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Effect of planting methods and cyanobacterial inoculants on yield, water productivity and economics of rice cultivation

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Abstract

The impact of two crop planting methods and of the application of cyanobacterial inoculants on plant growth, yield, water productivity and economics of rice cultivation was evaluated with the help of a split plot designed experiment during the rainy season of 2011 in New Delhi, India. Conventional transplanting and system of rice intensification (SRI) were tested as two different planting methods and seven treatments that considered cyanobacterial inoculants and compost were applied with three repetitions each. Results revealed no significant differences in plant performance and crop yield between both planting methods. However, the application of biofilm based BGA bio-fertiliser + 2/3 N had an overall positive impact on both, plant performance (plant height, number of tillers) and crop yield (number and weight of panicles) as well as on grain and straw yield. Higher net return and a higher benefit-cost ratio were observed in rice fields under SRI planting method, whereas the application of BGA + PGPR + 2/3 N resulted in highest values. Total water productivity and irrigation water productivity was significantly higher under SRI practices (5.95 and 3.67 kg ha^{-1} mm^{-1}) compared to practices of conventional transplanting (3.36 and 2.44), meaning that using SRI method, water saving of about 34 % could be achieved and significantly less water was required to produce one kg of rice. This study could show that a combination of plant growth promoting rhizobacteria (PGPR) in conjunction with BGA and 2/3 dose of mineral N fertiliser can support crop growth performance, crop yields and reduces overall production cost, wherefore this practices should be used in the integrated nutrient management of rice fields in India.

Keywords: conventional transplanting, system of rice intensification (SRI), water productivity, economics of rice, biofilm bio-fertiliser, plant growth promoting rhizobacteria (PGPR)

1 Introduction

Rice (*Oryza sativa* L.) is a staple food of more than 50 % of the world's population (Fageria, 2007) and supplies 20 % and 31 % of total calories required by world and the Indian population, respectively (Zeigler & Barclay, 2008). According to the Agricultural Policy Vision 2020 of the Indian Council of Agricultural Research, India has projected a requirement of 112 million tons of rice in the year 2020, which is 23 million tons more than current rice production (Mahajan *et al.*, 2012). Hence, to cope with the increasing demand for food, increases in rice yield and production will be required. Rice plant requires large amount of water and mineral nutrients including nitrogen (N) for their growth, development and grain production. Rice crops remove around 16–17 kg N for the production of each ton of rough rice including straw (De Datta, 1981; Sahrawat, 2000). However, most of the soils where rice is cultivated are deficient in nitrogen and fertiliser application that is applied generally in form of urea, is required to meet the rice crop's N demand. But the efficiency of added urea-N is

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very low, often only 30–40 %, and in some cases even lower (Choudhury & Khanif, 2001; Choudhury *et al.*, 2002). This low N-use efficiency is mainly due to denitrification, NH_3 volatilisation and leaching losses (De Datta & Buresh, 1989). Furthermore, NH_3 volatilisation and denitrification cause atmospheric pollution through the production of greenhouse gases like N_2O and NH_3 (Reeves *et al.*, 2002) and NO_3 leaching causes ground water toxicity (Shrestha & Ladha, 1998). These problems are of great concern to soil and environmental scientists around the world and alternate sources of N like bio-fertilisers and plant growth promoting rhizobacteria (PGPR) can be applied to minimize these problems.

Biological N fixation (BNF) through cyanobacteria, a member of algae group, can play an important role in substituting for commercially available N fertiliser use in rice, thus reducing environmental problems to some extent. The paddy field ecosystem represents a unique aquatic-terrestrial habitat, which provides a favourable environment for the growth and nitrogen fixation by cyanobacteria meeting their requirements for light, water, elevated temperature and nutrient availability (Prasanna *et al.*, 2009). Cyanobacteria comprise a large group of structurally complex and ecologically significant gram-negative prokaryotes, which exhibit a wide range of nutritional capabilities ranging from obligate phototrophy to heterotrophy (Vasudevan *et al.*, 2006). Cyanobacteria can play a major role in improving the soil environment in addition to N fixation. Wetland rice fields can provide an ideal condition for the growth of cyanobacteria, which accumulate 19–28 kg N ha^{-1} per crop, and can reduce the use of urea fertiliser in rice culture by 25–35 % (Hashem, 2001). Experimental results at the International Rice Research Institute (IRRI, Los Banos, Philippines) revealed that the amount of N accumulation by cyanobacteria varies from a few to 50 kg N ha^{-1} crop among different soils (Roger & Ladha, 1992). The literature on the beneficial effects of cyanobacteria on the growth and yield of rice can be voluminous (Kannaiyan *et al.*, 1997; Kennedy & Islam, 2001).

A biofilm is an aggregate of microorganisms in which cells adhere to each other and/or to a surface. The microbial cells growing in a biofilm are physiologically distinct from planktonic cells of the same organism, which, by contrast, are single-cells that may float or swim in a liquid medium. Microbes form a biofilm in response to many factors, which may include cellular recognition of specific or non-specific attachment sites on a surface, nutritional cue, or in some cases, by exposure of planktonic cells to sub-inhibitory concentrations of antibiotics. The biofilmed bio-fertilisers improve nitrogen fixing symbiosis in crops and could contribute directly to soil N fertility in the long term. Biofilms based on cyanobacteria could be beneficial for rice cultivation and have been well demonstrated in both green house and field conditions (Yanni *et al.*, 1997; Biswas *et al.*, 2000a,b).

The traditional method of rice cultivation requires a large amount of labour, water, and energy. Water and labour, however, are becoming increasingly scarce in the region, raising questions about the sustainability of rice production and the overall environment. In the north-west Indo-Gangetic plains (IGP) of India, increasing use of ground water for rice cultivation has led to a decline in the water table by 0.1 to 1.0 m $year^{-1}$, resulting in water scarcity and increased cost for pumping water (Hira, 2009; Rodell *et al.*, 2009; Humphreys *et al.*, 2010). Implementation of the Mahatma Gandhi National Rural Employment Guarantee Act (MNREGA), introduced by the Indian government in 2005 (Government of India, 2011), promising 100 days of paid work in people's home village, has been creating a labour scarcity in Punjab, Haryana and some other states in India as rice transplanting in this region is dependent on migrant labourers from other states. Since rice is primarily grown by transplanting seedlings in flooded puddled fields, it requires a large amount of water (~150 cm), of which 15–20 cm (Singh *et al.*, 2001) is used only for puddling. Alternatives like system of rice intensification (SRI) are required to save water and increase crop, water and labour productivity (Satyanarayana, 2005; Uphoff *et al.*, 2011; Suryavanshi *et al.*, 2012; Singh, 2013).

'SRI offers many insights into ways that production can be increased efficiently and water saved by managing rice crops with more attention to biology and agro-ecology, as summarised in a joint publication by Africare, Oxfam America and the WWF/ICRISAT Project, 2010' (Uphoff *et al.*, 2011). 'The validity of the SRI concept and its methods has been seen now in 42 countries, from Panama to the Democratic People's Republic of Korea. The governments in China, India, Indonesia, Cambodia and Vietnam, where two-thirds of the world's rice is produced, have come to accept and promote these alternative methods based on their own evaluations and experience' (Uphoff *et al.*, 2011). However, cyanobacteria need standing water for their growth, development and nitrogen fixation and unlike conventional method, standing water is not maintained during crop growth period in SRI. As consequence, this difference in water management may affect the growth, development and ultimately nitrogen fixation ability of beneficial cyanobacteria. Hence, in this study we conducted an experiment to evaluate the effect of conventional *vis-à-vis* SRI cultivation methods on growing performance of different cyanobacteria inoculants and their economic efficiency in rice production systems.

2 Materials and methods

2.1 Experimental site

The experiment was conducted during the rainy season (June to October) of 2011 at the research farm of the Indian Agricultural Research Institute (IARI), New Delhi, India (28° 40' N, 77° 12' E) located at 228.6 meters above the mean sea level (Arabian Sea). At the start of the experiment, composite soil samples were collected from different sites and analysed for their mechanical composition as well as important physico-mineral and biological properties. The soil of the experimental field was sandy clay loam in texture, with moderate water holding capacity and well levelled topography. The soils of experimental field had 134.9 kg ha^{-1} alkaline permanganate oxidizable N (after Subbiah & Asija, 1956), 15.90 kg ha^{-1} available P (Olsen's method) (after Jackson, 1973), 260.83 kg ha^{-1} 1N ammonium acetate exchangeable K (after Prasad *et al.*, 2006), 0.53 % organic carbon (after Walkley & Black, 1934) and pH 8.1 (1:2.5 soil and water ratio). The gross plot size was 6.2 m × 2.46 m for each treatment and crop was harvested in the last fortnight of October.

2.2 Agro-meteorological condition

The climate of Delhi is of sub-tropical and semi-arid type with hot and dry summer and cold winter and is categorised under the agro-climatic zone 'Trans-Gangatic plains'. The summer months of May and June are the hottest with maximum temperature ranging between 41°C and 46°C, while January is the coldest month of the year with a minimum temperature ranging from 5°C to 7°C. The mean annual normal rainfall is on average 650 mm, while August is normally the wettest month. The annual mean pan evaporation is about 850 mm. During June to October maximum and minimum temperatures ranged between 43.6°C (8 June) to 29.4°C (30 October) and 11.9°C (28 October) to 29°C (7 June), respectively. With 539.4 mm from June to October, the year 2011 had less than normal rainfall amounts out of which 43.8, 226.8 and 163.6 mm rainfall which comprised 80.5 % of the total rainfall was received during July, August and September 2011, respectively (Fig.1). There were 6, 9 and 11 numbers of rainy days during July, August and September months, respectively, with no rainfall in October. The onset of monsoon was late in 2011 wherefore the month July had much less rainfall than on average. Difference in maximum and minimum daily relative humidity was highest in June and October.

2.3 Treatments

The experiment was organised in split plot design with seven treatments combinations of cyanobacteria inoculants and incorporating two methods of rice cultivation, namely conventional transplanting (CT) and system of rice intensification (SRI). With three repetitions each, the following treatments were applied: (1) no nitrogen application, (2) recommended N application of 120 kg ha^{-1}, (3) compost application with 1/3 N + 2/3 N, (4) biofilm based Blue Green Algae- bio-fertiliser (BGA) + 2/3 N, (5) BGA + plant growth-promoting rhizobacteria (PGPR) + 2/3 N, (6) compost based BGA mixture inoculant + 2/3 N and (7) Fuller's earth (Multani mitti) based BGA inoculant + 2/3 N. The fertilisation with 2/3 N (80 kg ha^{-1}) and the recommended dose of N (120 kg ha^{-1}) was done through urea and applied in three equal splits at the stage of transplanting, active tillering and panicle initiation. PGPR and multani mitti based BGA were applied at the rate of 1.5 kg ha^{-1} at the time of rice transplanting through seedling root treatment. For the estimation of quantity of compost

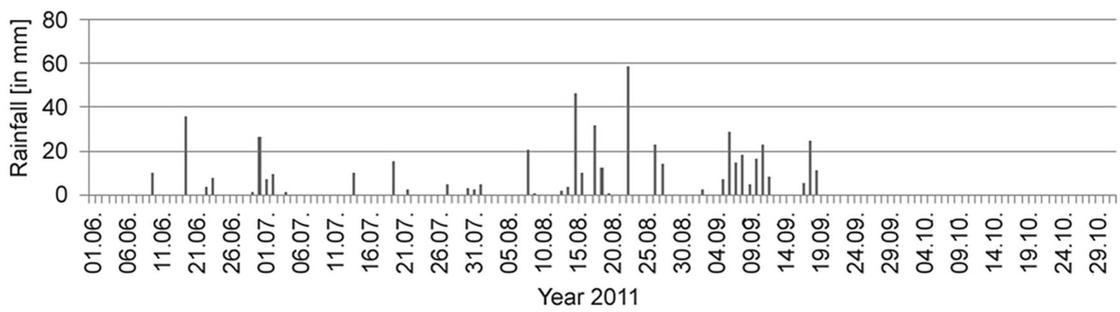

Fig. 1: *Daily rainfall amount (in mm) during the experimental period from June to October 2011 at the Indian Agricultural Research Institute.*

to supply 1/3 N, its N content (0.45 % N) was taken into consideration. The biofilm based BGA bio-fertiliser was developed on the base of compost and contained strains of *Anabaena* sp. and *Pseudomonas* sp. For BGA + PGPR, PR-10 strain of *Ochromobacterium* sp. and CR-2 strain of *Anabaena* sp. was used. In compost based BGA mixture *Anabaena* sp. (BF1, BE4) and *Noctoc* spp. (BF2, BF3) were taken whereas Multani mitti based BGA comprised cultures of *Anabaena* sp., *Noctoc* sp., *Tolipothrics* sp. and *Aulocera* sp..

2.4 Agronomic management of the experimental field

2.4.1 Seedling raising and transplanting

For conventional transplanting (CT), nursery beds of 1.0 m width and 4.0 m length were prepared with 50 cm drainage cum irrigation channels around the beds. A total size of 600 m^2 of nursery beds was required to transplant afterwards an area of one hectare. Rice seeds were pre-soaked for 12 hours and incubated in moist gunny cloth for further 24 hours before carrying uniformly to the nursery beds. For SRI, seeds were sown 12 days before proposed transplanting date with a seed rate of 6 kg ha^{-1}. After carrying the sprouted seeds 1:1 soil-farm yard manure mixture (FYM) was applied in a thin layer of 1–2 cm. Irrigation were carried out as required to keep the nursery bed moist. The experimental field was disc-ploughed twice and levelled. After puddling, seedlings of rice were transplanted under conventional transplanting with 20 cm × 10 cm spacing, keeping two seedlings per hill. For SRI, 12 days old seedlings were gently transplanted in main field at the spacing of 25 cm × 25 cm keeping one seedling per hill. For both methods transplanting was done manually on the same day and gap filling was done one week after transplanting.

2.4.2 Irrigation management

For the CT method, a 5 cm water level was maintained during the whole time from transplanting to grain filling stage and afterwards continuous moist soil conditions were maintained. However for SRI, a 2 cm water level was offered until panicle initiation stage first and then increased to a 5 cm water level to ensure grain filling. Also for SRI sufficient moist soil conditions were maintained after grain filling stage. However, alternate wetting and drying conditions were maintained until panicle initiation stage as described for the SRI method.

2.4.3 Nutrient and weed management

In the experiment equal doses of P_2O_5 and K_2O ha^{-1} at the rate of 60 kg ha^{-1} were applied in all the plots as basal application. Nitrogenous fertiliser was applied in three equal splits through urea at transplanting, active tillering and panicle initiation stage in all treatments except the treatment containing no nitrogen application. To control weeds, mechanical hand weeder (rotating hoe) was used in SRI method. It was done two times before the canopy closure. In conventional method hand-weeding was done to control weeds. Early flooding also helped in reducing weed population in CT.

2.5 Plant growth, yield and economic estimation

Plant height of the rice was measured from the base of the plant at ground surface to the tip of the tallest leaf or panicle. Numbers of tillers were noted by counting from the sampling unit. The leaf area index (LAI) indicates the photosynthetic capacity of a plant and was determined at 60 days after transplanting (60 DAT) as per the formula suggested by Evans (1972). Dry matter accumulation was calculated from five hills taken from each sampling area dry weight was calculated in g m^{-2} after oven drying at 60±2°C. Plant growth parameters were measured by taking observation in all three replications for each treatment. Ten panicles were selected from all replications of each treatment for measurement of panicle length and weight and number of grains per panicle. The 1,000-filled grains, taken from sampled panicles, were counted by a seed counter and afterwards weighed to compute the 1,000-grain weight. For rice yield measurements, an area of 4 m^2 per plot was harvested manually and kept for drying in field itself and before threshing total biomass was recorded to calculate straw yield. After harvesting, threshing, cleaning and drying the grain yield was recorded at 14 % moisture. Straw yield was obtained by subtracting grain yield from the total biomass yield. Yield was expressed in tons ha^{-1}. Gross and net returns were calculated based on the grain and straw yield and their prevailing market prices during the respective crop season. The benefit-cost ratio (BCR) was calculated by dividing the net returns from total cost of cultivation.

2.6 Water use and productivity

As described above, water level management varied for both cultivation methods. Water levels were measured by using an ordinary scale metre at ten selected spots after each irrigation and mean depth of irrigation water level was calculated for each plot. Irrigation water use (in mm) was described as the sum of mean depth for each irrigation and total water use (in mm) was the sum of irrigation water use and rainfall amount. The resulting water productivity and water savings were afterwards calculated as follows:

Water productivity ($kg\,ha^{-1}\,mm^{-1}$) = Grain yield ($kg\,ha^{-1}$) / Total water consumed (mm)

Water saving (%) = (Water used in CT – Water used in SRI) × 100 / Water use in CT.

2.7 *Statistical analysis*

All the data obtained from the experiment conducted via split plot design were statistically analysed using the F-test as per the procedure given by Gomez & Gomez (1984). Least significant difference (LSD) values at P = 0.05 were used to determine the significance of difference between treatment means. Furthermore, interaction effect was analysed considering the same experimental design.

3 Results

3.1 *Plant growth parameters*

In this study we found no significant effect of the cultivation method on overall plant growth performance (Table 1). Thus for instance, average rice plant height at harvest stage under CT and SRI was 105.7 cm and 104.5 cm, respectively. However, the treatment of rice plants with BGA+PGPR and 2/3 nitrogen through mineral fertiliser resulted an increase in plant height and plants were on average higher than treatments containing biofilm based BGA bio-fertiliser + 2/3 N, mineral fertiliser and multani mitti based BGA inoculant + 2/3 N through mineral fertiliser. The treatment with BGA+PGPR and 2/3 nitrogen showed also highest number of tillers per m^2 and highest dry matter accumulation (760.6 $g\,m^{-2}$), but did not differ significantly from treatments including compost application and compost based BGA mixture inoculant + 2/3 N. The treatment with BGA+PGPR and 2/3 nitrogen had furthermore a positive impact on leaf area and was significantly higher than for rice plants cultivated with biofilm based BGA bio-fertiliser + 2/3 N and multani mitti based BGA inoculant + 2/3 N. Furthermore, we found a significant interaction effect between planting method and bacterial inoculants for all plant growth parameters.

3.2 *Yield attributes*

While comparing average yield attributes of rice plants cultivated under CT and SRI, no significant differences were evident (Table 2). Thus for instance, numbers of panicle per m^2 rice field were 356.5 and 353.1 in CT and SRI, respectively while respective values for grain per panicle were 157.2 and 158.2. As for plant growing performance, the treatment with BGA+PGPR + 2/3 N also had a positive impact on the number, weight and length of panicles and the number of grain per panicle were differed significantly from those treatments that considered biofilm based BGA bio-fertiliser + 2/3 N and multani mitti based BGA inoculant + 2/3 N. With exception of test weight, we found a significant interaction effect between planting method and cyanobacterial inoculants for all rice yield attributes.

3.3 *Grain and straw yield*

Grain and straw yield as well as harvest index showed no significant differences under conventional transplanting and SRI method for rice cultivation (Table 3). Here, grain yield and straw yield of rice fields under CT cultivation were only marginally higher than under SRI cultivation and harvest index of 0.35 was the same for both cultivation methods. Under BGA+PGPR + 2/3 N, rice fields showed highest grain (4.69 $tons\,ha^{-1}$) and straw (8.56 $tons^{-1}$) yield which were significantly higher than of rice fields treated by biofilm based BGA bio-fertiliser + 2/3 N and multani mitti based BGA inoculant + 2/3 N. Although planting method alone did not has a significant impact on grain and straw yield, the interaction effect between planting method and cyanobacterial inoculants was significant.

3.4 *Water use and crop water productivity*

In total, 26 irrigation events from transplanting to grain filling stage were necessary to ensure rice growing performance (Table 4). Regarding the different cultivation methods, a total of 1300 litres of water was irrigated to produce one kilogramme of rice under CT cultivation and 730 litres of irrigation was used under SRI method. The additional amount of water during crop growth through rainfall was 492 mm on CT fields and 452.2 mm on SRI fields. Crop water productivity was significantly higher under SRI cultivation (5.95 $kg\,ha^{-1}\,mm^{-1}$) as compared to CT cultivation (3.36 $kg\,ha^{-1}\,mm^{-1}$). The total water utilisation (rainfall + irrigation) was higher under CT (1792 mm) as compared to SRI (1182.2 mm), resulting in a saving of 34.03 % water under SRI cultivation. Total water productivity of SRI was significantly higher (3.67 $kg\,ha^{-1}\,mm^{-1}$) as compared to CT (2.44 $kg\,ha^{-1}\,mm^{-1}$) and resulted in a decreased amount of irrigation water (1739.4 litres) and total water use (2816.9 litres) that is required to produce one kg of rice under SRI method. In comparison, for the conventional method of transplanting, 3001.3 litres of irrigation water and 4137.2 litres of total water had to be used to produce one kg of rice.

Table 1: *Effect of conventional transplanting and SRI method and seven cyanobacterial inoculants on rice plant growth parameters at crop harvest stage (LAI 60 DAT = leaf area index at 60 days after transplanting; NS = not significant; Sig. = significant at P=0.05 level).*

Treatment	*Plant height (in cm)*	*No. of tillers per m^2*	*Dry matter accumulation ($g\,m^{-2}$)*	*LAI (60 DAT)*
Planting method				
Conventional transplanting	105.7	356.5	711.2	4.80
SRI	104.2	353.1	709.3	4.78
SEM	0.74	1.75	2.07	0.032
LSD (P=0.05)	NS	NS	NS	NS
Cyanobacterial inoculants				
No nitrogen application	86.7	247.7	473.1	3.20
Recommended dose of N (120 kg ha^{-1})	110.7	378.5	754.0	5.23
Compost application (1/3 N) + 2/3 N	110.4	376.2	751.3	5.17
Biofilm based BGA bio-fertiliser + 2/3 N	103.6	362.8	743.3	4.82
BGA + PGPR + 2/3 N	111.4	382.8	760.6	5.26
Compost based BGA mixture + 2/3 N	109.8	375.0	750.3	5.12
Multani mitti based BGA inoculant + 2/3 N	102.2	360.8	739.1	4.75
SEM	1.52	4.01	5.06	0.087
LSD (P=0.05)	4.45	11.71	14.78	0.253
Planting method × Cyanobacterial inoculants				
SEM	2.15	5.67	7.15	0.122
LSD (P=0.05)	Sig.	Sig.	Sig.	Sig.

Table 2: *Effect of conventional transplanting and SRI method and seven cyanobacterial inoculants on rice yield attributes (NS = not significant; Sig. = significant at p=0.05 level).*

Treatment	*No. of panicle m^{-2}*	*Weight of panicle (g)*	*Length of panicle (cm)*	*Grains per panicle*	*Test weight (g)*
Planting method					
Conventional transplanting	356.5	2.8	28.7	157.2	21.4
SRI	353.1	2.8	28.7	158.2	21.4
SEM	1.75	0.02	0.08	0.70	0.11
LSD (P=0.05)	NS	NS	NS	NS	NS
Cyanobacterial inoculants					
No nitrogen application	247.7	1.8	26.1	125.7	21.2
Recommended dose of N (120 kg ha^{-1})	378.5	3.1	29.6	168.0	21.5
Compost application (1/3 N) + 2/3 N	376.2	3.0	29.4	165.7	21.4
Biofilm based BGA bio-fertiliser + 2/3 N	362.8	2.7	28.4	154.2	21.3
BGA + PGPR + 2/3 N	382.8	3.2	30.0	171.6	21.7
Compost based BGA mixture + 2/3 N	375.0	2.9	29.4	164.9	21.5
Multani mitti based BGA inoculant + 2/3 N	360.8	2.7	28.3	154.0	21.3
SEM	4.01	0.07	0.25	3.20	0.33
LSD (P=0.05)	11.71	0.20	0.74	9.35	0.95
Planting method × Cyanobacterial inoculants					
SEM	5.67	0.10	0.35	4.53	0.46
LSD (P=0.05)	Sig.	Sig.	Sig.	Sig.	NS

Table 3: *Effect of conventional transplanting and SRI method and seven cyanobacterial inoculants on rice grain yield, straw yield and harvest index (NS = not significant; Sig. = significant at P=0.05 level).*

Treatment	*Grain yield (tons ha^{-1})*	*Straw yield (tons ha^{-1})*	*Harvest index (%)*
Planting method			
Conventional transplanting	4.37	8.21	0.35
SRI	4.34	8.11	0.35
SEM	0.015	0.057	0.002
LSD (P=0.05)	NS	NS	NS
Cyanobacterial inoculants			
No nitrogen application	3.18	6.96	0.31
Recommended dose of N (120 kg ha^{-1})	4.68	8.54	0.36
Compost application (1/3 N) + 2/3 N	4.64	8.48	0.36
Biofilm based BGA bio-fertiliser + 2/3 N	4.38	8.06	0.35
BGA + PGPR + 2/3 N	4.69	8.56	0.36
Compost based BGA mixture + 2/3 N	4.63	8.51	0.35
Multani mitti based BGA inoculant + 2/3 N	4.29	8.00	0.35
SEM	0.070	0.121	0.01
LSD (P=0.05)	0.205	0.353	0.02
Planting method × Cyanobacterial inoculants			
SEM	0.099	0.171	0.008
LSD (P=0.05)	Sig.	Sig.	Sig.

Table 4: *Effect of planting method and cyanobacterial inoculants on water productivity of rice cultivation systems.*

Treatment	*Total water productivity (kg ha^{-1} mm^{-1})*	*Total water / kg of rice (litre kg^{-1})*	*Irrigation water productivity (kg ha^{-1} mm^{-1})*	*Irrigation water / kg of rice (litre kg^{-1})*
Planting method				
Conventional transplanting	2.44	4137.2	3.36	3001.3
SRI	3.67	2816.9	5.95	1739.4
SEM	0.0112	24.67	0.0181	16.66
LSD (P=0.05)	0.0679	150.09	0.1099	101.34
Cyanobacterial inoculants				
No nitrogen application	2.18	4634.9	3.30	3136.1
Recommended dose of N (120 kg ha^{-1})	3.31	3204.2	5.05	2191.5
Compost application (1/3 N) + 2/3 N	3.23	3185.7	4.91	2168.1
Biofilm based BGA bio-fertiliser + 2/3 N	3.06	3388.0	4.66	2308.8
BGA + PGPR + 2/3 N	3.30	3182.4	5.04	2174.4
Compost based BGA mixture + 2/3 N	3.31	3284.3	5.07	2255.0
Multani mitti based BGA inoculant + 2/3 N	3.00	3459.9	4.57	2358.7
SEM	0.055	58.39	0.087	38.84
LSD (P=0.05)	0.159	170.44	0.253	113.38
Planting method × Cyanobacterial inoculants				
SEM	0.077	82.58	0.122	54.93
LSD (P=0.05)	0.225	241.04	0.357	160.34

3.5 *Economics of rice cultivation*

Cost of cultivation was lower for all rice field treatments under SRI cultivation as compared to the conventional transplanting method (Table 5). Further, cost of cultivation was higher in the treatments considering compost application compared to other treatments. Net return and benefit-cost ratio in all treatments was also higher under SRI cultivation compared to CT cultivation. The BGA + PGPR + 2/3 N treatment (USD1381.4) and the treatment with recommended dose of N (RDN) (USD1380.6) under SRI method resulted in the highest net return per hectare and showed the best benefit-cost ratio.

4 Discussion

This study could show that plant growth and yield of experimental rice fields at the Indian Agricultural Research Institute in New Delhi were not affected by the two applied planting methods. Nissanka & Bandara (2004) found also no variation in plant height between the SRI and conventional transplanting method while Haque (2002) found the highest rice plant height under SRI cultivation, presumably due to lower planting densities. Also Akita & Tanaka (1992) reported that at maturity the tallest plants were found at low plant density. Tillering is an important factor which decides the numbers of panicle m^{-2} and ultimately the yield of rice. Numbers of tillers in both methods were statistically at par at harvest stage on unit area basis. However, tillers per hill were higher under SRI compared to CT and was probably the effect of higher plant spacing of the SRI cultivation (25 cm × 25 cm) which makes more space available for growth of individual hills compared to CT cultivation. Hence, a comparison of tillering ability of rice plants under different cultivation methods seems to be more appropriate for the calculation of rice crop yield since this formula considers unit area (see also Nissanka & Bandara, 2004). They also observed that the tiller number per plant was higher under SRI cultivation than under conventional transplanting, but when expressed per unit area basis; this parameter was not significantly different anymore. The practice of transplanting one young seedling per hill with wider spacing as this is done under SRI can result in a reduced transplanting injury, increased number of tillers (Horie *et al.*, 2004) and minimizes the competition between plants (Rabenandrasana, 1999). Furthermore, the early transplanting under SRI induced the transplanting shock at a more convenient point in the growth cycle of rice plants when they could rebound faster and had little effect on tillers (Uphoff, 2002). Maintenance of alternate wetting and drying at early crop growth stage

Table 5: *Economics of rice cultivation under conventional transplanting and of systems of rice intensification (SRI) using cyanobacterial inoculants (B: C ratio = benefit-cost ratio).*

Treatment	*Cost of cultivation ($USD\ ha^{-1}$)*	*Gross return ($USD\ ha^{-1}$)*	*Net return ($USD\ ha^{-1}$)*	*B:C ratio*
Conventional transplanting method				
No nitrogen application	753.43	1567.78	814.54	1.08
Recommended dose of N (120 kg ha^{-1})	778.98	2022.35	1243.37	1.60
Compost application (1/3 N) + 2/3 N	918.61	2047.41	1128.80	1.23
Biofilm based BGA bio-fertiliser + 2/3 N	771.94	1914.39	1142.44	1.48
BGA + PGPR + 2/3 N	771.94	2033.52	1261.57	1.63
Compost based BGA mixture + 2/3 N	771.94	1880.56	1108.61	1.44
Multani mitti based BGA inoculant + 2/3 N	771.94	1971.30	1199.35	1.55
SRI method				
No nitrogen application	705.26	1424.44	719.19	1.02
Recommended dose of N (120 kg ha^{-1})	734.19	2111.48	1380.67	1.89
Compost application (1/3 N) + 2/3 N	870.44	1890.37	676.96	1.35
Biofilm based BGA bio-fertiliser + 2/3 N	723.78	1892.04	1168.22	1.61
BGA + PGPR + 2/3 N	723.78	2105.19	1381.41	1.91
Compost based BGA mixture + 2/3 N	723.78	1886.30	1320.11	1.82
Multani mitti based BGA inoculant + 2/3 N	723.78	1877.22	1153.44	1.59

can support the opening of the soil for oxygen and nitrogen and can promote in turn the root growth during initial growth stages which ultimately increased tiller density under SRI (Uphoff, 2001). While Lu *et al.* (2004) reported that a dense spacing increased the dry matter production of rice, in our study dry matter accumulation did not show any significant difference between CT and SRI cultivation. In contrast to Kim *et al.* (1999) and Ray *et al.* (2000) who reported a higher leaf area index under closer spacing, and Vijayakumar *et al.* (2006) who observed a higher LAI in wider spacing, we found no differences in leaf area index under the two applied cultivation practices. Shrirame *et al.* (2000) could show that the number of functional leaves, leaf area and total number of tillers per hill were higher at wider spacing which leads to an increased photosynthetic rate, resulting in taller plants.

The evaluated yield attributes like panicle number m^{-2}, weight and length of panicles, number of grain per panicle and test weight of rice grain were statistically at par under conventional and SRI methods. However, Husain *et al.* (2004) observed higher number of effective tiller and number of grains per panicle under SRI compared to farmers' practice. Vongsakid (2002) noticed highest number of effective tillers when transplanted at spacing of 40 cm × 40 cm and Wang *et al.* (2002) reported higher number of effective tillers in the younger transplanted seedlings. Furthermore, Gasparillo *et al.* (2001) noted a significant variation in panicle length between the SRI and non-SRI methods. Nevertheless, likewise our experimental study could show, Anitha & Chellappan (2011) observed that although productive tillers and weight of panicles were higher in the 25 cm × 25 cm spacing, number of panicles was significantly more in the 20 cm × 15 cm spacing. In contrast, Ang *et al.* (2002) obtained maximum filled grains per panicle from 40 cm × 40 cm spacing of the SRI.

Concerning the 1000-grains weight, a study of Bari (2004) confirmed our observation about the only marginal impact of planting method on 1000-grains weight, while Hossain *et al.* (2003) and Husain *et al.* (2004) observed higher 1000-grains weight under SRI compared to the farmers' conventional transplanting practice.

In our experimental fields, grain and straw yield and harvest index under conventional and SRI method of planting showed also no significant differences. But contrasting results have been reported about the effects of planting methods on yield of rice, wherefore Anitha & Chellappan (2011) reported that yield under SRI management (planting 10 days old seedling at 25 cm × 25 cm + intermittent irrigation and conoweeding) was lower than that of recommended practices (20 days olds seedling at 20 cm × 15 cm + continuous irrigation and hand weeding) but it was greater than that of farmer practices. Nissanka & Bandara (2004) reported that grain yield in SRI was 7.6 t ha^{-1} which was 9 %, 20 % and 12 % greater than the conventional transplanting, and normal and high density broadcasting. They concluded that the higher grain yield production in the SRI farming system might be attributed to the vigorous and healthy growth, development of more productive tillers and leaves ensuring greater resource utilisation under SRI compared to conventional transplanting and broadcasting systems. Husain *et al.* (2003) found 39 % higher straw yield in SRI compared to traditional methods. Suryavanshi *et al.* (2012) reported significantly higher grain yield in SRI compared to conventional transplanting. Stoop (2005) and Hossain *et al.* (2003) also found a higher harvest index under SRI planting method compared to the conventional method, though, Barison (2003) found no difference for the same.

Although planting method did not show a significant impact on plant performance and crop yield in our experimental fields, the different treatments with cyanobacteria based inoculants and PGPR revealed a clear effect on both. The application of cyanobacteria based inoculants and PGPR to our experimental rice fields increased the crop growth, yield and water productivity. Free-living cyanobacteria are known to contribute an average of 20–30 kg N ha^{-1}, and the value is reported up to 600 kg ha^{-1} for the *Azolla-Anabaena* system. Besides their N-enrichment potential, they are known to increase the water holding capacity, porosity and cation exchange capacity of soils (Whitton, 2000). Sakthivel *et al.* (1986) reported 12–27 % greater plant height in response to PGPR inoculation than the non-inoculated control in rice. Sathiya & Ramesh (2009) also reported a positive influence of PGPR on growth parameters like plant height, tillers and dry matter production of aerobic rice under different nitrogen management practices. The PGPR isolates significantly increased the shoot length of rice seedlings (Ashrafuzzaman *et al.*, 2009) and Chi *et al.* (1998) could show from field trials that *Azospirillum* inoculated rice seedlings were taller and more vigorous than the non-inoculated controls. Ahmad *et al.* (2011) found increased plant height, tillers, dry matter accumulation, yield attributes and yield of rice due to the application of bio-fertilisers like BGA and *Azolla*. Prayitno *et al.* (1999) investigated the interaction between two groups of rice endophytic bacterial strains and several rice cultivars and found that rice-associating bacteria could promote, inhibit or have no influence on plant growth. Baghel (2011) reported increased plant height, tillers, dry matter accumulation and higher LAI of rice due to the application of nitrogen by different organic and inorganic sources. A significant increase in shoot dry matter of rice seedlings was observed in response to PGPR isolates (Ashrafuzzaman *et al.*, 2009). Choudhary *et al.* (2010) found a significantly positive impact of PGPR on number of panicles per hill and filled grains per hill of rice. Biswas *et al.* (2000a) reported that yield increase of PGPR-inoculated rice was obtained due to the significant increase in number of panicles and filled grains per panicle, and also the total number of spikelet per plant as compared to un-inoculated plants. Similarly, Elbadry *et al.* (1999) reported that inoculation with PGPR significantly increased plant dry weight and number of productive tillers when compared to the non-inoculated control. Hence, use of PGPR helps in improving the major yield attributes of rice.

Increase in crop growth and grain yield and their protein content due to fertilizing action of N_2-fixing cyanobacteria has been generally attributed to the release of synthesised nitrogenous compounds either by decomposition of the cells or by excretion (Nayak *et al.*, 2004). Wetland rice field can provide an ideal condition for the growth of cyanobacteria, which accumulate 19-38 kg N ha^{-1} per crop and reduce the use of urea fertiliser in rice culture by 25–33 % (Hashem, 2001). de Mule *et al.* (1999) reported positive effect of cyanobacteria inoculation on rice seedling, dry weight and shoot length as compared to control. Omar *et al.* (1989) reported 15–20 % increase in rice yield due to the application of PGPR while Kloepper *et al.* (1989) found only 4.9 to 15.5 % increase in yield. Trân Van *et al.* (2000) observed an increase in rice grain yield by 13 to 22 % due to application of PGPR. But several studies such as Smith *et al.* (1984) could also show that an inappropriate combination of bacteria and crop plant often resulted in a negative effect on the nitrogen accumulation and growth of the host plant. A number of experiments showed that the extent of the positive effect of the bacteria on nitrogen accumulation and crop growth varied with the species or variety of the host plant (Bouton & Brooks, 1982). Hence, because of varying ecological factors and environmental conditions, bacterial inoculation may not always result in persistent response (Lynch, 1990). Thus performance of cyanobacteria in terms of their nitrogen fixation ability which is reflected in yield of rice is highly influenced by the soil, climate, management practices and strain of cyanobacteria used. This might be the reasons for the variation in the results of numerous studies. Cyanobacteria in generally reported to respond better under submerged/flooded conditions but in our study cyanobacteria responded well even under SRI where standing flooded conditions were not maintained. This was reflected through our results about rice yields that showed no significant differences between both planting methods. This indicates that the used strains of cyanobacteria worked well in SRI having saturated moisture condition in soil.

Yield obtained using both methods of cultivation was similar, whereas the applied water amount under SRI cultivation was lower than under the conventional transplanting method. This reduced water application resulted in an increased efficiency of water resources which was measured in terms of water productivity, total water kg^{-1} of rice and percent water saving that reached 34.03 % under SRI cultivation practice. Similar results were reported earlier by Singh (2013) who detected water saving of 34.5–36.0 % in SRI over conventional rice whereas Suryavanshi et al. (2013) reported a saving of 27.4 % of irrigation water and 18.5 % of total water in SRI over conventional transplanting. The difference in amount of water saving was mainly due to variation in the rainfall over the year and duration of the crop. Mathew *et al.* (2003) reported that intermittent irrigation was as good as continuous submergence, but may save about 50 % of irrigation water use. Chapagain & Yamaji (2010) observed that the alternate wetting and drying (AWDI) saved 28 % water compared to the amount of water required in continuously flooded plots. Numerous studies conducted on the manipulation of depth and intervals of irrigation intended to save water have demonstrated that a continuous submergence is not essential for obtaining high rice yields (Guerra *et al.*, 1998). This could be also shown by our experiment as differences in rice yield for both planting methods was negligible. After conducting research over several years, Bhuiyan & Tuong (1995) concluded that maintaining a significant depth of water throughout the season is not needed for high rice yields. Thus, about 40–45 % of the water normally used in irrigating the rice crop can be saved by applying water in small quantities through keeping the soil saturated throughout the growing season, without sacrificing rice yield.

A higher water productivity due to the application of cyanobacterial and compost was also recorded. This might be due to better soil aggregation after the application of compost and cyanobacteria inoculants. In our experiment soil aggregations at 0–7.5 and 7.5–15 cm depths were significantly higher in the treatments having compost application (1/3 N) + 2/3 N (fertiliser) compared to other treatments. Cyanobacteria are known to contribute to macro-aggregation and result in an improved resistance to soil erosion, because as primary producers, they contribute to the enrichment of soil with soil organic matter and to the improvement of biological activity (Acea *et al.*, 2003). Cyanobacteria are further known to secrete extracellular polymeric substances (EPS) dominated by polysaccharides which can bind soil particles (Malam Issa *et al.*, 2001). Malam Issa *et al.* (2007) observed an improvement in the aggregation of cyanobacteria inoculated soils which could be related to the increased soil carbon and EPS that caused changes in the soil micro-morphological characteristics of the aggregates.

Our cost-benefit analysis revealed that highest BCRs were achieved by using the planting method of SRI. This was mainly due to lower expenditures for nursery, seeds and irrigation. Furthermore, the cost of rice cultivation was higher in the treatments that considered compost application that resulted in a higher price of per unit N supply.

5 Conclusion

Cyanobacteria inoculants can be used to replace approximately one-third (40 kg N) of the recommended dose of N fertiliser. From the present investigation we concluded that combination of plant growth promoting rhizobacteria (PGPR) in conjunction with BGA and 2/3 dose of mineral N fertiliser achieved a very good crop growth performance, high yields and reduced overall production cost, wherefore this practices can be used in the integrated nutrient management of rice fields in India. In comparison to conventional transplanting practices, only half of the irrigation water had to be used to produce also one kilogramme of rice by applying the planting method of SRI. Thus SRI can be adopted to save water without compromising yield.

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