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Effect of different weed management options on weed flora, rice grain yield and economics in dry direct-seeded rice

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ABSTRACT

The shift in the method of rice establishment from traditional manual transplanting of seedlings to direct seeding has occurred in many Asian countries including India. Weeds are the most important biotic constraint in dry direct-seeded rice (dry-DSR) production. Field experiments were carried out during 2015-16 and 2016-17 at Pandit Jawaharlal Nehru College of Agriculture & Research Institute, Karaikal, and Puducherry UT, India to study the effect of different weed management options on the diverse weed flora, rice grain yield and economics in dry-DSR under unpuddled condition. The grassy weeds dominated the weed flora, with 86.12% relative density of *Echinochloa colona* (L). Link. The sequential application of pendimethalin and bispyribac-sodium herbicides (1000 *fb* 25 g/ha) with a manual weeding in 40 days after sowing (DAS) reduced total weed density (14.4 /m^2) and biomass (37 g/m^2), resulted in better rice growth (plant height and tillers/m^2), yield parameters (panicle weight and 1000 grain weight) and higher rice grain yield (3.86 t/ha). Negative linear relationship was observed between rice grain yield and total weed biomass at 80 DAS. Uncontrolled weeds caused 68.3% dry-DSR yield loss. Pre-emergence pendimethalin 1.0 kg/ha application integrated with manual weeding with or without bispyribac-sodium application and manual weeding thrice recorded higher B: C ratio in deltaic coastal ecosystem of Karaikal, Puducherry UT.

INTRODUCTION

Rice is the most important food crop of India and provides food for half of the world population. Insufficient water availability, early maturing modern crop varieties, inexpensive and cost-efficient herbicides along with enhanced labour costs, labour shortage during peak planting season (Chauhan 2012), and declining profitability of rice production have encouraged many rice farmers in South-East Asian countries including India to shift from transplanting to direct-seeding (Rao *et al.* 2017a).

Direct-seeded rice (DSR) production system is subject to greater weed pressure than conventional rice transplanting systems, in which weeds are suppressed by flooding and transplanted rice seedlings have a "head start" over germinating weed seedlings (Moody 1983, Rao *et al.* 2007). Direct-seeding is practiced in two major ways, *viz.* wet-seeding and dry-seeding (Rao *et al.* 2017b). In wet-seeded rice, pre-germinated seeds are broadcasted onto the puddled soil. However, in dry direct-seeding of rice (dry-DSR), non pre-germinated seeds are sown onto dry-ploughed, unpuddled dry or moist soil. The major constraint for higher productivity in dry-DSR is weeds. Failure to manage the weeds result in 50 to 90% rice yield loss (Rao *et al.* 2007, Chauhan and Jhonson 2011). Generally farmers resort to single application of either pre or post-emergence herbicides which fail to manage the diverse spectrum of weeds in dry-DSR. The work is limited with regard to sequential/tank-mix application of herbicides or mechanical weeding in dry-DSR of the deltaic coastal ecosystem of Karaikal, Puducherry UT. Hence, a two year field experiment was conducted to evaluate the efficacy of varying weed management options to manage the weeds in dry-DSR at Karaikal, Puducherry UT, India.

MATERIALS AND METHODS

A field study was conducted for two years (September 2015 to January 2016 and September 2016 to January 2017) at research farm of Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal, Puducherry (11° 56' N latitude, 79° 53' E longitude, 4 m above mean level), India. The climate is sub-tropical, with an annual average rainfall of 1200 mm (75-80% of which is received due to North-East monsoon from October to December) with minimum temperature (23-28°C) in January and maximum temperature (33-38°C) in June. The soil at the experimental site was sandy clay loam in texture, near neutral in reaction (pH: 6.94), low in available nitrogen (119 kg/ha) and high in available phosphorus (24 kg/ha) and potassium (366 kg/ha).

The experiment in both years was arranged in randomized complete block design with three replications. Ten treatments were included to evaluate different weed management options in DSR, *viz*. bispyribac-sodium 25 g/ha at 20 DAS, pendimethalin *fb* bispyribac-sodium (1000 *fb* 25 g/ha) at 3 *fb* 20 DAS, oxadiargyl *fb* bispyribac-sodium (100 *fb* 25 g/ha) at 3 *fb* 20 DAS, pyrazosulfuron *fb* bispyribac-sodium (20 *fb* 25 g/ha) at 3 *fb* 20 DAS, pendimethalin *fb* bispyribac-sodium (1000 *fb* 25 g/ha) *fb* manual weeding at 3 *fb* 20 *fb* 40 DAS, pendimethalin (1000 g/ha) *fb* manual weeding at 3 *fb* 40 DAS, bispyribac-sodium + (chlorimuron + metsulfuron) 20 + 4 g/ha at 20 DAS, mechanical weeding thrice at 20,40 and 60 DAS, manual weeding thrice at 20,40 and 60 DAS and unweeded control.

Rice (cultivar '*ADT 46*' with duration of 135 days) was dry-seeded in the first week of September and harvested during the second week of January. Disc harrow was used twice to cultivate and wooden board was used to level the experimental field, respectively. Manual seeding was done with seed rate of 75 kg/ha at 25 cm inter - row spacing. The size of the experimental plots was 5 x 4 m. The field was surface irrigated immediately after the sowing with the water available in the farm ponds, in order to have enough moisture at pre-emergence herbicide application. Herbicides were applied using a knapsack sprayer fitted with a flat fan nozzle with water as a carrier at 500 L/ha for pre-emergence spray and 375 L/ha for post-emergence spray. Mechanical weeding was carried out in the experimental plots using the manually operated garden and weeder at 20 and 40 DAS and rice cono weeder at 60 DAS in the experimental plots due to the rainfall received from the North-East monsoon. Phosphorus (50 kg/ha) and potassium (50 kg/ha) were applied basal. The nitrogen (150 kg/ha) was applied at three equal splits starting from 20 DAS. Recommended rates of chlorpyriphos insecticide was used to manage insects and no major disease was observed during both the years of the experimentation. Pre-emergence and post-emergence herbicides were used as per the treatment. Weed density at 80 DAS was recorded using two quadrats (0.5 x 0.5 m) placed randomly in each plots. The composition of the weed flora in the unweeded control treatment was observed from composite weed samples using the quadrats and the relative density (RD) was computed using standard formula. Weeds were cut at ground level during weed observation at 80 DAS, washed with running water, sun dried, oven dried at 70°C for 48 h, and then weighed to record weed biomass. Rice grain yield was measured from the net plot leaving the border rows and expressed in t/ha at 14% moisture content.

Square root transformation ($\sqrt{x+0.5}$) was performed for the data on weed density and biomass before analyses. Unless indicated otherwise, differences were considered significant only at $p< 0.05$. The relationships between grain yield and weed biomass at 80 DAS were assessed using linear regression analysis. Experimental data were subjected to statistical scrutiny as per the procedures given by Panse and Sukhatme (1967).

RESULTS AND DISCUSSION

Weed floristic composition

Experimental field infested with diverse weed flora comprised of grasses sedge and broad-leaved-weeds. Analyses of the relative density revealed that *Echinochloa colona* was the major weed species (86.12%) in the experimental field which was followed by *F. miliaceae* (7.93%) and *L. chinensis* (3.28%). Previous studies revealed that DSR favors the growth of *E. colona* (Chauhan and Jhonson 2011), *L. chinensis* (Singh *et al*. 2005) and *Fimbristylis miliacea* (Azmi and Mashhor 1995). Rao *et al*. (2007) indicated that adaptation of *Echinochloa* species under the conditions of DSR is possibly due to the germination variability of their seeds and establishment in response to imposed water regime.

Weed density

E. colona density (4.3 and 9.8/m^2) has significantly reduced due to sequential application of pendimethalin *fb* bispyribac-sodium application integrated with manual weeding and the density reduction was found to be 97.9 and 95.3% compared to the unweeded control (**Table 1**). Lower density of *E. colona* was noticed under other sequential (pendimethalin *fb* bispyribac-sodium and pyrazosulfuron *fb* bispyribac-sodium) herbicide applications also. Persistence nature of pendimethalin herbicide is due to its half life period of 10.5 to 44 days depending upon soil temperature and moisture (Ramirez and Plaza 2015), which has potential to control grasses and in particular, *E. colona*. Khaliq and Matloob (2012) reported that pre-emergence pendimethalin application effectively controlled the density of jungle rice. Escape of *E. colona* population in the intra-row space during the operation of mechanical weeder led to its poor control and resulted in higher density of *E. colona* population (155.8/m^2) compared to the rest of the treatments.

The density of *Leptochloa chinensis* was significantly higher with the application of bispyribac-sodium alone (20.7/m^2). But, tank mix application of bispyribac –sodium +(chlorimuron + metsulfuron) improved the control of *L. chinensis* (10.7 /m^2). All other weed management treatments found to be effective in managing this weed compared to unweeded control. An earlier study revealed that bispyribac-sodium was ineffective against *L. chinensis* (Mahajan and Chauhan, 2013). *F. miliaceae* population was significantly lower with treatments received the single or sequential application of herbicides involving bispyribac-sodium. The number of *F. miliaceae* was higher with mechanical weeding thrice, unweeded control (19.3/m^2 each) and manual weeding twice (7.2/m^2) compared to rest of the treatments. Begum *et al.* (2008) indicated that ALS inhibitor bispyripac-sodium gave good control of *F. miliaceae* population in rice. The relative density of broadleaved weed population was less than 3% of the total weed flora and they were not significantly influenced by any of the weed management treatments. Further, the total weed density also followed the similar trend of *E. colona* (**Table 1**).

Weed biomass and weed control efficiency

The weed biomass was significantly influenced by weed management treatments except the broad-leaved weeds (BLW). Weed biomass ranged from 2.0- 158.0 g/m^2 in grasses, 0.1-6.0 g/m^2 in sedge, 0.1 – 3.8 g/m^2 in BLW and 3.7- 166.5 g/m^2 in total weed biomass. Sequential application of pendimethalin *fb* bispyribac-sodium herbicides integrated with manual weeding effectively reduced the grass and total biomass (2.0 and 3.7 g/m^2, respectively) whereas sequential application of oxadiargyl *fb* bispyribac-sodium and tank mix application of bispyribac-sodium + (chlorimuron + metsulfuron) recorded lower sedge and BLW biomass (0.1 g/m^2, respectively). Earlier studies also revealed that sequential application of pre- and post-emergence or tank mix herbicides is more effective against diverse weed flora (Singh *et al.* 2010, Choudhary and Dixit 2018). Total weed biomass was higher with unweeded control and mechanical weeding thrice (166.5 and 109.9 g/m^2). Cherati *et al.* (2011) reported that employing manually operated mechanical weeders for weed management resulted in higher weed biomass in rice crop.

Weed control efficiencies influenced due to weed biomass recorded in various treatments (**Table 2**). Higher weed control efficiency (97.7%) was recorded with sequential application of pendimethalin *fb* bispyribac-sodium herbicides integrated with manual weeding, which was followed by the manual weeding thrice (94.4%). However, plots treated with pre-emergence pendimethalin with or without bispyribac-sodium were comparable to each other (88-94%) but lower weed control efficiency was observed with mechanical weeding using weeders (34%). Singh *et al.* (2010) opined that herbicide combination widens the spectrum of weed control. The results of current study are also in agreement with earlier findings of better weed suppression with proper use of both pre- and post-herbicides in DSR (Chauhan 2012).

Rice growth, yield and economics

The rice plant height and tillers/m^2 were significantly ($p<0.05$) influenced by weed management treatments (**Table 3**). The sequential herbicide application of pendimethalin and bispyribac-sodium integrated with manual weeding and manual

Table 1. Effect of varying weed management treatments on weed density at 80 DAS in dry direct- seeded rice (mean data of two years)

Treatment	Weed density (no./m^2)								
	E. colona	*L. chinensis*	*F. meliaceae*	*L. perennis*	*B. capensis*	*S. indicus*	*E. alba*	*M. quadrifolia*	Total weeds
Bispyribac-sodium	5.50(28.8)	4.91(20.7)	1.91(2.0)	2.32(3.7)	2.12(3.0)	2.01(4.5)	0.50(0.0)	1.52(2.0)	8.5(64.7)
Pendimethalin *fb* bispyribac-sodium	4.14(13.7)	1.65(2.0)	1.58(3.5)	1.85(1.8)	0.74(0.2)	1.65(2.0)	0.97(0.7)	1.65(2.0)	5.5(25.9)
Oxadiargyl *fb* bispyribac-sodium	4.84(19.8)	0.50(0.0)	1.08(1.0)	2.42(5.7)	0.97(0.7)	2.16(4.7)	1.50(1.7)	1.17(1.3)	6.4(34.9)
Pyrazosulfuron *fb* bispyribac-sodium	4.45(17.5)	0.50(0.0)	1.08(1.0)	1.55(1.7)	0.74(0.2)	2.26(6.0)	1.17(1.3)	0.74(0.2)	5.5(27.9)
Pendimethalin *fb* bispyribac-sodium *fb* manual weeding	2.51(4.3)	0.97(0.7)	1.69(2.2)	1.91(2.0)	1.21(1.5)	1.97(3.7)	0.50(0.0)	0.50(0.0)	4.2(14.4)
Pendimethalin *fb* manual weeding	3.63(9.8)	0.50(0.0)	1.85(3.0)	2.27(5.0)	1.57(1.8)	1.91(2.0)	1.74(2.3)	0.97(0.7)	5.4(24.6)
Bispyribac-sodium + (chlorimuron + metsulfuron)	6.37(35.2)	3.57(10.7)	1.21(0.8)	1.36(1.2)	0.83(0.3)	1.93(2.2)	1.32(2.0)	0.97(0.3)	7.7(52.7)
Mechanical weeding thrice	13.0(155.8)	1.17(1.3)	4.78(19.3)	1.17(1.3)	0.50(0.0)	1.17(1.3)	2.17(5.0)	0.50(0.0)	14.0(184.0)
Manual weeding thrice	4.48(16.7)	1.17(1.3)	3.01(7.2)	0.50(0.0)	2.07(5.5)	2.22(4.7)	2.02(2.8)	0.50(0.0)	6.6(38.2)
Unweeded control	15.0(210.0)	2.70(8.0)	4.47(19.3)	1.41(1.3)	1.08(1.0)	1.78(2.5)	1.44(1.3)	0.83(0.3)	16.0(243.7)
LSD (p=0.05)	2.07	1.91	2.33	NS	NS	NS	NS	NS	2.27

LSD, least significant difference, DAS- Days after sowing; Figures in parentheses were original values weeding thrice resulted in taller rice plants with more tillers (114.8 and 108.9 cm; 464.6 and 408.2 tillers/m^2). Closure of canopy might have occurred due to better competitive ability and nutrient use-efficiency in weeds managed environment. The shorter rice plants with lesser number tillers were recorded in unweeded control (88.4 cm and 251.5 tillers). Azmi and Mashhor (1995) indicated that plant height of rice was significantly reduced when weeds were allowed to compete.

Grain yield of rice was significantly ($p<0.05$) influenced by weed management treatments during 2015-16 and 2016-17 (**Table 3**). During both the years, the highest grain yield was observed with sequential application of pre- and post-emergence application of pendimethalin and bispyribac-sodium herbicides integrated with manual weeding (3.84 and 3.88 t/ha) and the lowest in the unweeded control (1.12 and 1.33 t/ha). Average of two years data indicated that rice grain yield obtained from the plots treated with sequential/tank-mix application of herbicides or manual weeded thrice ranged from 2.86 to 3.86 t/ha and three mechanical weeding and unweeded plots ranged from 1.23 to 2.09 t/ha. Grain yield was statistically comparable with manual weeding thrice (3.61t/ha) and application of pre-emergence pendimethalin integrated with manual weeding once (3.56 t/ha). The response for the panicle weight and 1000 grain weight was similar to that observed for grain yield (**Table 3**). Poor filling of grains and less panicle weight under unweeded control may be due to the vigorous crop-weed competition for growth factors like nutrient, space, light and carbon dioxide (Tindall *et al*. 2005). Rice grain yield and total dry weight at 80 DAS showed negative linear relationship with co-efficient of determination of 0.949 (**Figure 1**). Current study clearly indicated that weed interference contributed to the negative influence on the growth and yield attributes of the crop, which cumulatively reduced the grain yield of dry-DSR. Uncontrolled weeds resulted in 68.3% yield reduction in dry-DSR. Earlier, rice yield loss to the tune of 86.3 was recorded in DSR at Karaikal, Puducherry UT (Saravanane *et al*. 2016).

Table 2. Effect of varying weed management treatments on weed biomass and weed control efficiency at 80 DAS in dry direct-seeded rice (mean data of two years)

Treatment	Weed biomass (g/m^2)				Weed control efficiency(%)
	Grasses	Sedges	BLW	Total	
Bispyribac-sodium	9.04 (77.6)	1.22 (0.9)	2.26(3.1)	11.52 (81.6)	51.0
Pendimethalin *fb* bispyribac- sodium	4.75 (18.4)	1.03 (0.8)	1.21 (0.7)	4.93 (19.9)	88.0
Oxadiargyl *fb* bispyribac- sodium	7.90 (58.7)	0.57 (0.1)	1.73 (1.8)	8.02 (60.6)	63.7
Pyrazosulfuron *fb* bispyribac- sodium	6.35 (45.7)	1.07 (0.5)	1.05(0.9)	6.56 (47.1)	71.7
Pendimethalin *fb* bispyribac- sodium *fb* manual weeding	1.63 (2.0)	0.94 (0.2)	1.70 (1.5)	2.41 (3.7)	97.7
Pendimethalin *fb* manual weeding	2.55 (4.7)	1.68 (1.4)	2.43 (3.8)	3.61 (9.9)	94.0
Bispyribac-sodium + (chlorimuron + metsulfuron)	7.19 (48.0)	0.95 (0.3)	0.70 (0.1)	7.21 (48.4)	71.1
Mechanical weeding thrice	10.78 (106.4)	1.50 (2.3)	1.53 (1.2)	10.96 (109.9)	34.0
Manual weeding thrice	2.84 (7.0)	1.18 (0.8)	1.64 (1.5)	3.26 (9.3)	94.4
Unweeded control	12.99 (158.0)	2.80 (6.0)	2.02 (2.5)	13.30 (166.5)	-
LSD (p=0.05)	3.79	1.18	0.92	3.67	

LSD, least significant difference, DAS- Days after sowing; the figures in parentheses were original values; BLW = Broad-leaved weeds

Table 3. Effect of varying weed management treatments on growth, yield and economics in dry direct-seeded rice (mean data of two years)

Treatment	Plant height (cm)	Tillers $/m^2$	Panicle weight (g)	1000-seed weight (g)	Grain yield (t/ha)			Weed index	GR (x 10^3/ ha)	NR (x 10^3/ ha)	B: C ratio		
					2015 -16	2016 -17	Mean				2015 -16	2016 -17	Mean
Bispyribac-sodium	105.2	398.4	2.01	24.05	2.60	2.60	2.60	32.6	52.60	27.28	0.96	1.18	1.07
Pendimethalin *fb* bispyribac- sodium	111.0	402.4	2.40	23.44	2.86	3.50	3.18	17.7	63.67	36.72	1.02	1.66	1.34
Oxadiargyl *fb* bispyribac- sodium	110.9	386.4	2.21	23.47	3.20	2.82	3.01	22.2	59.08	32.63	1.28	1.20	1.24
Pyrazosulfuron *fb* bispyribac- sodium	113.0	387.8	2.33	23.39	3.04	2.76	2.90	24.9	58.91	32.89	1.25	1.27	1.26
Pendimethalin *fb* bispyribac- sodium *fb* manual weeding	114.8	464.6	2.86	24.46	3.84	3.88	3.86	-	77.52	47.78	1.45	1.75	1.60
Pendimethalin *fb* manual weeding	111.1	405.5	2.60	24.43	3.67	3.45	3.56	07.8	71.32	43.74	1.51	1.65	1.58
Bispyribac-sodium + (chlorimuron + metsulfuron)	104.5	382.9	2.12	24.03	2.80	2.48	2.64	31.6	52.99	27.15	1.03	1.07	1.05
Mechanical weeding thrice	98.8	307.4	2.07	23.96	1.85	2.33	2.09	46.0	41.95	16.80	0.37	0.93	0.65
Manual weeding thrice	108.9	408.2	2.68	24.61	3.53	3.69	3.61	06.7	72.63	42.43	1.21	1.59	1.40
Unweeded control	88.4	251.5	1.57	22.92	1.12	1.33	1.23	68.3	24.29	1.14	-0.08	0.16	0.04
LSD (p=0.05)	7.36	69.9	0.40	0.91	0.77	0.72	0.40	-	-	-	-	-	-

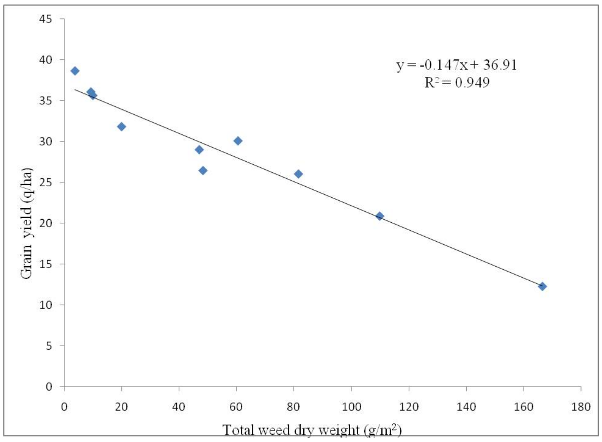

Figure 1. The relationship between grain yield and total weed biomass at 80 DAS

Pre-emergence pendimethalin 1.0 kg/ha application integrated with manual weeding with or without bispyribac-sodium application recorded higher benefit- cost ratio, which ranged between 1.45 to 1.51 and 1.65 to 1.75 during 2015-16 and 2016-17, respectively. Average of two years data indicated that manual weeding thrice (1.40) was also the other best option compared to other treatments (**Table 3**). These results are in conformity with earlier observations that herbicides used in combination with manual weeding were most economical (Rao and Ladha 2014, Saravanane *et al*. 2016).

It was concluded that farmers can opt for pre-emergence pendimethalin 1.0 kg/ha application integrated with manual weeding with or without bispyribac-sodium application in labour scarcity areas or manual weeding thrice at 20, 40 and 60 DAS in labour sufficient areas to effectively manage the diverse weed flora, enhance rice yield with better benefit- cost ratio in dry-DSR of the deltaic coastal ecosystem of Karaikal, Puducherry UT.

REFERENCES

Azmi M and Mashhor M. 1995. Weed succession from transplanting to direct-seeding method in Kemubu rice area, Malaysia. *Journal of Bioscience* **6**(2): 143–154.

Begum M, Juraimi AS, Amartalingum SR, Omar S and Man AB. 2009. Effect of *Fimbristylis miliacea* competition with MR220 rice in relation to different nitrogen levels and weed density. *International Journal of Agriculture and Biology* **11**: 183–187.

Chauhan BS and Johnson DE. 2011. Growth response of direct seeded rice to oxadiazon and bispyribac-sodium in aerobic and saturated soils. *Weed Science* **59**(1): 119–122.

Chauhan BS. 2012. Weed ecology and weed management strategies for direct-seeded rice in Asia. *Weed Technology* **26**: 1–13.

Cherati FE, Bahrami H and Asakereh A. 2011. Evaluation of traditional, mechanical and chemical weed control methods in rice fields. *Australian Journal of Crop Science* **5**(8): 1007–1013.

Choudhary VK and Dixit A. 2018. Herbicide weed management effect on dynamics, crop growth and yield in direct-seeded rice. *Indian Journal of Weed Science* **50**(1): 6–12.

Khalik A and Matloob A. 2012. Germination and growth response of rice and weeds to herbicides under aerobic conditions. *International Journal of Agriculture and Biology* **14**: 775–780.

Mahajan G and Chauhan BS. 2013. The role of cultivars in managing weeds in dry-seeded rice production systems. *Crop Protection* **49**: 52–57.

Moody K. 1983. The status of weed control in Asia. *FAO Plant Protection Bulletin* **30**: 119–120.

Panse VG and Sukhatame PU 1967. *Statistical Methods for Agricultural Workers*. ICAR, New Delhi.

Ramirez JG and Plaza G. 2015. Effect of post-emergence herbicide applications on rice crop weed communities in Tolima, Colombia. *Planta Daninha* **33**(3): 499–508.

Rao AN and Ladha JK. 2014. Economic weed management approaches for rice in Asia. pp. 500–509. In: *Proceedings of 24th Asian-Pacific Weed Science Society Conference*, October 22-25, 2013, Bandung, Indonesia.

Rao AN, Jhonson DE, Sivaprasad B, Ladha JK and Mortimer AM. 2007. Weed management in direct-seeded rice. *Advances in Agronomy* **93**: 153–255.

Rao AN, Wani SP, Ahmed S, Ali HH and Marambe B. 2017a. An overview of weeds and weed management in rice of south asia. pp. 247–281. In: *Weed management in Rice in the Asian-Pacific Region* (Eds. Rao AN and Matsumoto H). APWSS; The Weed Science Society of Japan, Japan and Indian Society of Weed Science, India.

Rao AN, Wani SP, Ramesha MS and Ladha JK. 2017b. Rice Production Systems. pp. 185–205, In: *Rice Production Worldwide*. (Eds. Chauhan BS, Jabran K and Mahajan G), Springer International Publishing AG 2017 185. DOI 10.1007/978-3-319-47516-5_8.

Saravanane P, Mala S and Chellamuthu V. 2016. Integrated weed management in aerobic rice. *Indian Journal of Weed Science* **48**(2): 152–154.

Singh VP, Singh G, Singh RK, Singh SP, Kumar A, Dhayani VC, Kumar M and Sharma G. 2005. Effect of herbicides alone and in combination on direct seeded rice. *Indian Journal of Weed Science* **37**(3&4): 197–201.

Singh RG, Singh S, Singh V and Gupta RK. 2010. Efficacy of azimsulfuron applied alone and tank mixed with metsulfuron + chlorimuron (almix) in dry direct-seeded rice. *Indian Journal of Weed Science* **42**: 168–172.

Tindall KV, Williams BJ, Stout MJ, Geaghan JP, Leonard BR and Webster EP. 2005. Yield components and quality of rice in response to graminaceous weed, weed density and rice stink bug population. *Crop Protection* **24**: 991–998.