Indian Journal of Agricultural Sciences **80** (10): 917–20, October 2010

Performance of rice (*Oryza sativa*) hybrids grown by the system of rice intensification with plant growth-promoting rhizobacteria*

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Received: 16 October 2009; Revised accepted: 24 October 2010

Key words: Plant growth-promoting rhizobacteria, Rice hybrids, Root growth, System of rice intensification, Yield

Low productivity of rice (*Oryza sativa* L.) in India is a major concern for food security. The scarcity of water for agricultural production is becoming a major problem in many countries, particularly the world's leading rice-producing countries like, China and India, where competition and growing demands for freshwater are coming from other sectors (Satyanarayana *et al*. 2007). In such a situation, the use of hybrids and water-saving approaches, such as aerobic rice, direct-seeded rice, mulching and system of rice intensification may help in increasing the rice productivity. Rice hybrids possess a mean grain yield of 6.0–7.9 tonnes/ha with 10–44% higher yield over the popular high-yielding varieties (Wanjari *et al.* 2006), which may help tremendously to raise the rice productivity in India. Furthermore, inoculation of rice seeds/seedlings with plant growth-promoting rhizobacteria may also help in improved nutrient availability, rice growth and yield (Zahir *et al.* 2003). In such scenario, the system of rice intensification (SRI) appears to be a viable alternative of rice cultivation that saves the expensive inputs, improves soil health/quality and protects the environment substantially (Satyanarayana *et al*. 2007). Thakur *et al.* (2010) reported that SRI practices out-yielded recommended management practices by 42%, with the higher yield associated with various phenotypical alterations. In SRI, the soil is kept near saturated moisture condition throughout the vegetative phase and a thin layer of 1–3 cm water is maintained during reproductive phase of rice. There are research reports suggesting the positive role of plant growth promoting rhizobacteria on rice growth and yield (Cong *et al.* 2009, Pedraza *et al.* 2009). The information on the use of plant growth-promoting rhizobacteria for enhanced growth, yield and nutrient uptake of hybrid rice in SRI method is not available. Hence, the present study was undertaken to evaluate the agronomic performance of different rice hybrids grown by system of rice intensification (SRI), along with inoculation of plant growth-promoting rhizobacteria.

A field experiment was conducted during 2007 at the research farm of Indian Agricultural Research Institute, New Delhi (77°12′ E and 28°40′ N; 228.4 m above MSL) during rainy (*kharif*) season (July–October). The soil was sandy clay loam, having 0.53% organic carbon, 0.05% total N, 14.5 kg/ha available P, 248 kg/ha available K and 7.9 *p*H. There were 18 treatments comprising combinations of 6 rice hybrids ('PRH 10', 'KRH 2', 'PHB 71', 'Arize 6444', 'Indam 100-001' and 'Indam 100-003') and 3 plant growth-promoting rhizobacteria (control, *Azospirillum brasilense* CD 4 and *Bacillus subtilis* RP 24), were allocated in factorial randomized block design with 3 replications. Rice nursery was sown on 14 June 2007 according to the SRI practices (Satyanarayana *et al*. 2007). The experimental field was disk-ploughed twice, puddled thrice with a puddler in standing water and leveled. Farmyard manure @ 5 tonnes/ha was incorporated at second ploughing. A uniform basal doses of 26 kg P/ha, 33 kg K/ha and 5 kg Zn/ha through single superphosphate, muriate of potash and zinc sulphate, respectively, were applied just before transplanting. The nitrogen @ 120 kg/ha was applied in 3 splits, i e 1/3 as basal, 1/3 at 13 days after transplanting and remaining 1/3 at 35 days after transplanting through prilled urea in all the plots. The carefully uprooted seedlings were immediately inoculated with 2 strains of rhizobacteria, as per treatment, and transplanted in the main field with gentle placement. One seedling of 14-days-old/hill was transplanted on 28 June 2007 in a square pattern of 25 cm × 25 cm. A thin layer of water depth was maintained uniformly for 10 days for establishment of seedling, then irrigated intermittently before

*Short note

Based on the complete information of MSc thesis of the first author submitted to IARI, New Delhi during 2008

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panicle initiation and after pancile initiation a thin layer of water (1–3 cm) was maintained during reproductive stage. The total rainfall received during the rice growing season of 2007 was 423 mm.

One hand weeding was done at 20 days after transplanting and 1 rotary weeding at 40 days after transplanting. To study the root parameters, root samples were taken from 0 to 20 cm soil depth with the help of core sampler at 60 days after transplanting. Root volume, length, diameter and surface area were determined with the help of a root scanner and after that root samples were dried in oven at 60°C for 24 hr and weighed to take root dry weight. Microbiological activity in terms of fluorescein diacetate hydrolysis (Green *et al*. 2006), dehydrogenase activity (Casida *et al*. 1964) and microbial biomass carbon (Nunan *et al*. 1998) were measured before puddling of the experimental field and just before harvesting of the crop (‘PRH 10’ 5 October 2007, ‘Indam 100-003’ and ‘KRH 2’ 20 October 2007, ‘PHB 71’ and ‘Arize 6444’ 30 October 2007, and ‘Indam 100-001’ 13 November 2007. The total duration of the hybrids ‘PRH 10’, ‘KRH 2’, ‘PHB 71’, ‘Arize 6444’, ‘Indam 100-001’ and ‘Indam 100-003’ was 111, 126, 136, 136, 150 and 126 days. The data relating to each character were analyzed as per the procedure of analysis of variance and significance of a factorial randomized block design, tested by ‘F’ test (Gomez and Gomez 1984).

Plant height increased almost quadratically with increasing plant age and maximum height was attained at harvest. At harvest, ‘Indam 100-001’ was significantly taller than all the other 5 hybrids (Table 1). Overall, the plant height ranged from 101.8 to 120.4 at harvest. Rice hybrid ‘Arize 6444’ accumulated higher dry matter in its shoots at 60 days after transplanting, which was at par with ‘KRH 2’, ‘PHB 71’, ‘PRH 10’ and ‘Indam 100-003’, and significantly higher than ‘Indam 100-001’. At harvest, ‘Indam 100-001’ gave highest number of tillers/hill, being at par to ‘KRH 2’ and ‘Arize 6444’ and significantly higher than ‘PHB 71’, ‘PRH 10’ and ‘Indam 100-003’. At 60 days after transplanting, higher leaf area index was recorded in ‘Indam 100-001’, being at par to ‘Indam 100-003’ and ‘Arize 6444’ but significantly greater than ‘PHB 71’, ‘KRH 2’ and ‘PRH 10’. The data pertaining to root growth parameters are given in Table 2. The higher root length was recorded with ‘Indam 100-003’, which was significantly longer than all other 5 hybrids. Rice hybrid ‘PRH 10’ recorded the least value of root length. ‘PHB 71’ accumulated higher root dry weight, being at par with ’KRH 2’, ‘Arize 6444’ and ‘Indam 100-001’, but significantly higher than ‘PRH 10’. The lowest root dry weight (0.87 g/hill) in ‘PRH 10’ could be attributed to its lower root length. The plant growth-promoting rhizobacteria had a positive and significant impact on root growth of rice. The higher values of root growth parameters, viz length and dry weight were observed with the inoculation of *Azospirillum brasilense*, which were at par to *Bacillus subtilis* inoculation, and significantly higher over the uninoculated control. Overall, inoculation of plant growth promoting rhizobacteria (*Bacillus*

Table 1 Effect of hybrids and plant growth-promoting rhizobacteria (PGPR) on growth, yield attributes and grain yield of rice

Treatment	Growth				Yield attributes					
	Plant height (cm) at harvest	Dry matter accumulation (g/hill) at 60 DAT	Tillers/hill at harvest	Leaf area index at 60 DAT	Panicles/ m^2	Panicle length (cm)	Filled grains/ panicle	Panicle weight (g)	1000-grain weight (g)	Grain yield (tonnes/ ha)
Rice hybrid										
‘KRH 2’	117.5	30.5	24.6	3.30	378	28.1	163	4.6	26.1	5.52
‘Arize 6444’	101.8	32.7	23.7	3.85	365	25.7	154	4.6	25.9	5.23
‘PHB 71’	110.0	26.9	21.4	3.24	331	27.3	161	3.9	24.6	4.93
‘Indam 100-001’	120.4	25.5	24.9	4.25	352	25.6	125	2.6	22.2	3.16
‘PRH 10’	106.3	31.8	20.4	2.93	301	27.7	153	4.2	25.6	4.32
‘Indam 100-003’	115.7	31.2	19.7	4.04	307	28.9	144	3.3	22.1	4.59
CD (*P*=0.05)	7.4	6.5	3.3	0.90	44.8	1.3	8.5	0.4	1.7	0.88
PGPR[1]										
Control	111.1	31.4	21.2	3.66	305	27.0	145	3.7	24.0	4.42
Azospirillum[2]	112.5	27.3	23.0	3.47	371	27.2	154	3.9	24.5	5.09
Bacillus[3]	112.1	30.6	23.0	3.67	341	27.5	151	4.0	24.7	4.39
CD (*P*=0.05)	NS	NS	NS	NS	32.0	NS	6.0	NS	NS	0.62
Rice hybrid × PGPR[1]										
CD (*P*=0.05)	NS	14.8	5.7	NS	80.0	NS	15.0	NS	NS	NS

[1]PGPR; [2]*Azospirillum brasilense* CD4; [3]*Bacillus subtilis* RP24; DAT, Days after transplanting; NS, non-significant

Table 2 Effect of hybrids and plant growth-promoting rhizobacteria on root growth, microbial activity and NPK uptake in rice

Treatment	Microbial activity			Root growth		Total NPK uptake (grain + straw) (kg/ha)		
	FDA[4] Hydrolysis (mg fl/gsoil/h)	Dehydrogen-ase activity (mg TPF/g soil/day)	Microbial biomass carbon (μg C/g soil)	Root dry weight (g/hill)	Root length (cm)	Nitrogen (N)	Phosphorus (P)	Potassium (K)
Rice hybrid								
'KRH 2'	0.50	4.8	148	1.21	2 827	117.3	19.50	171.6
'Arize 6444'	0.81	5.0	126	1.28	2 650	125.6	21.43	189.0
'PHB 71'	0.90	3.9	63	1.32	3 110	115.9	20.06	161.9
'Indam 100-001'	0.57	5.4	148	1.24	3 117	124.9	22.72	199.6
'PRH 10'	0.56	3.8	121	0.87	2 517	116.4	18.90	158.0
'Indam 100-003'	0.61	3.6	102	1.25	3 577	119.9	19.93	173.3
CD (*P*=0.05)	0.18	0.6	50	0.18	444	7.6	0.78	29.1
PGPR[1]								
Control	0.54	3.5	100	0.99	2 976	106.3	18.80	158.4
Azospirillum[2]	0.67	4.8	113	1.30	3 394	135.6	20.94	191.4
Bacillus[3]	0.77	4.9	141	1.30	3 095	118.0	21.52	176.9
CD (*P*=0.05)	0.13	0.4	35	0.13	312	5.4	0.56	20.6
Rice hybrid × PGPR[1]								
CD (*P*=0.05)	NS	1.1	NS	NS	NS	NS	NS	NS

PGPR, Plant growth-promoting rhizobacteria; [2]*Azospirillum brasilense* CD4; [3]*Bacillus subtilis* RP24; NS, non-significant; [4]FDA, Fluoresein diacetate

and *Azospirillum*) enhanced the root growth of rice substantially. Similarly Khalid *et al.* (2004) inoculated wheat seedlings with plant growth-promoting rhizobacteria under axenic conditions and reported increase in root elongation (up to 17.3%), root dry weight (up to 13.5%), shoot elongation (up to 17.3%), and shoot dry weight (up to 36.3%) over the control.

Hybrid 'KRH 2' recorded higher number of panicles/m^2, being at par to 'Arize 6444', 'PHB 71' and 'Indam 100-001' but significantly greater than 'PRH 10' and 'Indam 100-003' (Table 1). Effect of *A. brasilense* and *B. subtilis* inoculation was statistically similar but both gave significantly more number of panicles/m^2 over the uninoculated control. Inoculation of *A. brasilense* and *B. subtilis* resulted in statistically similar number of filled grains/panicle, and both recorded significantly higher number of filled grains/panicle over no inoculation. Higher grain yield was obtained in 'KRH 2', was at par with 'Arize 6444' and 'PHB 71' but significantly higher than that obtained in 'Indam 100–003', 'PRH 10' and 'Indam 100-001' (Table 1). Rice hybrids 'KRH 2', 'Arize 6444' and 'PHB 71' gave 74.7, 65.5 and 56.0% more grain yield, respectively, over 'Indam 100-001'. Inoculation of rice with *A. brasilense* increased the grain yield of rice significantly over the control (uninoculated) and *B. subtilis* inoculation. The increase in grain yield due to inoculation of *A. brasilense* over the control and *B. subtilis* inoculation was to the tune of 15.2 and 15.8% respectively. Biswas *et al.* (2000) reported yield increase of plant growth-promoting rhizobacteria-inoculated rice due to significant increase in number of panicles, filled grains/panicle and total number of spikelets/plant compared to uninoculated plants. The higher total N uptake was recorded in 'Arize 6444', being at par with 'Indam 100–001' and 'Indam 100-003', and significantly higher than 'KRH 2', 'PHB 71' and 'PRH 10' (Table 2). Higher total N uptake was recorded with *Azospirillum* inoculation, which was significantly more than *Bacillus* inoculated and non-inoculated control plots. Higher total P uptake was recorded with 'Indam 100-001', which was significantly higher than rest of the hybrids. *Bacillus* inoculated rice recorded the maximum total P uptake in rice, which was significantly higher to *Azospirillum* inoculated or non-inoculated control. The higher value of fluoresein diacetate hydrolysis was recorded with 'PHB 71', which was at par with 'Arize 6444', but significantly higher than all the other hybrids (Table 2). *Bacillus* inoculation registered higher fluoresein diacetate hydrolysis, which was significantly higher than *Azospirillum* inoculation and non-inoculated control. The dehydrogenase activity was higher in 'Indam 100-001', which was at par with 'Arize 6444' and significantly higher than 'KRH 2', 'PHB 71', 'PRH 10' and 'Indam 100-003'. *Bacillus* inoculation recorded the higher microbial biomass carbon, being at par with *Azospirillum* inoculation, and significantly higher than non-inoculated control.

SUMMARY

A field experiment was conducted at the Indian Agricultural Research Institute, New Delhi, to evaluate the field performance of 6 rice hybrids ('KRH 2', 'Arize 6444', 'PHB 71', 'Indam 100-001', 'PRH 10' and 'Indam 100-003') under system of rice intensification, with inoculation of 3 plant growth-promoting rhizobacteria (control, *A. brasilense* CD 4 and *B. subtilis* RP 24). Higher grain yield was obtained in 'KRH 2' (5.52 tonnes/ha), being at par to 'Arize 6444' (5.23 tonnes/ha) and 'PHB 71' (4.93 tonnes/ha), but significantly higher than that obtained in 'Indam 100-003' (4.59 tonnes/ha), 'PRH 10' (4.32 tonnes/ha) and 'Indam 100-001' (3.16 tonnes/ha). Rice hybrids 'KRH 2', 'Arize 6444' and 'PHB 71' produced 74.7, 65.5 and 56.0% more grain yield, respectively, over 'Indam 100-001'. Inoculation of rice seedlings with plant growth-promoting rhizobacteria had a favourable effect on microbial activity in soil, and shoot growth, root growth and NPK uptake of rice. The increase in grain yield due to inoculation of *A. brasilense* over control and *B. subtilis* inoculation was to the tune of 15.2 and 15.8% respectively.

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