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Efficacy of herbicides in managing *Alternanthera sessilis* (L.) R.Br. ex DC. and other weeds for improving the growth and yield of dry direct-seeded rice

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ABSTRACT

A field study was carried out during (rainy) *Kharif* seasons of 2019 and 2020 at Raipur, Chhattisgarh to study the efficacy of eight herbicide treatments in managing weed community dominated by *Alternanthera sessilis* (L.) R.Br. ex DC. and improving the growth and yield of dry direct-seeded rice. The most dominant weed species was *Alternanthera sessilis* accounting for 70% of the total weed density in weedy check. Other associated weeds were *Echinochloa colona* (L.) Link, *Brachiaria ramosa* (L.) Stapf and *Sporobolus diander* (Retz.) P. Beauv. among grasses and the sedge *Cyperus iria L.* The post-emergence of penoxsulam + cyhalofop–butyl 135 g/ha very effectively controlled the *A. sessilis* and other weeds, produced highest of 5.04 and 4.63 t/ha grain yield and net return of ₹ 71409 and 65563/ha and maximum weed control efficiency among the herbicide-based treatments during 2019 and 2020, respectively. Penoxsulam 22.5 g/ha post-emergence and bispyribac-sodium 25 g/ha post-emergence were also found to be equally effective to it with regards to rice grain yield.

INTRODUCTION

Direct-seeded rice (DSR) is economical and environment friendly crop establishment method with optimal yield potential, when the weed menace is adequately managed (Rao *et al*. 2007). In Chhattisgarh, the area under direct-seeded rice is increasing considerably as higher yields can be attained with lesser cost of cultivation due to the availability of new seeding machinery and proven effective pre-emergence herbicides to manage problematic weeds as the labour availability is becoming scarce and costly for transplanting of rice. Weeds are major constraints hindering adoption of DSR as rice yields are reduced by 35-100% in direct-seeded rice in the absence of proper weed management (Kumar *et al*. 2008) owing to the prevalence of congenial environment during the (rainy) *Kharif* season and the absence of impounding of water to suppress weeds at crop emergence. *Alternanthera sessilis of* Amaranthaceae is one of the world's worst tropical aquatic weeds of South American origin and has invaded all continents except Africa and Europe (Lu *et al*. 2002 and Ye *et al*. 2003). *Alternanthera sessilis* as an invasive aquatic/semi-aquatic perennial weed that rarely sets seeds and sessile and it invades direct-seeded rice too. *Echinochloa colona, Ischaemum rugosum, Cyperus iria, Cyprus difformis, Fimbristylis miliacea* and *Celosia argentea* are very common weeds which cause yield reduction in rice. However, weeds like *Alternanthera* spp. which was not observed earlier in Chhattisgarh area are now dominating the weed flora from last two to three years period and became serious weed of concern causing severe yield reduction. Thus, needs serious attention to evolve methods to manage it. Normally, *Alternanthera sessilis* is a rainy season weed but its presence could be seen even on field bunds, road sides and non-cropped area during *rabi* season too. Therefore, an effective herbicide or a suitable weed management practice to control this weed is essential to avoid rice yield losses due to it. The weed control options available for weed management in rice such as physical control, which is eco-friendly but is tedious and labour intensive and the biological control, by using different bio agents and myco-herbicides, can only be practiced effectively in irrigated lowland condition (Rao *et al.* 2017). Hence, herbicides-based weed management is being considered as the most cost effective and practical method for weed management in direct-seeded rice (Singh *et al.*, 2016). The present study was conducted with an objective to identify the suitable broad-spectrum herbicide for control of diverse weed flora and particularly the dominant *Alternanthera sessilis* in dry directed-seeded rice.

MATERIALS AND METHODS

The present study was carried out during (rainy) *Kharif* season of 2019 and 2020 at all india coordinated research project on weed management, Raipur, Chhattisgarh, India. The soil texture of the experimental field was clayey and neutral (pH 7.1) in reaction with medium fertility having 4.75 g/kg soil OC, low N (201.1 kg/ha), medium available P (14.42 kg/ha) and high available K (328 kg/ha) content. The experiment consisted of 10 treatments replicated 3 times in a randomized block design. The treatments were: pre-emergence application (PE) of pretilachlor 750 g/ha; post-emergence application (PoE) of bispyribac-sodium 25 g/ha, fenoxaprop-p-ethyl 56.25 g/ha PoE; cyhalofop-butyl 80 g/ha PoE; penoxsulam + cyhalofop-butyl (1.02 + 5.1%) (ready-mix) 135 g/ha PoE; penoxsulam 22.5 g/ha PoE; metsulfuron-methyl 20 g/ha PoE; 2,4-D ethyl ester 750 g/ha PoE; weed free by hand weeding thrice at 20, 40 and 60 days after seeding (DAS) and weedy check. The pre-emergence application of pretilachlor was done 3 DAS. The post-emergence application of herbicides was done at 22 days after sowing of rice, except penoxsulam which was applied at 16 DAS. The recommended dose of fertilizers (100:60: 40 N, P and K kg/ha) was used. Nitrogen, phosphorus and potassium were provided to crop by using urea (46 percent N), SSP (16% P) and muriate of potash (60% K), respectively. Half the dose of nitrogen and full dose of phosphorous and potash were applied as basal. The remaining half of nitrogen dose was applied in two split doses, the first split dose applied at active tillering stage and the second split at panicle initiation stage of rice in all the treatments. The test crop rice variety "*Indira Rajeshwari (IGKV R1)*" was directly line sown with a row-to-row distance of 20 cm on 08.07.2019 and 02.07.2020 and harvested on 15.11.2019 and 05.11.2020, respectively. The crop received 975- and 782-mm rainfall during two years.

The data on species wise weed density and biomass were recorded at 60 days after sowing and at harvest of crop with the help of quadrat (0.5 x 0.5 m) at three randomly selected places in each plot and then converted into per square meter. Weeds were cut at ground level, washed with tap water, sun dried and then oven dried at 75^0 C for 48 hours and weighed. Weed control efficiency (WCE) and weed index (%) were calculated by using standard formula suggested by Maity and Mukherjee (2011). The data on various crop growth and yield attributing characters were statistically analyzed as per the standard procedure. Minimum support price (MSP) was used to calculate the economics.

RESULTS AND DISCUSSION

The weed flora of the experimental field consisted of *Echinochloa colona, Brachiaria ramosa and Sporobolus diander* among grasses; *Cyperus iria,* the sedge and *Alternanthera sessilis*, the broad-leaved weed. *Alternanthera sessilis* dominated the weed flora during entire vegetative growth stage. *Brachiaria ramosa and Sporobolus diander* were present during later stages of the crop. The occurrence of other weeds like *Ischaemum rugosum, Cyanotis axillaris,* etc. was uneven with lesser density.

Effect on weed density

Alternanthera sessilis (81.6 and 83.0/m^2) was the predominant weed in weedy check with its density contribution of 74.2 and 71.6% to the total weed density. The pretilachlor 750 g/ha, bispyribac-sodium 25 g/ha and fenoxaprop-p-ethyl 56.25 g/ha and cyhalofop-butyl 80 g/ha could not effectively control *A. sessilis* resulting in higher density of it occurring with those treatments. The lowest density of *A. sessilis* was observed with 2,4-D ethyl-ester 750 g/ha and metsulfuron-methyl 4.0 g/ha during 2019 and 2020. Penoxsulam + cyhalofop-butyl 135 g/ ha and penoxsulam 22.5 g/ha also recorded lesser densities of *A. sessilis* during both the years of the study (**Table 1**). Singh *et al.* (2009) observed that penoxsulam PE at 3 DAT was more effective in reducing *A. sessilis* density compared to its early PoE at 10 DAS.

At all the growth stages, among all the treatment the highest weed density of total weeds was recorded under the weedy check and lowest weed density was noticed under the weed free. The lowest total weed density was observed under the application of penoxsulam + cyhalofop-butyl 135 g/ha (14.2 and 19.0/m^2) followed by penoxsulam 22 g/ha and metsulfuron- methyl 4.0 g/ha at 30 DAS, amongst herbicide-based treatments. The highest total weed density was observed with cyhalofop-butyl 80 g/ha (25.5 and 32.0/m^2). At 60 DAS, among the herbicide-based treatments the lowest total weed density was observed with penoxsulam + cyhalofop-butyl 135 g/ ha (35.4 and 39.0 /m^2) followed by 2,5-D ethyl-ester 750 g/ha, metsulfuron-methyl 4.0 g/ha and bispyribac-sodium 25 g/ha. At harvest, among the herbicide-based treatments, the lowest total weed density was observed with penoxsulam + cyhalofop-butyl 135 g/ha (34.2 and 35.0 /m^2) followed by metsulfuron-methyl 4.0 g/ha and penoxsulam 22 g/ ha. The highest total weed density (82.7 and 87.0 m^2) was observed with cyhalofop-butyl 80 g/ha. Similar observations were made by Yadav *et al.* (2018).

Weed biomass and weed control efficiency

Weed biomass is a better parameter to measure the competition than the weed number (Channappagoudar *et al.* 2013). Reduction in total weed biomass with the application of herbicides is clearly evident by their higher weed control efficiency. Among the herbicides-based treatments, lowest biomass of *A. sessilis* was observed with 2,4-D ethyl-ester 750 g/ha closely followed by penoxsulam 22.5 g/ha and they were at par with the weed free at 30 DAS. The lowest biomass of 12.9 and 14.0 g/m^2 and at harvest 29.1 and 30.2 g/m^2 *A.*

Table1. Density (no./m^2) of *Alternanthera sessilis* and total weeds at 30, 60 days after seeding (DAS) and at harvest as influenced by weed management treatments in dry direct-seeded rice

Treatment	*Alternanthera sessilis*						Total weeds					
	30 DAS		60 DAS		At harvest		30 DAS		60 DAS		At harvest	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Pretilachlor 750 g/ha pre-emergence	3.2 (9.7)	3.4 (11.0)	6.1 (37.0)	6.4 (40.0)	6.1 (36.7)	6.1 (37.0)	4.7 (21.2)	5.1 (25.0)	8.2 (67.05)	8.6 (73.0)	7.8 (60.5)	7.8 (61.0)
Bispyribac-sodium 25 g/ha post-emergence	3.6 (12.1)	3.7 (13.0)	5.92 (34.6)	6.0 (36.0)	6.8 (46.3)	7.0 (48.0)	4.5 (20.0)	5.0 (24.0)	7.3 (52.2)	7.5 (56.0)	8.1 (65.5)	8.3 (69.0)
Fenoxaprop-p-ethyl 56.25 g/ha post-emergence	4.1 (16.0)	4.2 (17.0)	7.61 (57.4)	7.7 (59.0)	7.2 (51.6)	7.3 (53.0)	4.9 (23.8)	5.2 (27.0)	9.7 (94.3)	9.4 (87.0)	8.1 (65.7)	8.4 (70.0)
Cyhalofop-butyl 80 g/ha post-emergence	4.3 (18.0)	4.5 (20.0)	7.54 (56.3)	7.7 (58.0)	7.7 (59.0)	7.8 (60.0)	5.1 (25.5)	5.7 (32.0)	9.1 (83.1)	9.9 (97.0)	9.1 (82.6)	9.4 (87.0)
Penoxsulam + cyhalofop-butyl (ready-mix) 135 g/ha	2.9 (7.9)	3.1 (9.0)	3.87 (14.5)	4.1 (16.0)	4.5 (19.5)	4.1 (16.0)	3.8 (14.2)	4.4 (19.0)	6.0 (35.4)	6.3 (39.0)	5.9 (34.2)	6.0 (35.0)
Penoxsulam 22.5 g/ha post-emergence	2.59 (6.2)	2.92 (8.0)	4.15 (16.7)	4.30 (18.0)	4.58 (20.4)	4.30 (18.0)	4.09 (16.2)	4.53 (20.0)	7.1 (50.3)	7.45 (55.0)	6.44 (41.0)	6.60 (43.0)
Metsulfuron-methyl 4 g/ha early post-emergence	2.01 (3.5)	2.12 (4.0)	3.35 (10.7)	2.35 (5.0)	3.09 (9.04)	2.92 (8.0)	4.24 (17.5)	4.53 (20.0)	6.9 (47.2)	7.11 (50.0)	6.31 (39.3)	6.52 (42.0)
2,4-D ethyl-ester 750 g/ha post-emergence	2.29 (4.7)	2.35 (5.0)	3.58 (12.3)	2.12 (4.0)	3.42 (11.2)	2.74 (7.0)	5.10 (25.5)	5.34 (28.0)	6.6 (43.1)	6.96 (48.0)	7.03 (48.9)	7.31 (53.0)
Weed free	1.58 (2.0)	1.87 (3.0)	1.41 (1.50)	1.58 (2.0)	2.99 (8.45)	3.24 (10.0)	2.12 (4.0)	2.92 (8.0)	1.9 (3.0)	2.74 (7.0)	4.31 (18.1)	4.85 (23.0)
Weedy check	4.36 (18.5)	4.53 (20.0)	7.91 (62.1)	8.09 (65.0)	9.06 (81.6)	9.14 (83.0)	6.12 (37.0)	6.52 (42.0)	9.4 (88.5)	9.77 (95.0)	10.50 (109.8)	10.79 (116.0)

Data in parentheses are original values

Table 2. Weed biomass (g/m^2) of *Alternanthera sessilis* and total weeds at 30, 60 days after seeding (DAS) and at harvest as influenced by weed management treatments in dry direct-seeded rice

Treatment	*Alternanthera sessilis*						Total weeds					
	30 DAS		60 DAS		At harvest		30 DAS		60 DAS		At harvest	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Pretilachlor 750 g/ha pre-emergence	3.7 (12.8)	3.8 (13.7)	6.2 (37.8)	6.3 (39.2)	7.6 (57.9)	7.7 (59.5)	4.7 (22.0)	4.8 (22.7)	8.9 (78.7)	9.0 (80.1)	10.9 (118.4)	11.0 (120.4)
Bispyribac-sodium 25 g/ha post-emergence	4.0 (15.5)	4.2 (17.0)	6.8 (25.1)	5.2 (26.2)	6.9 (47.1)	7.0 (48.7)	5.0 (24.2)	5.2 (26.3)	6.8 (45.5)	6.9 (47.3)	9.3 (86.0)	9.4 (88.2)
Fenoxaprop-p-ethyl 56.25 g/ha post-emergence	4.8 (22.6)	5.0 (24.2)	5.1 (47.2)	7.0 (48.5)	9.3 (85.0)	9.4 (87.0)	5.2 (26.5)	5.3 (27.3)	8.7 (75.1)	8.8 (76.4)	11.2 (125.0)	11.3 (127.1)
Cyhalofop-butyl 80 g/ha post-emergence	4.1 (16.5)	4.3 (18.0)	6.9 (47.7)	7.0 (49.1)	8.9 (78.0)	9.0 (80.0)	5.3 (27.8)	5.4 (29.0)	9.2 (84.0)	9.3 (85.2)	12.2 (149.0)	12.3 (151.3)
Penoxsulam + cyhalofop-butyl (ready-mix) 135 g/ha	1.8 (2.7)	1.8 (2.9)	3.7 (12.9)	3.8 (14.0)	5.3 (27.6)	5.5 (29.4)	4.2 (17.2)	4.3 (18.3)	6.0 (35.2)	6.1 (36.3)	8.1 (65.3)	8.2 (67.0)
Penoxsulam 22.5 g/ha post-emergence	1.8 (2.6)	1.8 (2.8)	3.7 (13.2)	3.9 (14.9)	5.4 (29.1)	5.5 (30.2)	4.7 (21.7)	4.9 (23.0)	7.0 (48.3)	7.1 (50.2)	8.9 (78.0)	8.9 (78.8)
Metsulfuron-methyl 4 g/ha early post-emergence	1.9 (3.3)	2.0 (3.6)	3.8 (13.8)	2.3 (4.6)	5.9 (34.1)	5.1 (25.2)	4.2 (16.8)	4.3 (17.6)	7.8 (60.8)	7.9 (61.9)	10.5 (110.0)	10.6 (112.1)
2,4-D ethyl-ester 750 g/ha post-emergence	1.8 (2.6)	1.8 (2.7)	3.8 (14.2)	2.5 (5.6)	5.5 (30.0)	4.7 (21.5)	4.5 (20.1)	4.7 (21.2)	7.3 (52.3)	7.4 (54.4)	9.8 (95.0)	9.8 (96.4)
Weed free	1.3 (1.3)	1.4 (1.6)	1.5 (1.7)	1.6 (2.1)	2.3 (4.9)	2.6 (6.1)	2.0 (3.5)	2.1 (4.1)	1.7 (2.5)	1.9 (3.1)	2.5 (5.7)	2.6 (6.2)
Weedy check	4.9 (23.5)	5.1 (25.7)	7.0 (49.1)	7.1 (50.4)	9.8 (95.8)	10.0 (98.7)	6.9 (46.7)	7.0 (48.7)	10.8 (115.6)	11.9 (140.2)	14.5 (210.3)	15.5 (238.3)
LSD (p=0.05)	0.4	0.5	0.6	0.6	0.7	0.8	0.6	0.6	0.7	0.9	1.5	1.4

sessilis at 60 DAS was recorded with penoxsulam + cyhalofop-butyl 135 g/ha PoE due to management of both the grassy and non- grassy weeds resulting in maximum weed control efficiency during 2019 and 2020, respectively. It was closely followed by penoxsulam 22.5 g/ha, metsulfuron-methyl 4 g/ha and 2,4-D ethyl ester 750 g/ha. The higher biomass of *Alternanthera sessilis* was recorded with fenoxaprop-p-ethyl 56.25 g/ha and cyhalofop-b-butyl 80 g/ha throughout the growing period as they both could not control the *Alternanthera sessilis.* Similar trend was observed in the total weed biomass at 30 and 60 DAS and at harvest (**Table 2**).

The highest 69.0 and 72.0 % total weed control efficiency (WCE) was achieved with the application of penoxsulam + cyhalofop-butyl 135 g/ha PoE, during 2019 and 2020, respectively, followed by penoxsulam 22.5 g/ha PoE and bispyribac-sodium 25 g/ha PoE at harvest. The highest weed control efficiency was observed with penoxsulam + cyhalofop-butyl (ready-mix) PoE was due to its broad-spectrum effect against diverse weed flora as compared to application of the component herbicides alone. The application of penoxsulam 22.5 g/ha PoE at 16 DAS coincided with the 2-3 leaf stage of weeds at which the weed is most susceptible to the herbicide and thus resulted in greater weed control efficiency. The fenoxaprop-p-ethyl 56.25 g/ha PoE and cyhalofop-butyl 80 g/ha PoE were not effective on *A. sessilis* and showed very less WCE at 60 DAS and at harvest as compared to the other herbicides tested (**Table 3**). The lowest control efficiency of 29.1 and 36.5% was recorded with cyhalofop-butyl 80 g/ha PoE during 2019 and 2020, respectively due to lower percentage reduction in total weed density and biomass as reported earlier by Singh *et al.* (2014). Weed index refers to the reduction in crop yield due to the presence of weeds in comparison to weed-free crop. The unmanaged weeds in weedy check caused the maximum yield loss of 65.0 and 81.1% during 2019 and 2020, respectively when compared to maximum grain yield recorded. Penoxsulam + cyhalofop-butyl 135 g/ha PoE; bispyribac-sodium 25 g/ha PoE and penoxsulam 22.5 g/ha PoE recorded minimum yield loss due to weeds when compared to the rest of the herbicide-based treatments.

Effect on rice grain yield

The highest grain yield of 5.04 and 4.63 t/ha was achieved with the application of penoxsulam + cyhalofop-butyl 135 g/ha PoE which was at par with weed free treatment 5.08 and 4.98 t/ha, the yield during 2019 and 2020, respectively. The bispyribac-sodium 25 g/ha PoE and penoxsulam 22.5 g/ha PoE have also recorded comparable yield to that of penoxsulam+ cyhalofop-butyl 135 g/ha (ready-mix) PoE (**Table 4**). The efficacy of penoxsulam was reported by Mishra *et al*. (2007). The lower weed biomass at 60 DAS and at harvest resulted in higher grain yields due to greater number of tillers with these three herbicidal treatments because of lesser competition with weeds at critical stages of plant growth and lesser removal of nutrients by weeds from soil. The grain yield of rice decreased by 25-28%, if *A. sessilis* was not controlled effectively as observed with pretilachlor 750 g/ha PE, fenoxaprop-p-ethyl 56.25 g/ha PoE and cyhalofop-butyl 80 g/ha PoE as reported earlier also by Bahar and Singh (2004). The grain yield losses due to uncontrolled *A. sessilis* in rice was also reported by Yi (1992) and Zhang *et al*. (2004). The ineffectiveness of fenoxaprop-p-ethyl 60 g/ ha PoE in controlling broad-leaved weeds was reported earlier by Mishra and Singh (2008) who observed a decrease (60%) in dry-

Table 3. Weed control efficiency and weed index as affected by different weed management treatments in dry direct-seeded rice

Treatment	Weed control efficiency (%)								Weed index (%)	
	Alternanthera sessilis				Total weeds					
	60 DAS		At harvest		60 DAS		At harvest			
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Pretilachlor 750 g/ha pre-emergence	23.0	22.2	39.6	39.7	31.9	42.9	43.7	49.5	24.6	41.0
Bispyribac-sodium 25 g/ha post-emergence	48.9	48.0	50.8	50.7	60.6	66.3	59.1	63.0	8.9	14.7
Fenoxaprop-p-ethyl 56.25 g/ha post-emergence	3.9	3.8	11.3	11.9	35.0	45.5	40.6	46.7	26.4	54.0
Cyhalofop-butyl 80 g/ha PoE	2.9	2.6	18.6	18.9	27.3	39.2	29.1	36.5	28.3	59.0
Penoxsulam + cyhalofop-butyl 135 g/ha post-emergence	73.7	72.2	71.2	70.2	69.6	74.1	69.0	72.0	0.8	7.0
Penoxsulam 22.5 g/ha post-emergence	73.1	70.4	69.6	69.4	58.2	64.2	62.9	67.0	8.5	16.9
Metsulfuron-methyl 4 g/ha early post-emergence	71.9	90.9	64.4	74.5	47.4	55.8	47.7	53.0	22.0	28.5
2,4-D ethyl-ester 750 g/ha post-emergence	71.1	88.9	68.7	78.2	54.8	61.2	54.8	59.5	20.5	19.7
Weed free	96.5	95.8	94.9	93.8	97.8	97.8	97.3	97.4	-	-
Weedy check	0	0	0	0	0	0	0	0	65.0	81.1

DAS: Days after seeding

Table 4. Effective tillers, grain yield, net return and B:C ratio as influenced by different weed management treatments in dry direct-seeded rice

Treatment	Effective tillers/m row length		Grain yield (t/ha)		Net return ($x10^3$ `/ha)		B:C ratio	
	2019	2020	2019	2020	2019	2020	2019	2020
Pretilachlor 750 g/ha pre-emergence	52.0	51.0	3.83	2.94	51.93	35.22	4.09	2.8
Bispyribac-sodium 25 g/ha post-emergence	58.3	51.9	4.63	4.25	66.50	59.53	4.82	4.0
Fenoxaprop-p-ethyl 56.25 g/ha post-emergence	53.7	49.3	3.74	2.29	50.17	23.01	4.03	2.2
Cyhalofop-butyl 80 g/ha PoE	50.7	47.6	3.64	2.04	48.62	18.34	3.90	1.9
Penoxsulam + cyhalofop-butyl 135 g/ha post-emergence	60.7	53.9	5.04	4.63	71.41	65.56	4.89	4.2
Penoxsulam 22.5 g/ha post-emergence	58.3	53.7	4.65	4.14	66.65	56.97	4.60	3.8
Metsulfuron-methyl 4 g/ha early post-emergence	57.3	51.4	3.96	3.56	55.20	47.50	4.23	3.5
2,4-D ethyl-ester 750 g/ha post-emergence	57.4	51.7	4.04	4.00	56.40	55.47	4.28	3.9
Weed free	62.3	54.0	5.08	4.98	66.02	64.76	3.13	3.6
Weedy check	23.3	21.1	1.78	0.94	14.37	-0.70	2.02	-1.0
LSD (p=0.05)	3.8	3.5	0.47	0.31	-	-	-	-

seeded rice yield when *A. sessilis* and other weeds competed with rice up to maturity.

The economics

The maximum net return of ₹ 71409 and 65,563/ha and highest B:C of 4.89 and 4.2 was recorded with penoxsulam + cyhalofop-butyl 135 g/ha PoE during 2019 and 2020, respectively followed by bispyribac-sodium 25 g/ha amongst the herbicides. Although the net return obtained with weed free treatment was higher than the most of the herbicides except penoxsulam + cyhalofop-butyl 135 g/ha, weed free has recorded lower benefit: cost ratio as compared to the herbicidal treatments because of the higher wages of labour and cost incurred on labour to keep it weed free used in this treatment.

Based on two years field experimentation, it was concluded that penoxsulam + cyhalofop-butyl (ready-mix) 133 g/ha PoE applied at 22 DAS under saturated moist field conditions appreciably reduced the density of *Alternanthera sessilis* and other weeds and produced significantly higher grain yield of dry direct-seeded rice and net return compared to rest of the treatments.

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