	13.7b(188)	13.4b(179)
Pendimethalin *fb* hand weeding	4.5f g(19)	3.9de(15)	4.7de(22)	5.3d(28)	4.4ef(19)	4.1de(16)	7.8 g(60)	7.7e(59)
Bispyribac sodium *fb* chlorimuron + metsulfuron	6.3c(39)	5.8c(34)	4.4e(19)	4.4e(19)	5.0de(24)	4.6cd(21)	9.1f(82)	8.6d(73)
Bispyribac sodium *fb* fenoxaprop	4.6f(20)	3.9de(15)	6.4c(40)	6.1c(36)	5.6cd(31)	5.0bc(25)	9.6e(91)	8.7d(76)
Bispyribac sodium *fb* hand weeding	4.0 gh(16)	3.6e(12)	4.5de(20)	4.5e(20)	4.2f g(17)	3.3f(11)	7.3 g(53)	6.6f(45)
Pendimethalin *fb* bispyribac sodium *fb* fenoxaprop + chlorimuron + metsulfuron	3.0i(9)	3.5e(12)	4.2e(17)	4.2e(18)	3.5h(12)	3.7ef(13)	6.1i(37)	6.6f(43)
Two hand weeding	3.7h(13)	3.4e(11)	4.3e(18)	3.7f(13)	3.6 gh(13)	2.4 g(5)	6.7h(44)	5.5 g(29)
Un-weeded (control)	10.2a(103)	9.7a(93)	11.0a(120)	11.7a(136)	9.8a(96)	8.8a(77)	17.9a(318)	17.5a(305)
LSD (P=0.05)	0.42	0.76	0.56	0.52	0.65	0.58	0.49	0.62
Weed dry weight (g/m^2)								
Pendimethalin *fb* bispyribac sodium	1.8c(2.8)*	1.9c(3.0)	2.7c(7.0)	2.6c(6.2)	2.1b(4.1)	2.0bc(3.4)	3.8c(13.9)	3.6c(12.7)
Pendimethalin *fb* chlorimuron + metsulfuron	2.6b(6.1)	2.2b(4.4)	2.0e(3.5)	2.3d(4.9)	2.2b(4.3)	2.1b(3.9)	3.8c(13.9)	3.7c(13.1)
Pendimethalin *fb* fenoxaprop	1.6d(2.1)	1.6d(2.1)	3.1b(9.3)	4.1b(16.5)	3.1a(8.9)	2.9a(7.9)	4.6b(20.2)	5.2b(26.5)
Pendimethalin *fb* hand weeding	1.4ef(1.4)	1.4e(1.4)	1.9ef(3.2)	2.3d(4.9)	1.6cd(2.2)	1.7e(2.2)	2.7f(6.8)	3.0e(8.6)
Bispyribac sodium *fb* chlorimuron + metsulfuron	1.9c(3.0)	1.9c(3.1)	1.7 gf(2.5)	2.0e(3.4)	1.8c(2.8)	1.8d(2.8)	3.0e(8.3)	3.1de(9.3)
Bispyribac sodium *fb* fenoxaprop	1.4e(1.5)	1.4ef(1.4)	2.3d(4.9)	2.6c(6.2)	2.0b(3.6)	1.9cd(3.1)	3.2d(10.1)	3.3d(10.7)
Bispyribac sodium *fb* hand weeding	1.3ef(1.2)	1.3ef(1.1)	1.7f g(2.4)	2.1e(3.7)	1.6d(2.1)	1.4f(1.6)	2.5 g(5.7)	2.6f(6.4)
Pendimethalin *fb* bispyribac sodium *fb* fenoxaprop + chlorimuron + metsulfuron	1.1 g(0.6)	1.3ef(1.1)	1.7 g(2.3)	1.9e(3.2)	1.2e(1.1)	1.4f(1.5)	2.1i(4.0)	2.5f(5.8)
Two hand weeding	1.2f(1.1)	1.2f(0.9)	1.7 gf(2.5)	1.5f(1.7)	1.3e(1.1)	1.1 g(0.8)	2.3h(4.7)	2.0 g(3.4)
Un-weeded (control)	3.5a(11.8)	3.0a(8.4)	4.0a(15.7)	4.9a(23.1)	3.1a(9.1)	3.0a(8.6)	6.1a(36.6)	6.4a(40.1)
LSD (P=0.05)	0.14	0.19	0.21	0.21	0.19	0.15	0.16	0.23

*Figures in parenthesis are original values and are subjected to square root transformation (x+0.5) when analyzing ANOVA. Figures in the same column with same letter(s) do not differ significantly (P<0.05)

2016, which were followed by each other in corresponding years (Table 1). It was noticed that bispyribac sodium alone was considerably superior but was less effective against some of the grasses like *Dactyloctenium aegypticum, Eleusine indica* and *Digitaria ciliaris*. However, with sequential application of pendimethalin *fb* bispyribac sodium further augmented the control of grassy weeds. It was also recorded that bispyribac sodium *fb* HW and pendimethalin *fb* HW significantly reduced the density and dry weight of grassy weeds over the un-weeded plots. Mahajan and Chauhan (2013) also found that bispyribac sodium alone as post-emergence reduced the weed density by 52% and weed dry weight by 50%, whereas pendimethalin *fb* bispyribac sodium had controlled 92% of weed density and 93% of weed dry weight.

Likewise, pendimethalin *fb* bispyribac sodium *fb* fenoxaprop + chlorimuron + metsulfuron had recorded the lowest density and dry weight of broadleaf weeds by 85.8 and 85.3%, respectively in 2015, whereas two HW plots had 90.4% reduced density and 92.6% lesser weed dry weight over un-weeded plots in 2016. Rest of the treatments followed almost similar trend of grasses; however, broadleaf weeds under sequential application of bispyribac sodium and pendimethalin *fb* chlorimuron +

metsulfuron were almost similar to sequential application of bispyribac sodium and pendimethalin *fb* HW (Table 1). The performance of HW and chlorimuron + metsulfuron treated plots had lower broadleaf weeds than the fenoxaprop treated plots. Similar to broadleaf weeds, sedges density was 87.7% lower in pendimethalin *fb* bispyribac sodium *fb* fenoxaprop + chlorimuron + metsulfuron, whereas two HW plots registered 93.1% lower density in 2016 over un-weeded plots. Likewise, sedges dry weight followed the similar trend during both the years. However, density and dry weight of sedges were recorded lower with the sequential application of pre- or post-emergence herbicide *fb* HW. It was also noticed that the application of chlorimuron + metsulfuron after pendimethalin or bispyribac sodium had considerably controlled the sedges resulted in lowered density and dry weight. However, it can be inferred from Table 1, that the reduction of sedge density and dry weight were more in bispyribac sodium and chlorimuron + metsulfuron than pendimethalin over the un-weeded plots.

The WCE followed the trend of weed dry biomass, and recorded the highest with sequential application of pendimethalin *fb* bispyribac sodium *fb* fenoxaprop + chlorimuron + metsulfuron (89%) during 2015, whereas two HW recorded higher WCE (91.5%) during 2016 over un-weeded plot. Other weed management practices were between these treatments; however, bispyribac sodium *fb* HW (84%) and pendimethalin *fb* HW (78.7–81.5%) were recorded next best WCE (Table 2). Bispyribac sodium alone was effective herbicide for controlling the wide range of weed species; however, this was less effective against some of the grasses like *D. aegyptium, E. indica, L. chinensis*; broadleaf weeds like *Alternanthera sessilis, Physalis minima* and sedges like *C. rotundus*. The efficacy of bispyribac sodium further increased with the pre-emergence application of pendimethalin and sequential application of fenoxaprop and chlorimuron + metsulfuron. Use of single herbicide could not manage the weeds throughout the crop growing season, therefore, the addition of at least one more herbicide or one HW is required in order to control the weeds for longer time (Chauhan and Opeña 2013).

Yield attributes and yield of rice: Imposition of two HW recorded the highest panicles (305.7 and 318.5/m^2 in 2015

Table 2 Effect of weed management practices on weed control efficiency, yield attributes, grain yield and economic parameters of dry direct seeded rice in 2015 and 2016

Treatments	WCE at 75 DAS (%)		Panicle (no./m^2)		Grains (no./panicle)		Grain yield (t/ha)	
	2015	2016	2015	2016	2015	2016	2015	2016
Pendimethalin *fb* bispyribac sodium	62.0	68.4	271.1c	277.0e	94.7bcd	91.7b	3.90c	4.00d
Pendimethalin *fb* chlorimuron + metsulfuron	62.1	67.2	240.6d	260.9f	89.7cd	89.0b	3.45d	3.55f
Pendimethalin *fb* fenoxaprop	44.7	33.9	223.3e	235.0g	66.7e	68.3c	2.36e	2.42g
Pendimethalin *fb* hand weeding	81.5	78.7	276.0c	293.1bcd	96.0bc	92.0b	4.11b	4.26d
Bispyribac sodium *fb* chlorimuron + metsulfuron	77.4	76.8	265.3c	287.7cde	91.3cd	89.3b	3.75c	3.98d
Bispyribac sodium *fb* fenoxaprop	72.5	73.4	265.8c	281.6de	89.0d	87.3b	3.55d	3.76e
Bispyribac sodium *fb* hand weeding	84.5	84.0	290.5b	296.6bc	95.7bc	99.0a	4.27b	4.43c
Pendimethalin *fb* bispyribac sodium *fb* fenoxaprop + chlorimuron + metsulfuron	89.0	85.5	292.6b	304.3b	101.0ab	102.7a	4.78a	4.95a
Two hand weeding	87.2	91.5	305.7a	318.5a	106.0a	105.3a	4.60a	4.73b
Un-weeded (control)	62.0	68.4	87.5f	87.0h	56.0f	61.3d	0.77f	0.97h
LSD (P=0.05)			10.86	12.79	6.46	6.49	0.18	0.17
Economic parameters	*Common cost*		*Variable cost*		*Net return (₹/ha)*		*Benefit-cost ratio*	
					2015	*2016*	*2015*	*2016*
Pendimethalin *fb* bispyribac sodium	24670		3250		29875	33033	2.07b	2.18b
Pendimethalin *fb* chlorimuron + metsulfuron	24670		1935		24775	27767	1.93c	2.04c
Pendimethalin *fb* fenoxaprop	24670		3000		7854	10050	1.28f	1.36e
Pendimethalin *fb* hand weeding	24670		9025		27254	31113	1.81de	1.92d
Bispyribac sodium *fb* chlorimuron + metsulfuron	24670		2185		28813	33833	2.07b	2.26b
Bispyribac sodium *fb* fenoxaprop	24670		3250		24688	29505	1.88cd	2.06c
Bispyribac sodium *fb* hand weeding	24670		8200		30248	34520	1.92c	2.05c
Pendimethalin *fb* bispyribac sodium *fb* fenoxaprop + chlorimuron + metsulfuron	24670		5185		40793	45252	2.37a	2.52a
Two hand weeding	24670		13975		29413	33233	1.76e	1.86d
Un-weeded (control)	24670		0		-11681	-8302	0.53g	0.66f
LSD (P=0.05)							0.091	0.092

and 2016, respectively) followed by sequential application of pendimethalin *fb* bispyribac sodium *fb* fenoxaprop + chlorimuron + metsulfuron, while the lowest panicles (87.5 and 87.0/m^2 in 2015 and 2016, respectively) were found in the un-weeded plots. The imposition of HW either with pre- or post-emergence herbicides was also comparable to two HW. Grains/panicle was also the highest with two HW (106.0 and 105.3 in 2015 and 2016, respectively) followed by pendimethalin *fb* bispyribac sodium *fb* fenoxaprop + chlorimuron + metsulfuron (Table 2). It was recorded that HW either with pre- or post-emergence herbicides were comparable to two HW at 15 and 30 DAS. The lowest grains/panicle was obtained in un-weeded plots (56.0 and 61.3 grains/panicle in 2015 and 2016, respectively).

The rice grain yield was the highest in pendimethalin *fb* bispyribac sodium *fb* fenoxaprop + chlorimuron + metsulfuron (4.78 and 4.95 t/ha in 2015 and 2016, respectively) followed by two HW at 15 and 30 DAS (4.60 and 4.73 t/ha in 2015 and 2016, respectively). The lowest rice grain yield was recorded in un-weeded plots (0.77 and 0.97 t/ha in 2015 and 2016, respectively). The plots received bispyribac sodium *fb* HW and pendimethalin *fb* HW had recorded considerably higher rice grain yield, yet their effect was less in relation to pendimethalin *fb* bispyribac sodium *fb* fenoxaprop + chlorimuron + metsulfuron and two HW but was superior to other weed management treatments (Table 2). Pendimethalin *fb* bispyribac sodium had recorded the considerably higher rice grain yield (3.9 and 4.0 t/ha in 2015 and 2016, respectively), yet their performance was not superior over pendimethalin *fb* bispyribac sodium *fb* fenoxaprop + chlorimuron + metsulfuron and two HW but was close to bispyribac sodium *fb* HW and pendimethalin *fb* HW, and superior over other treatments. Chlorimuron + metsulfuron gave superior yield than fenoxaprop treated plots of pre- and post-emergent treated plots (pendimethalin and bispyribac sodium) during both the years. Similar to our finding Walia *et al.* (2008) also reported that pendimethalin 750 g/ha *fb* bispyribac sodium 25 g/ha gave 372% yield advantages over un-weeded plots and led to better weed control.

Economic parameters: Economics for the cultivation under different treatments were calculated and presented in Table 2. The cost of cultivation varied from ₹ 24670–38645/ha. The highest cost was involved in two HW at 15 and 30 DAS, whereas the lowest cost incurred with the un-weeded plots. The additional cost due to weed management varied from ₹ 1935 (pendimethalin *fb* chlorimuron + metsulfuron) to 13975 (two HW)/ha. The highest net return and B: C ratio was obtained with pendimethalin *fb* bispyribac sodium *fb* fenoxaprop + chlorimuron + metsulfuron (₹ 40793/ha and 1.44 in 2015 and ₹ 45252/ha and 1.54 in 2016, respectively), whereas negative net return was recorded in un-weeded plots during both the years, with the lowest B: C ratio. A similar finding was corroborated by Mahajan and Chauhan (2015) and Choudhary and Dixit (2018) in direct seeded rice.

From the study, it is concluded that pre-emergence herbicides reduces the germination and growth of some of the grasses and broadleaf weeds, whereas sequential application of bispyribac sodium further suppressed the grasses, broadleaf weeds and sedges. Herbicides may only be used, if weed density are sufficient enough to cause penalty on rice grain yield. Chlorimuron + metsulfuron reduced the broadleaf weeds and sedges, whereas fenoxaprop controlled the grassy weeds. Thus, as per the weed flora either of the herbicide may be used in sequence after using pre- and post-emergence herbicides. However, inclusion of one hand weeding with pre- or post-emergence herbicides provided the best control of weeds.

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