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Influence of Crop Nutrition on Grain Yield, Seed Quality and Water Productivity under Two Rice Cultivation Systems

Y. V. SINGH[1], K. K. SINGH[2], S. K. SHARMA[2]
([1]*Centre for Conservation and Utilization of Blue Green Algae, Indian Agricultural Research Institute, New Delhi-110012, India;* [2]*Seed Production Unit, Indian Agricultural Research Institute, New Delhi-110012, India*)

Abstract: The system of rice intensification (SRI) is reported to have advantages like lower seed requirement, less pest attack, shorter crop duration, higher water use efficiency and the ability to withstand higher degree of moisture stress than traditional method of rice cultivation. With this background, SRI was compared with traditional transplanting technique at Indian Agricultural Research Institute, New Delhi, India during two wet seasons (2009–2011). In the experiment laid out in a factorial randomized block design, two methods of rice cultivation [conventional transplanting (CT) and SRI] and two rice varieties (Pusa Basmati 1 and Pusa 44) were used under seven crop nutrition treatments, *viz*. T_1, 120 kg/hm^2 N, 26.2 kg/hm^2 P and 33 kg/hm^2 K; T_2, 20 t/hm^2 farmyard manure (FYM); T_3, 10 t/hm^2 FYM + 60 kg/hm^2 N; T_4, 5 t/hm^2 FYM + 90 kg/hm^2 N; T_5, 5 t/hm^2 FYM + 60 kg/hm^2 N + 1.5 kg/hm^2 blue green algae (BGA); T_6, 5 t/hm^2 FYM + 60 kg/hm^2 N + 1.0 t/hm^2 *Azolla*, and T_7, $N_0P_0K_0$ (control, no NPK application) to study the effect on seed quality, yield and water use. In SRI, soil was kept at saturated moisture condition throughout vegetative phase and thin layer of water (2–3 cm) was maintained during the reproductive phase of rice, however, in CT, standing water was maintained in crop growing season. Results revealed that CT and SRI gave statistically *at par* grain yield but straw yield was significantly higher in CT as compared to SRI. Seed quality was superior in SRI as compared to CT. Integrated nutrient management (INM) resulted in higher plant height with longer leaves than chemical fertilizer alone in both the rice varieties. Grain yield attributes such as number of effective tillers per hill, panicle length and panicle weight of rice in both the varieties were significantly higher in INM as compared to chemical fertilizer alone. Grain yields of both the varieties were the highest in INM followed by the recommended doses of chemical fertilizer. The grain yield and its attributes of Pusa 44 were significantly higher than those of Pusa Basmati 1. The seed quality parameters like germination rate and vigor index as well as N uptake and soil organic carbon content were higher in INM than those in chemical fertilizer alone. CT rice used higher amount of water than SRI, with water saving of 37.6% to 34.5% in SRI. Significantly higher water productivity was recorded in SRI as compared to CT rice.
Key words: rice; crop nutrition; grain yield; seed quality; system of rice intensification; water productivity

To assure food security in the rice-consuming countries of the world, those countries will have to produce 50% more rice with improved quality to meet consumers' demand by 2025. This additional rice will have to be produced on less land with less water, less labor and fewer chemicals. The task becomes even more difficult when rice quality preferences gradually receive more attention. Crop improvement and management played an important role in increasing the production of major food crops in the past. There is no doubt that the task of making gains becomes even more difficult when rice yield has already been at a high level. The system of rice intensification (SRI), developed in Madagascar over a 25-year period and synthesized in the early 1980s (Stoop et al, 2002), offers opportunities to researchers and farmers to expand their understanding of potentials already existing in the rice genome. SRI has been promoted for more than a decade as a set of agronomic management practices for rice cultivation that enhances yield (Kabir and Uphoff, 2007; Senthilkumar et al, 2008; Zhao et al, 2009), reduces water requirements (Satyanarayana et al, 2007), raises input productivity (Sinha and Talati, 2007), which is accessible to smallholders (Stoop et al, 2002), and is more favorable for the environment than conventional

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Corresponding author: Y. V. SINGH (yvsingh63@yahoo.co.in)

practice with its continuous flooding of paddies and heavy reliance on inorganic fertilization (Uphoff, 2003). Given that water scarcity at field level affects more and more rice growers around the world, SRI has attracted considerable interest, particularly in Asian countries. It is claimed that due to the changes in the cultural practices for growing irrigated rice under SRI can lead to much more productive phenotypes (Uphoff and Randriamiharisoa, 2002). These changes include the use of much younger seedlings than normal transplanting; planting them singly and carefully in a square pattern with wide spacing; in soil that is kept moist but not continuously saturated; and with increased soil amendments of organic matter and active aeration of the soil during weed control operations. However, these recommendations have encountered controversy and reports of yield benefits and phenotypical changes with SRI management have been challenged on various grounds (Dobermann, 2004; McDonald et al, 2006). SRI is referred to as methodology, not a technology or fixed set of practices (Uphoff, 2003), to be tested and optimized under a range of different agro-ecological environments (Stoop et al, 2002). With such background, the experiment was conducted with two rice varieties to assess the performance of varieties with different crop nutrition practices under two methods of rice cultivation on the yield and quality of seed and soil.

MATERIALS AND METHODS

Site description

A field experiment was conducted during two wet seasons (2009–2011) at the research farm of Indian Agricultural Research Institute, New Delhi, India, sited at 28°40′ N and 77°12′ E, with the altitude of 228.6 m above the mean sea level (Arabian Sea). The soils of experimental field were sandy clay loam, having 229 kg/hm^2 alkaline permanganate oxidizable N, 19.4 kg/hm^2 available P, 275 kg/hm^2 1 mol/L ammonium acetate exchangeable K and 0.54% organic C, and the pH of soil was 7.6.

Experimental details

In the experiment laid out in a factorial randomized block design, two methods of rice cultivation [conventional transplanting (CT) and SRI], and two rice varieties (Pusa Basmati 1 and Pusa 44) were used under seven crop nutrition treatments, *viz*. T_1, 120 kg/hm^2 N, 26.2 kg/hm^2 P and 33 kg/hm^2 K; T_2, 20 t/hm^2 farmyard manure (FYM)*;* T_3, 10 t/hm^2 FYM + 60 kg/hm^2 N; T_4, 5 t/hm^2 FYM + 90 kg/hm^2 N; T_5, 5 t/hm^2 FYM + 60 kg/hm^2 N + 1.5 kg/hm^2 blue green algae (BGA); T_6, 5 t/hm^2 FYM + 60 kg/hm^2 N + 1.0 t/hm^2 *Azolla*, and T_7, $N_0P_0K_0$ (control, no NPK application). Recommended doses of P and K (26.2 kg/hm^2 P as single super phosphate and 33 kg/hm^2 K as muriate of potash) were applied at the time of transplanting in all the treatments except the control ($N_0P_0K_0$).

Azolla microphylla at 1.0 t/hm^2 and *Multani mitti* based BGA biofertilizer having composite culture of four species *viz*., *Anabaena* sp., *Nostoc* sp., *Tolypothrix* sp. and *Aulosira* sp. were applied at 1.5 kg/hm^2 as topdressing fertilizer at 2 d after transplanting, and for proper growth of these biofertilizers, standing water (3–5 cm) was maintained in rice fields. Both *Azolla* and BGA multiplied for about 25–30 d and later decomposed when good mat developed and rice crop canopy had shading effect. Establishment of *Azolla* and algal inoculums could be observed within a week of inoculation as floating mats. The mats of BGA were more prominent in the afternoon. Biomass of *Azolla* (on dry weight basis) contained 3.5%–3.7% N, 0.73%–0.75% P, 4.0%–4.2% K, 745–755 mg/kg Fe, 82–85 mg/kg Zn, 165–174 mg/kg Mg and 14–17 mg/kg Cu while dry biomass of BGA contained 3.9%–4.1% N, 0.83%–0.88% P, 4.4%–4.7% K, 678–695 mg/kg Fe, 72–74 mg/kg Zn, 164–165 mg/kg Mn and 18–21 mg/kg Cu. FYM contained 0.73%–0.77% N, 0.17%–0.18% P and 3.8%–4.0% K. The gross and net plot sizes were 24 m^2 and 16 m^2, respectively.

In CT, 21-day-old seedlings of both the rice varieties were transplanted at 20 cm × 10 cm spacing keeping two seedlings per hill, while in SRI, 12-day-old seedlings of the same rice varieties were transplanted at 25 cm × 25 cm spacing keeping one seedling per hill. In SRI, the soil was kept near saturated moisture condition throughout the vegetative phase and a thin layer of 1–3 cm water was maintained during the reproductive phase of rice. However, in CT, 3–5 cm water was maintained from transplanting to grain filling stage and later saturated condition was maintained. In CT, one hand weeding was done at 20 d after transplanting (DAT) while in SRI, one weeding was done at 20 DAT followed by one weeding through rotary weeder at 40 DAT.

Observation

The observations on plant height, grain yield and grain quality attributes were taken. The grain yield attributes included number of total tillers per hill, number of effective tillers per hill, panicle length, panicle exertion, number of filled grains per panicle, spikelet fertility, grain yield and seed recovery. Seed quality parameters like grain length, grain width, 1000-grain weight, grain moisture content, germination rate, seedling length, seedling dry weight and vigor indices were also studied. For assessing the effect of treatments on 1000-grain weight, a random sample of 1 000 seeds in eight replications was taken from each treatment and weighed in gram. Grain moisture content was determined by the low constant temperature oven method (ISTA, 1999). The germination rate was determined by using ‘between the papers’ method. The vigor indices of seeds were assessed based on germination rate, seedling length and seedling dry weight as suggested by Abdulbaki and Anderson (1973). Vigor indices were calculated by following formulae:

Vigor index I = Germination rate × Seedling length (cm);

Vigor index II = Germination rate × Seedling dry weight (mg).

Seedling length was measured on linear scale from 10 normal seedlings randomly selected from standard germination test. For determination of seedling dry weight, 10 normal seedlings from replicate of the standard germination test were randomly selected and kept for oven drying overnight at 90 °C (ISTA, 1999).

Grain and plant samples collected at harvest were dried in hot air oven at 60 °C for 24 h after sun drying. The oven dried samples of plants and air dried samples of grains having moisture content (12%) were ground to pass through 40 mesh sieve in a Macro-wiley mill. From each replication, 0.5 g samples were taken for chemical analysis to determine the N concentration. The N concentrations in grains and straw of rice samples were determined by the modified Kjeldahl method (Jackson, 1973). N uptake was calculated by multiplying grain and straw yields with corresponding values of N concentration and expressed in kg/hm^2. Crude protein content in grains was obtained by multiplying N concentration with a factor 5.95. Soil samples were taken at the harvest stage from 0–15 cm depth and analyzed for their organic carbon content (Prasad et al, 2006).

Water use and productivity

Data on water use were recorded from the two methods of rice cultivation. Each irrigation depth was measured by Parshall Flume and using an ordinary scale meter, which had mm and cm marks. In each plot, the depth of water was measured at 10 selected spots after each irrigation and on the basis of these observations; the mean depth of irrigation water was calculated for each plot. The other measurements were calculated as given below:

Irrigation water use (mm) = Sum of mean depth of each irrigation;

Total water use (mm) = Irrigation water use + Rainfall;

Water productivity [$kg/(hm^2 \cdot mm)$] = Grain yield (kg/hm^2) / Total water consumed (mm);

Water saving (%) = (Water use in control paddy – water use in aerobic treatment) / Water use in control paddy × 100%.

Statistical analysis

All data obtained from the experiment, conducted under factorial randomized block design were statistically analyzed using the *F*-test as per the procedure given by Gomez and Gomez (1984). LSD values at P = 0.05 were used to determine the significance of difference between treatment means.

RESULTS

Plant growth and yield attributes

At harvest, plant height of rice was significantly higher due to the integrated application of biofertilizers and / or organic manure in combination with chemical fertilizer (urea) as compared to that of the control (Table 1). Plant height was significantly higher in CT as compared to those grown through SRI. Pusa Basmati 1 (PB1) variety produced higher plants than Pusa 44. Numbers of total tillers per hill were higher in SRI as compared to those in CT. Pusa 44 produced higher number of total tillers per hill as compared to PB1 and the numbers were significantly higher in both the varieties due to application of nutrients at the recommended doses as well as integrated nutrient management (INM) as compared to the control. Similar trend was observed in the number of effective tillers per hill. Days to 50% maturity was not significantly influenced due to varietal difference or different doses of nutrition, but panicle length was significantly influenced due to different doses of nutrition. 1000-grain weight of PB1 was significantly higher as compared to that of Pusa 44 and the test weight was significantly

Table 1. Influence of rice varieties and nutrient management under two methods of cultivation on plant growth, yield attributes and yield of rice.

Treatment	Plant height (cm)		No. of total tillers per hill		No. of effective tillers per hill		Panicle length (cm)		Days to 50% maturity (d)		1000-grain weight (g)		Spikelet fertility (%)		Grain yield (t/hm²)		Straw yield (t/hm²)		Harvest index	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
Cultivation method																				
CT	114.6	113.9	21.9	20.6	19.2	18.2	26.4	27.4	130	131	24.6	24.5	93.6	94.7	4.93	4.85	12.38	12.66	28.5	27.7
SRI	111.4	110.1	23.5	24.7	21.1	21.2	27.6	27.8	130	130	23.9	24.4	94.4	93.8	4.76	4.68	11.12	10.52	30.0	30.8
LSD (5%)	2.1	2.9	1.7	1.9	1.4	1.2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.90	1.20	1.3	1.6
Variety																				
PB1	112.8	109.7	21.9	21.4	18.3	17.7	27.5	26.3	132	130	24.4	24.3	92.6	94.2	4.50	4.22	13.43	13.16	25.1	24.3
Pusa 44	106.1	104.8	24.3	23.3	21.3	20.1	28.5	27.4	130	129	22.9	23.2	93.7	93.2	5.06	4.63	13.99	12.84	26.6	26.5
LSD (5%)	3.5	5.7	1.7	1.4	1.7	1.2	NS	NS	NS	NS	0.8	0.7	0.8	0.7	0.42	0.28	0.41	0.34	2.3	1.4
Nutrient management																				
T_1	109.9	104.5	23.5	21.4	18.6	16.9	26.7	25.4	131	129	23.5	23.9	92.0	92.2	4.44	4.23	14.12	13.23	23.9	24.2
T_2	110.4	106.8	25.2	24.3	19.8	17.8	28.0	26.3	132	132	23.0	24.1	94.3	94.4	4.93	4.56	14.67	13.76	23.3	24.9
T_3	108.4	104.8	23.4	22.9	20.2	16.6	27.8	27.4	130	131	22.9	23.7	92.3	93.9	4.91	4.67	15.32	14.71	24.3	24.1
T_4	110.6	106.9	23.7	24.1	21.0	20.8	27.5	27.9	131	132	22.4	23.6	92.7	94.7	4.40	4.50	14.54	14.53	23.2	23.6
T_5	113.7	107.0	24.9	24.8	22.4	20.3	28.4	26.6	130	132	22.2	23.2	93.5	94.3	4.68	4.63	14.74	14.32	24.1	24.4
T_6	108.7	106.4	22.8	24.5	21.8	21.0	28.5	27.4	130	131	21.9	23.8	93.4	93.2	4.74	4.86	15.11	15.53	23.9	23.8
T_7	104.5	101.3	12.1	11.4	12.5	13.2	25.9	24.4	129	128	22.0	22.5	92.7	92.0	2.14	1.86	7.35	6.11	22.6	23.3
LSD (5%)	2.3	1.8	3.9	1.7	1.2	3.6	1.5	1.3	NS	NS	1.2	3.6	1.5	1.3	0.53	0.67	1.14	1.36	NS	NS

CT, Conventional transplanting; SRI, System of rice intensification; PB1, Pusa Basmati 1; T_1, 120 kg/hm² N, 26.2 kg/hm² P and 33 kg/hm² K; T_2, 20 t/hm² farmyard manure (FYM); T_3, 10 t/hm² FYM + 60 kg/hm² N; T_4, 5 t/hm² FYM + 90 kg/hm² N; T_5, 5 t/hm² FYM + 60 kg/hm² N + 1.5 kg/hm² blue green algae (BGA); T_6, 5 t/hm² FYM + 60 kg/hm² N + 1.0 t/hm² *Azolla*; T_7, $N_0P_0K_0$ (control, no NPK application). NS, Not significant.

increased due to application of recommended doses of chemical fertilizer as well as INM. However, the INM and chemical fertilizers application did not influence test weight significantly.

Grain and straw yields

Rice grown through CT gave significantly higher grain and straw yields as compared to that grown through SRI (Table 1). Rice variety Pusa 44 showed significantly higher number of filled grains per panicle and spikelet fertility over PB1 (data not shown). Grain yield of rice was significantly influenced by INM as well as application of inorganic fertilizer over the control. The grain yields of 4.44 to 4.23 t/hm² were recorded with the recommended doses of chemical fertilizers which were statistically *at par* in the INM treatments. However, grain yield was higher in INM as compared to the recommended doses of chemical fertilizers. The similar trend was recorded in straw yield. Harvest index of Pusa 44 was significantly higher as compared to that of PB1, but it was not significantly influenced due to difference in crop nutrition. Grain yields obtained under SRI and CT were statistically *at par*, but straw yields were significantly higher in CT.

Seed quality

Both the rice varieties showed very high germination rates during both the years of experimentation, and the differences in germination rate were not significant due to variation in crop nutrition (Table 2). Germination rate was very high under both methods of rice cultivation and it ranged from 95.4% to 96.2%. Shoot and seedling lengths of Pusa 44 were significantly higher than those of PB1. INM and the recommended doses of chemical fertilizers enhanced the seedling length significantly over the control though shoot length was not *at par* in all the treatments. Pusa 44 showed significantly higher vigor indices as compared to PB1. Vigor index I and vigor index II were significantly influenced by INM and the recommended doses of chemical fertilizers as compared to the control. The seed quality as evident by quality parameters was superior in SRI as compared to that in CT.

Concentration and uptake of nitrogen

Concentrations of N in grains and straws of rice were significantly increased due to application of the recommended doses of chemical fertilizers and INM as compared to the control (Table 3). However, the concentrations of N between both the methods of cultivation and rice varieties were statistically *at par*.

Table 2. Influence of rice varieties, nutrient management and methods of cultivation on seed quality parameters.

Treatment	Germination rate (%)		Shoot length (cm)		Seedling length (cm)		Seedling dry weight (mg)		Vigor index I		Vigor index II	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
Cultivation method												
CT	95.4	96.0	5.1	5.2	14.5	13.5	56.9	58.3	1 870	1 795	5 428	5 597
SRI	96.2	95.5	5.8	6.3	14.4	14.6	58.6	56.3	1 943	1 996	5 637	5 377
LSD (5%)	NS	NS	0.6	0.8	NS	NS	NS	NS	47	69	123	158
Variety												
Pusa Basmati 1	96.6	94.3	4.2	4.7	13.9	12.4	48.1	51.2	1 748	1 613	4 646	4 828
Pusa 44	95.9	93.9	5.9	5.6	14.5	14.7	60.4	63.3	1 950	1 906	5 792	5 944
LSD (5%)	NS	NS	0.9	0.6	0.3	0.7	4.3	4.8	126	172	357	513
Nutrient management												
T1	95.1	94.6	5.8	5.9	13.4	13.7	54.7	55.3	1 826	1 854	5 202	5 231
T2	96.0	96.3	5.6	5.6	13.9	12.5	56.3	56.5	1 872	1 743	5 405	5 441
T3	94.4	95.4	5.2	5.8	12.8	13.6	60.0	65.3	1 699	1 851	5 664	6 230
T4	97.0	94.6	4.9	5.4	11.9	12.7	60.0	63.8	1 630	1 712	5 820	6 035
T5	96.6	95.9	4.5	4.9	12.2	13.8	65.6	60.3	1 613	1 793	6 337	5 783
T6	97.3	96.4	4.6	4.7	12.3	14.7	62.1	61.4	1 644	1 870	6 042	5 919
T7	95.1	94.0	4.1	4.3	10.1	11.2	51.2	53.1	1 350	1 457	4 869	4 991
LSD (5%)	NS	NS	NS	NS	0.5	0.7	2.3	1.7	154	141	163	187

CT, Conventional transplanting; SRI, System of rice intensification; T_1, 120 kg/hm^2 N, 26.2 kg/hm^2 P and 33 kg/hm^2 K; T_2, 20 t/hm^2 farmyard manure (FYM); T_3, 10 t/hm^2 FYM + 60 kg/hm^2 N; T_4, 5 t/hm^2 FYM + 90 kg/hm^2 N; T_5, 5 t/hm^2 FYM + 60 kg/hm^2 N + 1.5 kg/hm^2 blue green algae (BGA); T_6, 5 t/hm^2 FYM + 60 kg/hm^2 N + 1.0 t/hm^2 *Azolla*; T_7, $N_0P_0K_0$ (control, no NPK application). NS, Not significant.

Table 3. Influence of rice varieties, nutrient management and methods of cultivation on nitrogen uptake and soil organic carbon content.

Treatment	N concentration in grains (%)		N concentration in straws (%)		Protein content in grains (%)		N uptake in grains (kg/hm^2)		N uptake in straws (kg/hm^2)		Soil organic carbon content (%)	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
Cultivation method												
CT	1.34	1.35	0.56	0.57	8.0	8.0	66.1	65.5	69.3	72.2	0.47	0.46
SRI	1.42	1.40	0.58	0.59	8.4	8.3	67.6	65.5	64.5	62.0	0.45	0.44
LSD (5%)	NS	NS	NS	NS	NS	NS	1.2	NS	3.1	5.2	NS	NS
Variety												
Pusa Basmati 1	1.35	1.37	0.60	0.58	8.0	8.2	60.8	57.8	92.6	67.9	0.45	0.43
Pusa 44	1.31	1.29	0.58	0.57	7.8	7.7	66.3	59.7	81.1	77.7	0.42	0.40
LSD (5%)	NS	NS	NS	NS	NS	NS	4.3	1.7	5.3	8.4	NS	NS
Nutrient management												
T1	1.33	1.35	0.54	0.55	7.9	8.0	59.1	57.1	76.2	77.8	0.37	0.36
T2	1.34	1.37	0.56	0.57	8.0	8.2	66.1	62.5	82.2	78.4	0.43	0.44
T3	1.36	1.39	0.56	0.58	8.1	8.3	66.7	64.9	85.8	85.3	0.45	0.47
T4	1.35	1.37	0.57	0.56	8.0	8.2	59.4	61.7	82.9	81.8	0.45	0.46
T5	1.34	1.36	0.59	0.57	8.0	8.1	62.7	63.0	87.0	81.6	0.43	0.40
T6	1.35	1.40	0.58	0.59	8.0	8.3	64.0	68.0	87.6	91.6	0.46	0.44
T7	1.28	1.32	0.53	0.51	7.6	7.9	27.4	24.6	39.0	31.2	0.32	0.31
LSD (5%)	0.03	0.04	0.03	0.04	NS	NS	7.5	8.4	13.6	16.2	0.06	0.09

CT, Conventional transplanting; SRI, System of rice intensification; T_1, 120 kg/hm^2 N, 26.2 kg/hm^2 P and 33 kg/hm^2 K; T_2, 20 t/hm^2 farmyard manure (FYM); T_3, 10 t/hm^2 FYM + 60 kg/hm^2 N; T_4, 5 t/hm^2 FYM + 90 kg/hm^2 N; T_5, 5 t/hm^2 FYM + 60 kg/hm^2 N + 1.5 kg/hm^2 blue green algae (BGA); T_6, 5 t/hm^2 FYM + 60 kg/hm^2 N + 1.0 t/hm^2 *Azolla*; T_7, $N_0P_0K_0$ (control, no NPK application). NS, Not significant.

Similar trend was recorded in the protein content in grains and N content in straws. Significantly higher uptake of N in grains and straws was found due to the INM and the recommended doses of fertilizers. Higher concentration and uptake of N was recorded in SRI as compared to CT.

Soil organic carbon content

The soil organic carbon content (SOCC) was significantly enhanced due to the application of nutrients either as INM or as the recommended doses of fertilizers, but rice varieties and cultivation methods did not show any significant influence on the SOCC (Table 3). SOCC was statistically *at par* under SRI and CT, and it ranged from 0.36% to 0.47% with the recommended doses of fertilizers and INM, but declined to 0.31% in the control.

Water use and productivity

Conventional transplanted rice needed higher number

Table 4. Effects of rice cultivation methods on water saving and its productivity.

Treatment	Irrigation water use (mm)		Irrigation water saving (%)		Irrigation water productivity [kg/(hm²·mm)]		Total water use (mm) [a]		Water saving (%)		Water productivity [kg/(hm²·mm)]	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
CT	800 (16)	700 (14)	-	-	6.16	6.93	1 568.8	1 594.4	-	-	3.14	3.04
SRI	210 (7)	180 (6)	73.8	74.3	22.29	26.00	978.8	1 044.4	37.61	34.50	4.86	4.48
LSD (5%)	128	67			5.47	7.85	154.4	112.5			0.41	0.29

CT, Conventional transplanting; SRI, System of rice intensification.

Values in parenthesis indicate number of irrigations. [a] Rainfall of 2009 and 2010 was 768.8 and 894.4 mm during cropping season, respectively.

of irrigations (16 and 14) than SRI (7 and 6) in both years (Table 4). Therefore, there was a saving of 9 and 8 irrigations in SRI as compared to CT. Besides saving in number of irrigations, there was also saving in water amount in each irrigation, since only 3 cm water was filled in SRI whereas in CT 5 cm water was filled in each irrigation. CT used higher amount of water (1 568.8 and 1 594.4 mm) than SRI (978.8 and 1 044.4 mm), so there was water saving of 37.6% and 34.5% in both years. Significantly higher grain per unit quantity of water used was produced under SRI [3.14 and 3.04 kg/(hm^2·mm)] as compared to conventional rice which produced 4.86 and 4.48 kg/(hm^2·mm) grain for the same amount of water. A saving of 37.6% and 34.5% water under SRI over CT was recorded during both the years due to the adoption of alternate wetting and drying irrigation (AWDI).

DISCUSSION

Plant height is influenced by several management and environmental factors, but is a genetically controlled trait (Jennings et al, 1979). Numbers of total tillers per hill were higher in SRI as compared to CT. Shrirame et al (2000) reported that the number of functional leaves, leaf area and total number of tillers per hill were higher at wider spacing which increased the photosynthetic rate leading to higher plant height. This may be because SRI effects are based on biological and physiological dynamics. INM and chemical fertilizers application did not influence test weight significantly. Increase in growth and yield attributes might be due to higher availability of biological N, P and K (Meena and Shivay, 2010).

Higher number of total and effective tillers recorded in SRI can be attributed to the management practices of SRI that included transplantation of young seedlings with wider spacing and one seedling per hill. Water management was undertaken to maintain paddy soils in mostly aerobic condition and active soil aeration was done through mechanical weeding and application of organic matter. These management practices improved soil structure and function as well as nutrient availability (Dobermann 2004; Tsujimoto et al 2009; Thakur 2010; Thakur et al, 2010b), which might have affected the synergistic effects on the growth and yield of the rice plants. Young seedlings used in SRI encourage developmental changes in terms of energy dependence at this stage of plant growth, moving from reliance on nutrients from the endosperm to benefiting from photosynthesis at the leaf age of 2.4 (Sasaki and Hoshikawa, 1997; Sasaki, 2004), when one-quarter of the endosperm nutrients still remain in young seedlings. This could be a basis for rapid rooting and development after transplanting. This ability of rooting and development was shown to be attributable to the crown roots from the first and coleoptiles nodes (Sasaki and Hoskikawa, 1997; Sasaki, 2004). Reports suggest that transplanting young seedlings could help them develop rapidly and hence the tillering begins from the lower nodes compared to transplanting older seedlings, which brings out the tillering potential of rice plants more fully (Nemoto et al, 1995). Transplanting at shallow depth in SRI is favorable for more tillering from rice seedlings (Sasaki, 2004). Improved biological potential of rice seedlings in an oxic nursery environment for young seedlings (12-day-old) transplanted even in flooded paddy field was reported (Mishra and Salokhe, 2008). Wider plant spacing or plant density is one of the key techniques of SRI. Thakur et al (2010a) reported that SRI practices through optimum spacing attempt to minimize competition among rice plants for the various growth factors. Although chlorophyll content of the flag leaves and the third leaves from the top decreased with ripening, the rate of decrease is different among planting densities, and chlorophyll content was higher with wider spacing (30 cm × 30 cm) compared to narrow spacing (20 cm × 20 cm) (Mishra and Salokhe, 2010). This high chlorophyll content with wider spacing was attributed to higher root-oxidizing activity of more widely-spaced rice plants (Mishra and Salokhe, 2010). Plants grown under wider spacing have a higher photosynthetic rate in their leaves than those with closer spacing regardless of water management during the ripening stage (Thakur et al, 2010a). The wider spacing between plants under SRI management leads to a more prolonged, open crop canopy (Stoop, 2005).

Conventionally transplanted rice gave significantly higher grain and straw yields as compared to rice grown through SRI. Rice variety Pusa 44 showed significantly higher grain yield than PB1, which was mainly attributed to the higher total and effective tillers per hill, panicle length, filled grain number per panicle and spikelet fertility. Grain and straw yields of rice were significantly influenced by INM as well as application of inorganic fertilizer over the control. However, these yields were higher in INM as compared to the recommended doses of chemical fertilizers. The sustainable yield advantages by INM have been emphasized by many workers (Singh and Mandal, 1997; Dixit and Gupta, 2000; Gunri et al, 2004). Increase in grain yield of rice due to BGA and *Azolla* has been reported by Singh and Mandal (1997) and Dixit and Gupta (2000). Grain yields obtained under SRI and CT were statistically *at par*, but straw yields were significantly higher in CT. Lu et al (2000) reported that dense spacing increased the dry matter production of rice, which might have caused higher grain and straw yields in CT as compared to SRI. Higher grain yield under SRI management has been reported and compilation of results from 11 surveys in 8 countries, including 16 000 SRI farmers, has shown, on average, 47% yield increases, 40% water savings, 23% lower production costs, and 68% increase in farmer income, compared to conventional rice cultivation (Sato and Uphoff, 2007; Africare et al, 2010). Fernandes and Uphoff (2002) summarized SRI reports from 17 countries and found that SRI yields averaged 6.8 t/hm^2, while that from conventional cultivation practices was 3.9 t/hm^2. Harvest index (HI) was found significantly higher in SRI as compared to CT in the present study, which was in accordance with the previous results (Husain et al, 2003; Stoop, 2005; Zhao et al, 2009; Thakur et al, 2010b). Significantly higher root dry weight per hill and per unit area in SRI compared to recommended management practices (kept flooded to maintain a ponded water of 5–8 cm depth during the entire vegetative stage of rice plants) was observed during the early ripening stage. In addition, the amount of xylem exudates and the exudation rate per hill were significantly higher in SRI than in recommended management practices (Thakur et al, 2010a, b).

Vigor index I and vigor index II were significantly influenced by INM and the recommended doses of chemical fertilizers. The increased supply of nutrients either by increased fertilizer doses, application of organics or integration of both the sources must have improved the nutrient uptake and balanced nutrition to the crop under the influence of improved physico-chemical properties of soils (Singh and Mandal, 1997; Gunri et al, 2004), which might have influenced the seed quality positively. The seed quality as evident by quality parameters was superior in SRI as compared to CT. The oxic environment in SRI enhanced the nitrification of ammonium in plow-layer soil. As the rhizosphere of the rice plants is a favorable place for ammonium-oxidizing bacteria (Briones et al, 2003), the expansion of the rhizosphere volume benefitted rice plants to take up more N, not only as ammonium but also as nitrate, which may be produced in the rhizosphere and may contribute as a signal to enhance ammonium uptake (Zhao et al, 2008) as well as a possible N reserve (Bloom, 1997) for dry matter production at the reproductive growth stage and all these factors might have improved the seed quality.

Application of the recommended doses of chemical fertilizers and INM significantly increased the concentrations and uptake of N in grains and straw of rice compared to the control. Organic matter is considered a reservoir of nutrients in soils and also a good indicator of available N into the soils. Similar findings were reported by Chaphale et al (2000) and Singh et al (2002). Due to the inoculation of biofertilizers like BGA and *Azolla*, the amount of fixed atmospheric N_2 and organic matter content into soils was enhanced. Marginal increase in N content of rice straw due to inoculation of BGA and *Azolla* has been reported (Singh and Mandal, 1997). This might be due to increase in the N availability through synchronized released from the inoculation of N_2-fixing micro-organisms, which increased the N concentration proportionately in grains and straw and finally led to higher N uptake with the highest level of N (Mhaskar and Thorat, 2005; Oo et al, 2007; Shivay et al, 2008). N is one of the major nutrients for crops, and the yield of rice was regulated by the N uptake pattern and the amount of N absorbed by the rice plants. Higher concentration and uptake of N was recorded in SRI as compared to conventional rice. Wider density in SRI affected the N dynamics in paddy fields. The amount of exchangeable ammonium

N disappeared earlier with narrow spacing than with wider spacing when basal N fertilizer was applied (Takahashi et al, 1973). Generally, a linear relationship between the amount of N in rice plants and yield under conventional practices was recognized in a wide range of brown rice yields from 3 to 9 t/hm^2 in Japan (Makino et al, 2006). There was a linear relationship between the two parameters, regardless of whether SRI or conventional practices were used, in the various plant density levels. Tsujimoto et al (2009) reported that average mineralizable N (at depths of 0–30 cm) was linearly related to rice grain yield irrespective of management practices.

Nutrient application either through INM or as the recommended doses of fertilizers significantly enhanced SOCC over the control, but rice varieties and cultivation methods did not show any significant influence on the SOCC. The increase in SOCC due to application of *Azolla*, BGA, FYM and INM has also been reported by Dixit and Gupta (2000), Singh et al (2007) and Singh et al (2011). Sahrawat (2004) reported the positive influence of balanced fertilization and addition of fresh organic matter on better decomposition of soil organic matter and N mineralization under continuously submerged rice soils, where two or three rice varieties were grown in a year on a long-term basis.

Higher numbers of irrigation were required in CT than SRI and there was a saving of 9 and 8 irrigations in SRI as compared to CT. So there was water saving of 37.6% and 34.5% in both years. In conventional practices, total water use was 2 times higher than modified SRI irrigation in India (Satyanarayana et al, 2007) and 1.4 times higher in Japan (Chapagain and Yamaji, 2010). Consequently, water productivity in SRI irrigation was higher than in conventional irrigation. Satyanarayana et al (2007) summarized the previous reports about water savings of SRI and concluded that SRI practice in different environments could save substantial water, accompanied by significant gains in rice production and profitability. Root length density of rice plants grown under SRI (intermittent flooding) was higher than under continuously flooded management, especially at the middle and late ripening growth stages (Mishra and Salokhe, 2010). Similar findings were reported by Thiagarajan et al (2002). Anbumozhi et al (1998) reported increased water productivity (1.26 kg/m^3) in AWDI plot at 9 cm ponding depth compared to continuous flooding (0.96 kg/m^3). Mao (1993, 1996) also concluded that in southern China, AWDI for rice should be more widely used because of its potential for saving water (20%–35%), increasing water productivity (from 0.65–0.82 to 1.18–1.50 kg/m^3), while also increasing rice yield (15%–28%), and improving the water and soil environment (soil oxygen content was increased by 120%–200%). Significantly higher grain per unit quantity of water used was produced under SRI [3.14 and 3.04 kg/(hm^2·mm)] as compared to conventional rice, which produced 4.86 and 4.48 kg/(hm^2·mm) grain for the same amount of water. Suryavanshi et al (2013) also recorded significantly higher water productivity in SRI [3.56 kg/(hm^2·mm)] as compared to conventional transplanting [2.61 kg/(hm^2·mm)]. Chapagain and Yamaji (2010) found 28% saving of irrigation water, without reducing grain yield by using AWDI practice. They also recorded better crop growth and reduced disease / pest incidence under these conditions. Singh (2013) reported water saving of 34.5%–36.0% in SRI compared to conventional transplanting. Sato and Uphoff (2007) found that continuous submergence is not essential for achieving high rice yields. Sandhu et al (2012) concluded that irrigation water can also be saved in puddled transplanted rice by applying irrigation 3 d after disappearance of ponded water as compared to recommended practice of applying irrigation 2 d after disappearance of ponded water, and this practice does not lead to any significant reduction in grain yield. Kato et al (2009) and Katsura et al (2010) have suggested the possibility that upland conditions without severe water stress could be more appropriate to show the potential ability of rice plants. Katsura et al (2010) showed significantly higher radiation use efficiency (RUE) as well as a higher fraction of radiation intercepted under upland conditions (water potential was between ca. -5 kPa and ca.-80 kPa) compared to submerged ones. Thakur et al (2010b) assessed the physiological effects of saturated water management in SRI practice with submerged soil conditions (recommended management practice), and found higher intercepted radiation during the reproductive stage as well as increase of rooting depth and RUE for SRI management.

CONCLUSIONS

It was concluded that the grain yield and seed quality were influenced due to the genetic potentials of rice varieties. However, addition of organic amendments like FYM, BGA and *Azolla* in integrated manner with chemical fertilizers produced higher quantity of grain and the seed quality was also more superior than those obtained in sole chemical fertilizer application and control treatments. Protein content and N uptake in grains were positively influenced due to INM practice. Grain yield was almost the same in SRI and CT but straw yield was significantly higher in CT. The seed quality was superior in SRI as compared to CT. Conventional transplanted rice needed higher (8–9) number of irrigations than SRI and required more amount of water in each irrigation. SRI method saved 34.5%–37.6% of water over CT without much reduction in yield, and thus was a promising method for rice cultivation.

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