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Sesbania, Azolla and herbicide use for weed management and optimizing yield in direct-seeded rice

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ABSTRACT

The experiment was conducted at Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj (U.P.) during *Kharif* seasons of 2009 and 2010 to assess the performance of direct-seeded rice as influenced by *Sesbania*/ *Azolla* with nitrogen levels and herbicide use for managing weeds and optimizing the yield of direct-seeded rice (DSR). Weed density and dry weight were consistently lower with *Azolla* culture than with *Sesbania* during initial crop growth stages, however, they were similar at 90 days after sowing (DAS). Among weed management practices, pretilachlor (with safener) at 0.3 kg /ha at 2 DAS as pre-emergence application followed by (*fb*) hand weeding (HW) at 45 DAS was effective in controlling weeds and increasing the grain yield of DSR, which resulted in higher net returns and benefit cost ratio than HW twice at 20 and 45 DAS. The higher yields were recorded under *Sesbania* and *Azolla* than DSR (sole) crop. *Sesbania Azolla* + 100% recommended dose of nitrogen with pretilachlor (with safener) 0.3 kg /ha at 2 DAS as pre-emergence application *fb* HW at 45 DAS recorded lower weeds density, dry weight and higher economic returns in direct-seeded rice.

INTRODUCTION

Water crises and shortage of labour at critical times as well as hike in wage rates (Mishra *et al*. 2019), threatens the sustainability of transplanted rice in India. Direct-seeded rice (DSR) system has various advantages over transplanted rice in terms of less water (35-57%) and labour (up to 67%) requirement (Choudhary 2018, Arya and Syriac 2018). However, performance of DSR depends on effective weed control (Brar and Bhullar 2012), because there is no seedling size advantage as in transplanted rice and weed seedlings and crop plants emerge concurrently as well as no standing water to conquest weed emergence and growth at crop emergence. Weeds in DSR can cause a huge yield loss (up to 95%) in India (Choudhary 2018). Manual weeding is becoming less common because of not availability of labor at critical time and increased labour costs (Choudhary 2018, Arya and Syriac 2018, Mishra *et al*. 2019). Herbicides are replacing manual weeding as they are easy to use, economical and practicable; however, there are also worries about the sole use of herbicides, such as evolution of herbicide resistance in weeds, shifts in weed populations, and concerns about the environment (Arya and Syriac 2018).

Raising *Sesbania* or *Azolla* conjointly with DSR, and incorporating them at 35-40 days of growth has revealed increase in rice yield and profitability with assured adding of organic matter and weed suppression (Singh Kumarjit *et al*. 2005, Ravisankar *et al*. 2008, Anitha and Mathew 2010, Subramanian *et al*. 2011). Though, the potential for exploiting *Sesbania*/ *Azolla* to smother or suppress weeds and the efficacy of herbicide are needed to formulate integrated weed management strategies in DSR. Therefore, this study was conducted to compare the effects of *Sesbania*, *Azolla* and herbicide use in DSR (drum seeded unpuddled) for managing weeds and optimizing the yield.

MATERIALS AND METHODS

The experiment was conducted during rainy (*Kharif*) seasons of 2009 and 2010 at the Crop Research Farm of Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj

(U.P.) India. The annual average rainfall and temperature of the region range from 1000 to 1200 mm and from 5^0C to 45^0C, respectively. The soil was sandy loam in texture with pH 8.4; organic carbon 0.54%; available N 208.3, P 15.9 and K 186.6 kg/ha.

The experiment was laid out in a split-plot design and replicated thrice. The main plots treatments included combinations of rice plating systems and nitrogen levels while, weed management practices were taken as the sub-plots treatments. The rice planting systems included were: transplanted rice (TPR), DSR (sole), DSR + *Sesbania* (brown manuring) and DSR + *Azolla*. The nitrogen levels were 100% recommended dose of nitrogen (RDN) and 75% RDN. The weed management practices in the sub-plots treatments were: no weeding, pretilachlor (with safener) 0.3 kg/ha at 2 DAS as pre-emergence application followed by (*fb*) hand weeding (HW) at 45 DAS and HW twice at 20 and 45 DAS. The preparation of field was done according to the planting systems/treatments during both the years. After preparation of the field, direct-seeding of rice (50 kg seed/ha) was done using a drum seeder in rows 20 cm apart. The plots were kept in saturated condition at the time of sowing and for next ten days in case of DSR while, in transplanted rice, a thin film of water was maintained at the time of transplanting. Later irrigation was applied periodically.

The N was applied 150 kg/ha in three splits, ½ as basal and the remainder in two equal splits; one half at tillering (42 DAS) and the remaining at panicle initiation stage (65 DAS) as top dressing. Both P and K 60 kg/ha and zinc 25 kg/ha as $ZnSO_4$ were broadcasted and mixed in all plots uniformly before rice sowing/transplanting. In treatments, DSR + *Sesbania* + 100% RDN and DSR + *Sesbania* + 75% RDN, *Sesbania* seed 25 kg/ha was uniformly broadcasted after rice seeding and was controlled by spraying 2, 4-D 500 g/ha at 37 days after sowing (DAS). In treatments DSR + *Azolla* + 100% RDN and DSR + *Azolla* + 75% RDN, the *Azolla* at 200 kg/ ha was uniformly broadcasted after a week of rice sowing. In the sub-plots treatment, pretilachlor (with safener) was applied as pre-emergence using a knap-sack sprayer fitted with a flat-fan nozzle in a spray volume of 600 L/ha. Weed density and dry weight data were collected at 30, 60, and 90 DAS. Weed count, for estimating weed density, was recorded with the help of a quadrate (0.5 x 0.5 m) placed randomly at two spots in each plot. Weeds were cut at ground level, washed with tap water, dried at 70 ºC for 48 hours, and then weighed and this data was subjected to square-root $\sqrt{x+0.5}$ transformation to normalize its distribution prior to statistical analysis. Weed smothering efficiency was worked out as per the standard formula (Mani *et al*. 1973) at 30 DAS. Grain and straw yields were taken from a 4.2 m^2 area in the center of each plot and expressed in t/ha at 14% moisture. The data was analyzed statistically and least significant difference (LSD) was used to compare the treatment means at 5% probability level (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Weed flora

The common weeds infested the experimental field included grasses *Digitaria sanguinalis* (8.39%), *Echinochloa crus-galli* (12.69%), *Echinochloa colona* (16.57%), *Panicum repens* (5.94%) and broad-leaved weeds *Commelina benghalensis* 11.99%), *Digera arvensis* (13.04%), *Convolvulus arvensis* (3.29%) and *Cyperus rotundus* (8.42%), *Cyperus esculentus* (5.57%) and *Fimbristylis miliacea* (14.10%) among the sedges.

Weeds density and dry weight

Sesbania and *Azolla* significantly (p=0.05) reduced grass and broad-leaved weeds as well as total weeds density and dry weight (**Table 1** and **2**). DSR with *Sesbania* or *Azolla* recorded significantly lower density of grass and broad-leaved weeds compared to DSR (sole) in 2009 and 2010 at 30, 60 and 90 DAS. Among the weed management practices, significantly highest grass and broad-leaved weeds count was recorded in weedy check plots, whereas, the lowest weed density was recorded in pretilachlor (with safener) 0.3 kg/ha at 2 DAS *fb* HW at 45 DAS except at 30 DAS as weeding was done on 10 days before the count of weeds in HW twice treatment (**Table 1**).

The total weed density decreased up to 90 DAS in DSR in sequence with *Sesbania* or *Azolla* and both recorded significantly lower density and dry weight than DSR (sole) in 2009 and 2010 at 30, 60 and 90 DAS. DSR (sole) recorded higher total weed density and dry weight than with *Sesbania* or *Azolla* (**Table 2**). The densities of grass and broad-leaved weeds as well as total weed dry weight were consistently lower with *Azolla* (**Table 1** and **2**), being similar to *Sesbania*. This is consistent with the findings of Ravisankar *et al*. (2008), except that at later stage (90 DAS) the dry weight of weeds with *Sesbania* and *Azolla* did not differ in present study. In comparison to DSR (sole), *Sesbania* or *Azolla* alone caused a considerable reduction in total weeds density and dry weight at 60 DAS. At 60 DAS, *Azolla* with 100% RDN reduced the total weed density to the extent of

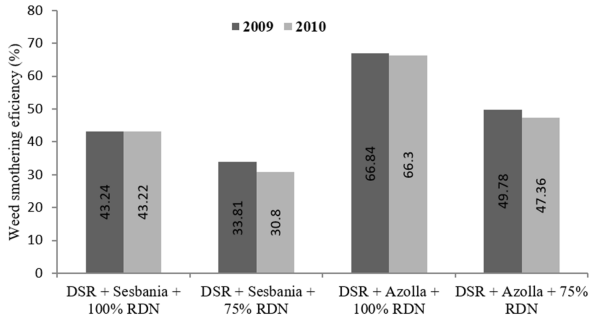

Figure 1. Weed smothering efficiency as influenced by dual culture in direct-seeded rice

81% (**Table 2**), which could be due to the covered surface of rice field, reduces photosynthetic activity of weeds by intercepting light (Anitha *et al.* 2012). In this study, *Azolla* proved to be as effective as *Sesbania* in weed-suppressing ability. *Azolla* this way also did not require additional irrigation and labour for incorporation and also recorded higher weed smothering efficiency (**Figure 1**).

The no-weeding treatment recorded significantly (p=0.05) maximum total weeds density and dry weight (**Table 2**). Total weeds density was lower with pretilachlor (with safener) 0.3 kg/ha at 2 DAS *fb* HW at 45 DAS, which reduced the total weeds density by 86%in 2010 at 60 DAS. Hand weeding twice at 20 and 45 DAS gave around 81% reduction in weeds density at 60 DAS during both the years compared to no weeding. The weeds dry weight also followed the same trend, however; HW twice was not equally effective in reducing total weeds dry weight. Pretilachlor (with safener) is known to control of grasses followed by broad-leaved weeds and sedges (Suganthi *et al.* 2005, Ravisankar *et al.* 2008).

Effect on rice yield

The DSR in sequence with *Sesbania* and *Azolla* being at par recorded significantly higher yields than DSR (sole) (**Table 3**). DSR with *Sesbania* and 100% RDN recorded 20.9% and 15.3% higher yield in 2009 and 2010, respectively than DSR (sole). Contrary to the earlier study that intercropping of *Sesbania* with rice can cause rice yield loss (Mathew and Alexander 1995), our study revealed that there was a beneficial effect mainly due to weed suppression. It supports findings of Singh *et al.* (2007). (Gupta *et al.* 2006)

Table 1. Effect of planting systems of rice with nitrogen levels and weed management practices on density of grass and broad-leaved weeds in direct-seeded rice

Treatment	Grass weeds (no./m^2)						Broad-leaved weeds (no./m^2)					
	30 DAS		60 DAS		90 DAS		30 DAS		60 DAS		90 DAS	
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Planting systems with nitrogen levels												
M_1N_1-TPR + 100% RDN	4.22 (18.3)	3.96 (16.0)	3.71 (19.1)	3.32 (15.8)	3.52 (17.9)	3.19 (15.0)	3.46 (12.8)	3.21 (11.3)	3.03 (14.2)	2.82 (12.1)	2.84 (12.9)	2.52 (10.2)
M_1N_2-TPR + 75% RDN	4.75 (23.5)	4.44 (20.4)	4.23 (23.4)	3.79 (19.7)	3.97 (21.5)	3.61 (17.9)	3.81 (15.2)	3.59 (13.7)	3.89 (21.4)	3.44 (17.3)	3.62 (20.0)	3.17 (15.9)
M_2N_1-DSR (sole) + 100% RDN	9.15 (92.5)	8.45 (78.3)	9.47 (120.7)	8.62 (99.7)	9.20 (116.0)	8.48 (99.1)	8.66 (77.1)	7.60 (60.7)	8.59 (89.4)	7.61 (70.9)	8.32 (84.8)	7.62 (73.0)
M_2N_2-DSR (sole) + 75% RDN	8.70 (83.5)	8.10 (72.7)	9.15 (112.7)	8.24 (91.7)	8.92 (109.7)	8.24 (93.9)	8.09 (68.2)	7.34 (56.8)	7.77 (73.4)	6.93 (58.5)	7.52 (69.8)	6.88 (60.1)
M_3N_1-DSR +*Sesbania* + 100% RDN	7.70 (63.2)	7.06 (53.9)	6.82 (54.0)	6.14 (43.8)	6.50 (49.3)	5.98 (41.8)	7.18 (53.7)	6.58 (45.5)	6.15 (41.0)	5.42 (32.0)	5.93 (38.7)	5.40 (32.8)
M_3N_2-DSR + *Sesbania* + 75% RDN	6.84 (58.7)	6.81 (50.1)	6.54 (50.5)	5.92 (41.1)	6.20 (45.7)	5.74 (39.1)	6.57 (45.7)	6.12 (40.4)	5.61 (35.3)	4.92 (27.3)	5.33 (32.4)	4.84 (27.4)
M_4N_1-DSR + *Azolla* + 100% RDN	6.84 (51.2)	6.36 (44.7)	5.94 (44.0)	5.33 (35.7)	5.60 (39.8)	5.16 (33.8)	5.31 (31.9)	5.05 (28.7)	4.65 (26.4)	4.10 (20.7)	4.33 (24.1)	3.92 (20.1)
M_4N_2-DSR + *Azolla* + 75% RDN	7.13 (54.9)	6.66 (48.5)	6.24 (47.1)	5.65 (38.5)	5.93 (42.9)	5.43 (36.2)	5.88 (36.9)	5.41 (32.1)	5.03 (29.5)	4.42 (23.0)	4.59 (26.0)	4.20 (22.2)
LSD (p=0.05)	0.33	0.27	0.31	0.29	0.34	0.29	0.77	0.72	0.76	0.67	0.68	0.58
Weed management												
Pretilachlor (with safener) 0.3 kg/ha at 2 DAS *fb* HW at 45 DAS	6.69 (46.0)	5.98 (36.4)	3.92 (16.5)	3.43 (12.7)	3.59 (13.8)	3.29 (11.5)	5.79 (36.6)	5.02 (26.9)	3.45 (13.9)	2.92 (9.6)	3.10 (11.5)	2.61 (7.9)
HW twice at 20 and 45 DAS	4.70 (22.7)	4.40 (19.9)	4.28 (19.3)	3.89 (16.1)	4.05 (17.5)	3.68 (14.5)	4.56 (23.6)	4.02 (17.9)	4.12 (18.7)	3.71 (15.3)	3.83 (16.5)	3.46 (13.7)
No weeding	9.57 (98.4)	9.05 (87.9)	11.34 (141.0)	10.30 (115.9)	11.05 (134.7)	10.22 (115.3)	8.01 (67.9)	7.76 (63.6)	9.19 (91.4)	8.24 (73.3)	9.00 (87.7)	8.39 (76.6)
LSD (p=0.05)	0.32	0.18	0.25	0.22	0.22	0.19	0.28	0.18	0.42	0.36	0.42	0.38

M_1= Transplanted rice; M_2= DSR (sole); M_3= DSR + *Sesbania*; M_4= DSR + *Azolla*; N_1= 100% RDN; N_1= 75% RDN; TPR: Transplanted rice, RDN: Recommended dose of nitrogen, DSR: Direct-seeded rice, DAS: Days after sowing, *fb*: followed by, HW: Hand weeding, no.: numbers, Data were subjected to square root ($\sqrt{x+0.5}$); the figures in the parentheses are original values

Table 2. Effect of planting systems of rice with nitrogen levels and weed management practices on total weeds density and dry weight of weeds in direct-seeded rice

Treatment	Total weed density (no./m^2)						Weeds dry weight (g/m^2)					
	30 DAS		60 DAS		90 DAS		30 DAS		60 DAS		90 DAS	
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Planting systems with nitrogen levels												
M_1N_1-TPR+100% RDN	7.58	6.99	6.94	6.19	6.56	5.92	2.84	2.67	3.83	3.58	5.80	5.43
	(61.2)	(52.3)	(64.7)	(52.9)	(59.7)	(49.9)	(10.9)	(9.5)	(16.7)	(14.6)	(37.0)	(32.8)
M_1N_2-TPR+75% RDN	8.27	7.66	7.81	6.94	7.34	6.67	3.28	3.10	4.48	4.21	6.17	5.90
	(72.1)	(62.3)	(78.9)	(64.4)	(72.8)	(61.3)	(14.3)	(12.7)	(23.5)	(20.9)	(41.3)	(38.1)
M_2N_1-DSR (sole)+100% RDN	15.43	13.84	15.46	13.93	14.99	13.85	8.21	7.66	9.40	9.05	12.35	11.89
	(250.8)	(205.1)	(299.5)	(244.1)	(286.0)	(246.0)	(81.4)	(72.1)	(109.7)	(101.8)	(195.0)	(183.0)
M_2N_2-DSR (sole)+75% RDN	15.20	13.40	14.67	13.16	14.25	13.15	7.07	6.52	8.91	8.58	12.01	11.57
	(244.9)	(193.0)	(270.9)	(218.3)	(259.8)	(223.1)	(60.4)	(51.2)	(99.7)	(92.4)	(186.8)	(175.4)
M_3N_1-DSR+ *Sesbania*+100% RDN	13.18	11.98	11.56	10.32	11.03	10.05	5.99	5.63	5.92	5.69	7.94	7.60
	(182.0)	(153.2)	(151.4)	(121.1)	(139.7)	(116.2)	(46.2)	(40.9)	(36.8)	(33.8)	(69.8)	(64.5)
M_3N_2-DSR+ *Sesbania*+75% RDN	12.57	11.43	10.94	9.78	10.44	9.52	5.49	5.15	5.31	5.12	7.44	7.12
	(166.5)	(140.5)	(138.2)	(110.5)	(127.0)	(106.1)	(40.0)	(35.4)	(29.2)	(27.1)	(60.5)	(55.9)
M_4N_1-DSR+ *Azolla*+100% RDN	11.36	10.37	9.85	8.80	9.34	8.50	4.42	4.18	4.37	4.19	6.81	6.53
	(138.5)	(118.1)	(116.9)	(93.4)	(106.9)	(88.3)	(27.0)	(24.3)	(20.5)	(18.8)	(52.1)	(48.3)
M_4N_2-DSR+ *Azolla*+75% RDN	11.92	10.95	10.39	9.26	9.84	8.95	4.74	4.48	4.87	4.66	7.09	6.76
	(150.4)	(129.7)	(127.1)	(101.0)	(115.4)	(96.0)	(30.3)	(27.0)	(25.3)	(23.0)	(56.0)	(51.8)
LSD (p=0.05)	0.71	0.62	0.52	0.47	0.46	0.39	0.75	0.63	0.71	0.71	0.60	0.61
Weed management												
Pretilachlor (with safener) 0.3 kg/ha at 2 DAS *fb* HW at 45 DAS	11.53	9.79	6.88	5.98	6.35	5.69	4.91	4.70	3.84	3.72	5.56	5.13
	(140.5)	(99.2)	(50.7)	(38.5)	(43.5)	(34.9)	(26.6)	(24.2)	(15.6)	(14.7)	(31.9)	(27.1)
HW twice at 20 and 45 DAS	8.64	7.76	7.78	7.03	7.34	6.68	2.03	1.82	4.94	4.66	6.24	5.98
	(78.8)	(63.3)	(64.4)	(52.8)	(57.8)	(48.3)	(5.0)	(3.8)	(25.6)	(22.8)	(40.6)	(37.4)
No weeding	15.64	14.92	18.20	16.39	17.73	16.35	8.82	8.25	8.88	8.52	12.80	12.44
	(255.7)	(232.9)	(352.8)	(285.9)	(336.3)	(286.8)	(84.9)	(74.3)	(94.3)	(87.2)	(189.4)	(179.2)
LSD (p=0.05)	0.49	0.22	0.32	0.30	0.34	0.29	0.56	0.53	0.45	0.43	0.43	0.43

M_1= Transplanted rice; M_2= DSR (sole); M_3= DSR + *Sesbania*; M_4= DSR + *Azolla*; N_1= 100% RDN; N_1= 75% RDN; TPR: Transplanted rice, RDN: Recommended dose of nitrogen, DSR: Direct-seeded rice, DAS: Days after sowing, *fb*: followed by, HW: Hand weeding, no.: numbers, Data were subjected to square root ($\sqrt{x+0.5}$); the figures in the parentheses are original values

Table 3. Effect of planting systems of rice with nitrogen levels and weed management practices on grain and straw yields (t/ha) as well as economic returns of direct-seeded rice

Treatment	Grain yield (t/ha)		Straw yield (t/ha)		Cost of cultivation (x10^3 `/ha)		Gross income (x10^3 `/ha)		Net returns (x10^3 `/ha)		B:C ratio	
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Planting systems with nitrogen levels												
M_1N_1-TPR + 100% RDN	3.88	4.27	6.95	7.26	39.7	39.7	68.3	74.3	28.6	34.6	1.72	1.87
M_1N_2-TPR + 75% RDN	3.73	4.11	6.83	7.02	39.2	39.2	65.9	71.5	26.7	32.3	1.68	1.82
M_2N_1-DSR (sole) + 100%RDN	3.15	3.72	6.29	6.73	31.9	31.9	56.7	65.6	24.8	33.6	1.77	2.05
M_2N_2-DSR (ole) + 75% RDN	2.99	3.52	5.98	6.45	31.4	31.4	53.8	62.3	22.4	30.8	1.71	1.98
M_3N_1-DSR + *Sesbania* + 100% RDN	3.81	4.29	6.80	7.00	33.0	33.0	66.9	74.0	33.8	41.0	2.02	2.24
M_3N_2-DSR + *Sesbania* + 75% RDN	3.66	4.05	6.61	6.81	32.5	32.5	64.5	70.3	32.0	37.7	1.98	2.16
M_4N_1-DSR + *Azolla* + 100% RDN	3.76	4.18	6.79	6.85	32.9	32.9	66.3	72.2	33.4	39.3	2.01	2.19
M_4N_2-DSR + *Azolla* + 75% RDN	3.64	3.98	6.66	6.74	32.4	32.4	64.3	69.2	31.9	36.8	1.98	2.13
LSD (p=0.05)	0.21	0.39	0.40	0.83	-	-	-	-	-	-	-	-
Weed management												
Pretilachlor (with safener) 0.3 kg/ha at 2 DAS *fb* HW at 45 DAS	4.43	5.20	7.79	8.25	38.2	38.2	77.6	89.3	39.3	51.1	2.02	2.33
HW twice at 20 and 45 DAS	4.24	4.70	7.55	7.83	41.3	41.3	74.6	81.4	33.2	40.1	1.80	1.96
No weeding	2.06	2.15	4.50	4.50	34.1	34.1	37.9	39.1	38.1	49.6	1.11	1.14
LSD (p=0.05)	0.19	0.15	0.20	0.44	-	-	-	-	-	-	-	-

M_1= Transplanted rice; M_2= DSR (sole); M_3= DSR + *Sesbania*; M_4= DSR + *Azolla*; N_1= 100% RDN; N_1= 75% RDN; TPR: Transplanted rice, RDN: Recommended dose of nitrogen, DSR: Direct-seeded rice, DAS: Days after sowing, *fb*: followed by, HW: Hand weeding; selling price of rice = 14000/t, selling price of strow = 2000/t

Table 4. Grain yield, gross realization, cost of cultivation, net realization and benefit cost ratio of direct-seeded rice as per the treatment combinations

Treatment	Grain yield (t/ha)		Gross realization (x10^3`/ ha)		Cost of cultivation (x10^3`/ ha)		Net realization (x10^3`/ ha)		B:C ratio	
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
$M_1N_1W_1$	2.52	2.85	45.3	50.4	39.7	39.7	5.6	10.7	1.14	1.27
$M_1N_1W_2$	4.64	5.31	81.1	91.5	43.7	43.7	37.3	47.7	1.85	2.09
$M_1N_1W_3$	4.49	4.65	78.4	81.1	46.9	46.9	31.5	34.2	1.67	1.72
$M_1N_2W_1$	2.35	2.65	42.7	47.0	39.2	39.2	3.5	7.8	1.08	1.20
$M_1N_2W_2$	4.47	5.16	78.4	89.0	43.2	43.2	35.1	45.7	1.81	2.05
$M_1N_2W_3$	4.38	4.51	76.7	78.6	46.4	46.4	30.3	32.2	1.65	1.69
$M_2N_1W_1$	1.57	1.80	30.4	33.1	31.9	31.9	1.43	1.2	0.95	1.03
$M_2N_1W_2$	4.05	4.92	71.6	85.8	36.0	36.0	35.6	49.8	1.99	2.38
$M_2N_1W_3$	3.83	4.44	68.2	77.8	39.1	39.1	29.0	38.7	1.74	1.98
$M_2N_2W_1$	1.39	1.72	27.4	31.5	31.4	31.4	-4.0	0.07	0.87	1.00
$M_2N_2W_2$	3.93	4.60	69.5	80.6	35.5	35.5	34.0	45.0	1.95	2.26
$M_2N_2W_3$	3.65	4.23	64.6	74.5	38.6	38.6	26.0	35.9	1.67	1.92
$M_3N_1W_1$	2.33	2.26	41.6	41.1	33.0	33.0	8.6	8.1	1.26	1.24
$M_3N_1W_2$	4.62	5.54	80.9	94.2	37.1	37.1	43.7	57.0	2.17	2.53
$M_3N_1W_3$	4.47	5.06	78.2	86.8	40.2	40.2	38.0	46.6	1.94	2.15
$M_3N_2W_1$	2.08	1.94	38.2	36.3	32.5	32.5	5.6	3.7	1.17	1.11
$M_3N_2W_2$	4.54	5.36	79.1	91.0	36.6	36.6	42.4	54.4	2.15	2.48
$M_3N_2W_3$	4.37	4.84	76.4	83.6	39.7	39.7	36.6	43.9	1.92	2.10
$M_4N_1W_1$	2.25	2.02	40.7	37.1	32.9	32.9	7.8	4.1	1.23	1.12
$M_4N_1W_2$	4.61	5.45	80.5	92.8	37.0	37.0	43.5	55.8	2.17	2.50
$M_4N_1W_3$	4.42	5.07	77.6	86.8	40.1	40.1	37.4	46.7	1.93	2.16
$M_4N_2W_1$	2.02	1.94	37.1	36.1	32.4	32.4	4.7	3.6	1.14	1.11
$M_4N_2W_2$	4.55	5.24	79.4	89.7	36.5	36.5	42.9	53.2	2.17	2.45
$M_4N_2W_3$	4.36	4.76	76.4	81.9	39.6	39.63	36.8	42.2	1.92	2.06
LSD (p=0.05)	NS	0.43	-	-	-	-	-	-	-	-

M_1= Transplanted rice; M_2= DSR (sole); M_3= DSR + *Sesbania*; M_4= DSR + *Azolla*; N_1= 100% RDN; N_1= 75% RDN; W_1= No weeding; W_2= pretilachlor (with safener) 0.3 kg/ha at 2 DAS *fb* HW at 45 DAS; W_3= HW twice at 20 and 45 DAS, Selling price of paddy = 1400/ quintal, Selling price of straw = 200/ quintal

reported that co-culture of *Sesbania* in rice and its subsequent knock down by 2,4-D-ester reduced the weed population by nearly half without any adverse effect on rice yield. When *Sesbania* seed is not readily available, farmers can opt for growing *Azolla* with direct-seeded rice up to 37 DAS. The dual culture of *Azolla* provides an alternative to *Sesbania* with respect to environmental fate of herbicides use. DSR intercropped with *Sesbania rostrata* or *Azolla microphylla* combined with physical incorporation at 37 DAS, suppressed weeds effectively and resulted in comparable yields with transplanted rice.

The rice grain yield with the pretilachlor (with safener) 0.3 kg/ha at 2 DAS *fb* HW at 45 DAS treatment was significantly higher in 2009 and 2010 (4.5 to 10.6%) than with the HW twice at 20 and 45 DAS. The efficacy of pretilachlor (with safener) in combination with HW in controlling weeds in wet-seeded rice was reported by (Ravisankar *et al.* 2008). The interaction was significant only in 2010. Such yield advantages might be due to weed free environment from beginning and supply of nutrients in soil after decomposition of these dual crops which resulted in increased test weight and yield (Majhi *et al.* 2009)

Economics

Economic analysis showed that *Sesbania* and *Azolla* were equally good in realizing higher economic returns (**Table 3**), in spite of variation in the cost of *Sesbania* (INR1125/ha) and *Azolla* (INR1000/ha), whereas, it was lower in DSR (sole) crop. Amongst weed management practices, the net returns with pretilachlor (with safener) 0.3 kg/ha at 2 DAS *fb* HW at 45 DAS were higher than with the HW twice at 20 and 45 DAS because of the lower cost of the herbicide-based weed control method. Among the interaction effect, the highest net realization (INR43674 and 56982/ha) and B:C ratios (2.17 and 2.53) were recorded in DSR + *Sesbania* + 100% RDN coupled with pretilachlor (with safener) 0.3 kg/ ha at 2 DAS as pre-emergence application *fb* HW at 45 DAS in 2009 and 2010 respectively (**Table 4**).

Thus, it was concluded that, DSR with *Sesbania* or *Azolla* + 100% RDN with pretilachlor (with safener) 0.3 kg/ha at 2 DAS as pre-emergence application *fb* HW at 45 DAS recorded lower weeds density, dry weight and profitable grain yield and it might be recommended to the farmers for getting optimum yield with higher farm income.

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