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Weed dynamics, crop growth and yield as affected by different weed management practices and plant growth-promoting rhizobacteria in direct-seeded upland rice

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ABSTRACT

Effect of different weed management practices and plant growth-promoting rhizobacteria (PGPR) were evaluated in Jorhat (Assam) on weed dynamics, crop growth and yield in direct-seeded upland rice during 2018 and 2019. Results revealed that density and dry weight of weeds were the lowest with *Pseudomonas fluorescens* among PGPR treatments. The growth and yield attributing characters were significantly improved due to *P. fluorescens* contributing to the highest grain and straw yield of rice. Single application of pretilachlor pre-emergence 0.75 kg/ha or application of pretilachlor pre-emergence 0.75 kg/ha followed by one hand weeding at 30 DAS resulted in least density and dry weight of weeds at initial stages of crop growth. The lowest values were recorded in three hand weedings done at 15, 30 and 45 DAS. Better growth and yield attributing characters of rice with three hand weedings at 15, 30 and 45 DAS resulted in the highest grain and straw yields. Combination of *P. fluorescens* with either three hand weedings at 15, 30 and 45 DAS or pretilachlor pre-emergence 0.75 kg/ha followed by one hand weeding at 30 DAS was found to be superior with grain and straw yields along with similar trend in gross and net returns. However, the benefit: cost ratio was the highest in the combination of *P. fluorescens* with pretilachlor pre-emergence at 0.75 kg/ha followed by one hand weeding at 30 DAS.

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important staple food crops in the world and it occupies a pivotal position in the food security system in India. Direct-seeded rice (DSR) serves several advantages *i.e*. saves labour, helps faster, easier and timely planting, less drudgery, early crop maturity by 7-10 days, less water requirement, high tolerance to water deficit, often high yield, low production cost, more profit and less methane emission (Balasubramanian and Hill 2002). Weed management is the major challenge towards the success of this crop as weeds are comparatively denser in this system than in transplanted situation, because of simultaneous emergence of rice and weeds due to the absence of standing water at the early stage of rice growth (Chauhan 2012) and they compete with crop for nutrients, light, space and moisture. The extent of yield reduction of rice due to weeds has been estimated up to 95% in India (Naresh *et al*. 2011). Weed control constitutes one of the major input costs of crop production. Manual control of weeds is considered to be the best but it is labour intensive, tedious and back breaking.

It is suggested to use pre-emergence herbicides in DSR to prevent the simultaneous emergence of the weeds with rice and to provide competitive advantage to the crop under relatively weed free condition. Integrated weed management, combining herbicide and other means is essential for effective weed management as one single application of a pre-emergence herbicide cannot facilitate a competition-free environment during critical growth period of upland direct seeded rice. Plant growth promoting rhizobacteria (PGPR) is the bacterium that improves plant growth by inoculating seeds, roots or soil through various mechanisms. An improved growth and vigour of the crop might indirectly help in suppressing the associated weeds. Keeping in view the above issues, this study was conducted with the objectives of studying the performance of plant growth-promoting rhizobacteria and weed management practices on crop growth and yield of rice.

MATERIALS AND METHODS

A field study was conducted during autumn rice season from March to July *(ahu)*, 2018 and 2019 at Assam Agricultural University, Jorhat (Assam). The soil of the experimental site was sandy loam in texture, acidic in reaction (pH: 5.5), medium in organic carbon (0.54%), low in available N (191 kg/ha), available P (22.28 kg/ha) and available K (107.05 kg/ha). Seeds of rice variety '*Inglongkiri*' (100-110 days duration) 75 kg/ha were sown in rows 20 cm apart in individual plots of 4 x 3 m size during both the years. Crop was applied with 40:20:20 of N:P:K kg/ha. Nitrogen was applied in 3 split doses *i.e.*, ½ of N was applied in final ploughing, ¼ at active tillering stage and remaining ¼ at panicle initiation stage. All the phosphatic and potassic fertilizers were applied during final land preparation. The experiment was laid out in factorial randomized block design with three replications. The treatments consisted of three PGPR inoculations, *viz*.; *Bacillus cereus*, *Pseudomonas fluorescens* and no inoculation and four weed management practices, *viz*.; pretilachlor pre-emergence at 0.75 kg/ha, pretilachlor pre-emergence at 0.75 kg/ha followed by one hand weeding at 30 DAS, three hand weedings at 15, 30 and 45 DAS and weedy check. In case of PGPR inoculation, the surface sterile rice seed were inoculated by immersion in the appropriate PGPR suspension (at 10^7 cfu/ml)and air dried before sowing.

Weed samples were collected with the help of a quadrate of 50 x 50 cm from two places in each plot to determine the density and dry weight of different weeds. Weed dry weight was recorded after drying the weed samples at 70°C for 48 h. Weed control efficiency (WCE) was calculated based on the data recorded at 15, 30, 45, 60 DAS and at harvest as per standard formula. Weed density and dry weight were square root transformed before analysis.

Plant population at 15 DAS, plant height (cm), tillers/m and total dry matter (g/m^2) at 45 DAS were recorded. Panicle length (cm), panicles/m^2, number of grains per panicle were recorded just before harvesting. The grain and straw yield were recorded after harvest and sun dried for 3 days. Harvest index was calculated using standard formula.

All the data wherever needed were statistically analysed for factorial randomized block design. Least significant differences (LSD) at 5 per cent probability level were calculated only when the F value was found to be significant.

RESULTS AND DISCUSSION

Weed flora

The relative density in weedy check were *Eleusine indica* (14.03 and 22.43%), *Digitaria setigera* (25.18 and 32.04%), *Cynodon dactylon* (13.24 and 12.82%), *Cyperus difformis* (8.31 and 6.41%), *Cyperus rotundus* (6.23 and 6.41%), *Ageratum houstonianum* (4.65 and 3.21%), *Commelina diffusa* (6.87 and 5.77%), *Oldenlandia corymbosa* (3.58 and 1.28%), *Spermacoce articularis* (7.58 and 3.21%), *Cleome rutidosperma* (3.65 and 3.21%), *Mimosa pudica* (3.58 and 3.21%) and *Acmella ciliata* (3.1 and 0%) at 60 DAS in 2018 and 2019, respectively. The most dominant weed species was *D. setigera* in both the years. It might be due to favourably high rainfall and high temperature in the different crop growth stages and also presence of vegetative propagules in soil, and rich seed bank of weeds in soil that could help in early establishment and abundance of these weed species.

Weed density, dry weight and weed control efficiency

At 15 and 30 DAS inoculation with *P. fluorescens* resulted in significantly lower weed density and dry weight as compared to other PGPR treatments (**Table 1** and **2**). Schroth and Hancock (1982) suggested that rhizobacteria do not necessarily eradicate the weeds, but significantly suppress early growth of weeds and allow the development of crop plants to effectively compete with weakened weed seedlings. The maximum weed density and dry weight at all the growth stages, was recorded in weedy check in both the years. Application of pretilachlor was more effective at initial crop growth stage which might be due to the activity of the herbicide up to 30 days after application. Similar findings were reported by Mahanta *et al.* (2019). Significantly, the lower weed density and dry weight was observed with hand weeding at all crop growth stages other than 45 DAS where it was at par with pretilachlor 0.75 kg/ha followed by one hand weeding at 30 DAS (**Table 1** and **2**). This might be due to timely eradication of weeds by intercultural tools, which uprooted and killed the weeds.

Among the PGPR inoculations, highest WCE was found in *P. fluorescens* followed by *Bacillus cereus* in both the years (**Table 3**). In the initial stages, the WCE was higher due to greater suppression of weed density at the initial stages of crop growth as compared to later stages (Kremer and Kennedy 1996).

Application of pretilachlor at 0.75 kg/ha and pretilachlor at 0.75 kg/ha followed by one hand weeding at 30 DAS resulted in higher WCE due to lower weed density at 15 DAS in both the years. Similar findings were found by Saha (2005). At 30, 45, 60 DAS and harvest, three hand weedings and pretilachlor at 0.75 kg/ha + one hand weeding at 30 DAS resulted in higher WCE due to effective and sustained weed control by these treatments.

Crop growth parameters

There was no significant difference in plant population at 15 DAS amongst the PGPR inoculation and weed management practices and their interaction.

Significantly higher plant height, number of tillers/m and dry matter accumulation (g/m^2) in both the years were recorded in *P. fluorescens* which could be due to production of plant growth hormones like

Table 1. Effect of PGPR and weed management on weed density at different days after sowing (DAS) and harvest in 2018 and 2019

Treatment	Weed density (no./m^2) 15 DAS		30 DAS		45 DAS		60 DAS		At harvest	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
PGPR										
Bacillus cereus	5.7(34.0)	5.8(34.8)	8.3(69.2)	8.3(69.3)	7.8(68.7)	7.7(68.7)	9.4(93.8)	9.3(93.5)	11.0(123.5)	10.9(123.3)
Pseudomonas fluorescens	5.3(29.3)	5.4(29.9)	7.6(58.5)	7.5(58.5)	7.7(66.8)	7.6(66.7)	9.0(87.2)	9.0(87.5)	10.9(121.9)	10.9(122.2)
No inoculation	6.5(43.6)	6.6(44.7)	8.7(75.7)	8.6(75.6)	8.2(73.8)	8.1(73.7)	9.6(98.6)	9.6(98.9)	11.3(130.1)	11.3(130.3)
LSD (p=0.05)	0.41	0.39	0.35	0.36	NS	NS	NS	NS	NS	NS
Weed management										
Pretilachlor 0.75 kg/ha	4.7(21.8)	4.8(22.7)	8.1(66.1)	8.1(65.8)	9.9(98.3)	9.9(98.0)	10.9(119.4)	10.9(119.2)	12.5(156.7)	12.5(156.9)
Pretilachlor 0.75 kg/ha + 1 HW at 30 DAS	4.7(22.3)	4.8(23.0)	8.0(64.1)	8.0(63.7)	5.0(24.8)	4.9(24.4)	7.7(59.1)	7.7(59.1)	9.9(98.2)	9.9(97.7)
Three HW at 15, 30 and 45 DAS	7.0(48.8)	7.0(49.3)	6.8(45.8)	6.7(45.8)	5.3(27.8)	5.2(27.3)	6.2(38.9)	6.2(38.9)	8.8(76.7)	8.7(76.1)
Weedy check	7.0(49.7)	7.2(51.0)	9.8(95.2)	9.8(96.0)	11.3(128.2)	11.3(129.0)	12.5(155.3)	12.5(156.1)	13.0(169.1)	11.1(170.4)
LSD (p=0.05)	0.47	0.45	0.41	0.42	0.72	0.73	0.67	0.67	0.51	0.52
Interaction (P × W)										
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

LSD-least significant difference at 5% level of significance, NS- Non-significant, DAS- Days after sowing, original values in parentheses were subject to square root transformation $\sqrt{x+0.5}$

Table 2. Effect of PGPR and weed management on weed dry matter accumulation at different days after sowing (DAS) and harvest in 2018 and 2019

Treatment	Weed dry weight (g/m^2) 15 DAS		30 DAS		45 DAS		60 DAS		At harvest	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
PGPR										
Bacillus cereus	2.4(5.8)	2.4(5.8)	4.7(22.4)	4.7(22.5)	5.2(32.1)	5.1(32.1)	6.4(48.9)	6.3(48.7)	9.6(96.3)	9.5(96.3)
Pseudomonas fluorescens	2.2(4.9)	2.1(4.3)	4.4(19.7)	4.4(19.7)	5.2(31.4)	5.1(31.8)	6.3(47.4)	6.3(47.5)	9.5(95.1)	9.4(95.3)
No inoculation	2.7(7.2)	2.7(7.2)	5.1(26.5)	5.1(26.6)	5.2(33.3)	5.2(33.6)	6.6(51.1)	6.5(51.0)	9.8(101.0)	9.6(100.8)
LSD (p=0.05)	0.18	0.22	0.29	0.29	NS	NS	NS	NS	NS	NS
Weed management										
Pretilachlor 0.75 kg/ha	1.9(3.2)	1.9(3.2)	5.0(24.6)	5.0(24.7)	7.2(51.0)	7.1(50.8)	7.8(61.0)	7.8(60.9)	10.8(115.7)	10.7(115.6)
Pretilachlor 0.75 kg/ha + one HW at 30 DAS	1.9(3.3)	1.9(3.2)	4.9(23.2)	4.8(23.1)	2.8(7.3)	2.7(7.3)	4.1(16.5)	4.1(16.3)	8.5(72.7)	8.5(72.5)
Three HW at 15, 30 and 45 DAS	3.0(8.6)	2.8(7.8)	3.5(12.2)	3.5(12.2)	2.8(7.6)	2.8(7.7)	3.2(9.5)	3.1(9.3)	6.3(39.2)	6.2(39.2)
Weedy check	3.0(8.7)	3.0(8.8)	5.6(31.4)	5.6(31.7)	8.0(63.1)	8.0(64.1)	10.5(109.4)	10.4(109.8)	12.7(162.1)	12.7(162.5)
LSD (p=0.05)	0.21	0.25	0.34	0.34	0.26	0.29	0.29	0.27	0.30	0.29
Interaction (P × W)										
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

LSD-least significant difference at 5% level of significance, NS- Non-significant, DAS- Days after sowing, original values in parentheses were subject to square root transformation $\sqrt{x+0.5}$

Table 3. Effect of PGPR and weed management on weed control efficiency at different days after sowing (DAS) and harvest in 2018 and 2019

Treatment	Weed control efficiency (%) 15 DAS		30 DAS		45 DAS		60 DAS		At harvest	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
PGPR										
Bacillus cereus	21.98	22.17	8.48	8.27	6.99	6.68	4.82	5.40	5.06	5.37
Pseudomonas fluorescens	32.70	33.14	22.69	22.60	9.48	9.50	11.57	11.54	6.27	6.26
No inoculation	-	-	-	-	-	-	-	-	-	-
Weed management										
Pretilachlor 0.75 kg/ha	56.15	55.55	30.57	31.48	23.31	24.03	23.11	23.63	7.36	7.95
Pretilachlor 0.75 kg/ha + one HW at 30 DAS	55.04	54.90	32.67	33.68	80.67	81.03	61.95	62.14	41.92	42.70
Three HW at 15, 30 and 45 DAS	1.79	3.27	51.92	52.31	78.33	78.81	74.96	75.08	54.66	55.34
Weedy check	-	-	-	-	-	-	-	-	-	-

auxin by the bacteria. Similar findings were also obtained by Kaushal *et al*. (2013). Among the weed management practices, growth parameters like plant height, number of tillers per/m^2 and dry matter accumulation (g/m^2) were higher with the treatment of three hand weeding but it was at par with pretilachlor 0.75 kg/ha + hand weeding at 30 DAS in both the years (**Table 4**).

Yield attributing characters

The yield attributes of rice were significantly influenced due to PGPR inoculation. Panicle length, number of panicles/m^2 and number of grains/panicles were significantly increased by *P. fluorescens* in both the years (**Table 5**). Elekhtyar (2015) reported the ability of PGPR to increase nitrogen uptake efficiency, capable of solving phosphorus problem and increased auxin production.

Among all the weed management practices, the highest panicle length, number of panicles/m^2 and number of grains/panicles were recorded in three hand weedings at 15, 30 and 45 DAS in both the years (**Table 5**). This was closely followed by pretilachlor 0.75 kg/ha + hand weeding at 30 DAS. The higher yield attributes under these treatments might be due to reduced weed density, weed dry weight and higher weed control efficiency leading to effective control of the weeds at critical crop growth period and a better establishment of crop. However, the weed management practices could not affect significantly the test weight of grains.

Grain and straw yield

Grain and straw yields of rice increased significantly due to *P. fluorescens* inoculation in both the years (**Table 5**). Jambhulkar and Sharma (2013) reported that PGPR increased the availability of nitrogen and phosphorous and also amounts of cytokinin, gibberelin, auxin leading to better grain and straw yield. Among the weed management practices, significantly higher grain and straw yield were recorded under three hand weedings at 15, 30 and 45 DAS, which was closely followed by pretilachlor at 0.75 kg/ha + hand weeding at 30 DAS. Better management of weeds at critical stages of crop

Table 4. Effect of PGPR and weed management on crop growth parameters in 2018 and 2019

Treatment	Plant population/m at 15 DAS		Plant height (cm) at 45 DAS		No. of tillers/m at 45 DAS		Dry matter accumulation (g/m^2) at 45 DAS	
	2018	2019	2018	2019	2018	2019	2018	2019
PGPR								
Bacillus cereus	14.8	15.6	44.2	45.29	44.50	46.33	49.71	51.58
Pseudomonas fluorescens	14.8	15.8	47.2	48.52	50.67	52.42	54.85	55.88
No inoculation	14.7	15.3	41.2	42.36	42.25	43.83	46.61	48.53
LSD (p=0.05)	NS	NS	2.90	2.95	6.11	6.07	4.26	4.18
Weed management								
Pretilachlor 0.75 kg/ha	14.6	15.1	40.3	41.62	41.78	43.22	48.23	49.96
Pretilachlor 0.75 kg/ha + one HW at 30 DAS	14.7	15.7	48.8	50.08	53.22	55.11	53.28	55.14
Three HW at 15, 30 and 45 DAS	15.3	16.1	51.8	53.08	60.00	62.00	57.68	59.33
Weedy check	14.6	15.2	35.8	36.78	28.22	29.78	41.70	43.54
LSD (p=0.05)	NS	NS	3.35	3.41	7.06	7.01	4.92	4.83
Interaction (P × W)								
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

LSD-least significant difference at 5% level of significance, NS- Non-significant, DAS- Days after sowing

Table 5. Effect of PGPR and weed management on yield attributing parameters, yield and harvest index in 2018 and 2019

Treatment	Panicle length (cm)		No. of panicles/ m^2		No. of grains/ panicle		Test weight (g)		Grain yield (t/ha)		Straw yield (t/ha)		Harvest index (%)	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
PGPR														
Bacillus cereus	10.23	17.32	179.17	181.58	97.5	120.92	17.53	17.80	1.39	1.60	1.82	2.06	43.3	43.7
Pseudomonas fluorescens	10.86	18.99	193.08	196.67	106.83	137.50	17.60	17.92	1.66	1.85	2.14	2.37	43.7	43.8
No inoculation	9.63	16.77	169.42	174.33	94.58	117.00	17.23	17.51	1.15	1.35	1.55	1.79	42.6	43.4
LSD (p=0.05)	0.65	1.37	13.27	12.72	8.25	15.95	NS	NS	0.13	0.12	0.16	0.16	-	
Weed management														
Pretilachlor 0.75 kg/ha	9.93	15.78	150.78	153.67	91.67	124.33	17.43	17.74	1.07	1.29	1.65	1.88	39.3	40.7
Pretilachlor 0.75 kg/ha + one HW at 30 DAS	10.69	20.92	215.78	219.89	109.67	143.11	17.47	17.76	1.88	2.08	2.19	2.42	46.2	46.2
Three HW at 15, 30 and 45 DAS	11.71	22.79	232.33	236.33	131.00	161.78	17.70	17.97	2.05	2.26	2.38	2.62	46.3	46.3
Weedy check	8.62	11.28	123.33	126.89	66.22	71.33	17.22	17.50	0.60	0.76	1.14	1.35	34.6	36.1
LSD (p=0.05)	0.75	1.58	15.32	14.69	9.52	18.42	NS	NS	0.15	0.14	0.18	0.19	-	-
Interaction (P × W)														
LSD p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	0.26	0.25	0.32	0.33	-	-

LSD-least significant difference at 5% level of significance**,** NS- Non-significant

Table 6. Economic analysis of different treatment combinations in 2018 and 2019

Treatment	Cost of cultivation (x10^3 `/ha)		Gross returns (x10^3 `/ha)		Net returns (x10^3 `/ha)		B:C ratio	
	2018	2019	2018	2019	2018	2019	2018	2019
Bacillus cereus with pretilachlor 0.75 kg/ha	25.65	25.65	25.82	31.12	0.17	5.47	1.01	1.21
Bacillus cereus with pretilachlor 0.75 kg/ha + one HW at 30 DAS	26.50	26.50	43.89	49.09	17.39	22.59	1.66	1.85
Bacillus cereus with three hand weedings (HW) at 15, 30 and 45 DAS	28.90	28.90	50.98	55.87	22.08	26.97	1.76	1.93
Bacillus cereus with weedy check	24.65	24.65	15.28	19.75	-9.37	-4.90	0.62	0.80
Pseudomonas fluorescens with pretilachlor 0.75 kg/ha	25.65	25.65	31.45	36.55	5.80	10.90	1.23	1.43
Pseudomonas fluorescens with pretilachlor 0.75 kg/ha + one HW at 30 DAS	26.50	26.50	52.53	58.30	26.03	31.80	1.98	2.20
Pseudomonas fluorescens with three HW at 15, 30 and 45 DAS	28.90	28.90	56.74	61.74	27.84	32.84	1.96	2.13
Pseudomonas fluorescens with weedy check	24.65	24.65	21.16	24.19	-3.49	-0.46	0.86	0.98
No inoculation with pretilachlor 0.75 kg/ha	25.15	25.15	24.70	29.63	-0.44	4.48	0.98	1.17
No inoculation with pretilachlor 0.75 kg/ha + one HW at 30 DAS	26.00	26.00	37.79	42.54	11.79	16.54	1.45	1.64
No inoculation with Three HW at 15, 30 and 45 DAS	28.40	28.40	37.78	42.88	9.38	14.48	1.33	1.51
No inoculation with weedy check	24.15	24.15	13.06	17.42	-11.09	-6.72	0.54	0.72

growth under these two treatments could have minimized the competition between crop and weeds leading to higher crop uptake of nutrients resulting in better crop growth and yield attributing characters, thus contributing to higher grain yield.

The PGPR and weed management treatments interacted significantly with regards to grain and straw yield. The highest values were given by the combination of *P. fluorescens* and three hand weedings at 15, 30 and 45 DAS which were at par with the combination of *P. fluorescens* and pretilachlor 0.75 kg/ha + hand weeding at 30 DAS. Better weed suppression, plant growth and yield attributing characters under these treatment combinations could finally increase the yields.

P. fluorescens resulted the highest harvest index (43.7 and 43.8) followed by *B. cereus* (43.3 and 43.7) and no inoculation (42.6 and 43.4) in 2018 and 2019, respectively (**Table 5**). Higher dry matter accumulation and its efficient mobilization into grains due to *P. fluorescens* might have resulted higher harvest index. Regarding weed management practices, three hand weedings at 15, 30 and 45 DAS resulted highest harvest index (46.3) closely followed by pretilachlor 0.75 kg/ha + hand weeding at 30 DAS (46.2) in both the years.

Cost of cultivation

Inoculation of *P. fluorescens* along with three hand weedings at 15, 30 and 45 DAS resulted in highest gross returns and net returns but the B: C ratio was lower than *P. fluorescens* along with pretilachlor at 0.75 kg/ha + hand weeding at 30 DAS as the cost of cultivation was higher in the previous treatment due to costly labour requirement to carry out the hand weedings (**Table 6**).

It could be concluded from the study that treatment of rice seeds with *P. fluorescens* and weed management by three hand weedings at 15, 30 and 45 DAS or pretilachlor pre-emergence at 0.75 kg/ha followed by one hand weeding at 30 DAS performed the best in terms of weed suppression, grain yield and economics.

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