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

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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 against traditional transplanting technique at IARI, New Delhi, India during two wet seasons (2009-2011). These two systems of rice cultivation were tested with two rice varieties (Pusa Basmati 1 and Pusa 44) under different nutritional practices on seed yield and quality parameters. In the experiment laid out in factorial randomized block design, two methods of rice cultivation (conventional transplanting (CT) and SRI; and two rice varieties were grown under seven crop nutrition treatments, viz. $T_1$, $N_{120}P_{60}K_{60}$; $T_2$, Farmyard manure (FYM) 20 t/hm$^2$; $T_3$, FYM 10 t/hm$^2$ + $N_{60}$; $T_4$, FYM 5 t/hm$^2$ + $N_{60}$; $T_5$, FYM 5 t/hm$^2$ + $N_{60}$ + Azolla 1.0 t/hm$^2$ and $T_6$, $N_{120}P_{60}K_{60}$ (control). 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 seed 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 plants with longer leaves than that of chemical fertilizer alone in both the rice varieties. Seed yield attributes like number of effective tillers, panicle length and panicle weight of rice in both the varieties were significantly better with INM as compared to chemical fertilizer alone. Seed yield of both the varieties was the highest with INM followed by recommended dose of chemical fertilizer. The seed yield attributes and seed yield of Pusa 44 were significantly higher as compared to Pusa Basmati 1. The seed quality parameters like germination rate and vigor were higher at INM. N uptake and soil organic carbon content were also higher in INM. There was a saving of 8-9 irrigations in SRI as compared to CT rice. Conventional rice cultivation used higher amount of water than SRI and there was water saving of 37.6% to 34.5% in SRI. Significantly higher water productivity was recorded in SRI as compared to conventional rice.

Key words: basmati rice; seed quality; system of rice intensification; vigor index; water use; 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 have 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 is already at the 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), is accessible to smallholders (Stoop et al, 2002), and is more favorable for the environment than conventional 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 under SRI due to the changes in the cultural practices for growing irrigated rice can lead to much more productive phenotypes (Uphoff and Randriamiharisoa, 2002). These changes include the use of much younger seedlings than normally transplanted; 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 SRI 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 situated at a latitude of 28°40′ N and longitude of 77°12′ E, altitude of 228.6 m above the mean sea level (Arabian Sea). The soils of experimental field was sandy clay loam and having 229 kg/hm² alkaline (Arabian Sea). The soils of experimental field was sandy clay loam and having 229 kg/hm² alkaline permanganate oxidizable N, 19.4 kg/hm² available P, 275 kg/hm² 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); two rice varieties (Pusa Basmati 1 and Pusa 44) were grown under seven crop nutrition treatments, viz, T1, N12P60K60; T2, Farmyard manure (FYM) 20 t/hm²; T3, FYM 10 t/hm² + N60; T4, FYM 5 t/hm² + N60; T5, FYM 5 t/hm² + N90; T6, Blue green algae (BGA) 1.5 kg; T7, FYM 5 t/hm² + N60 + Azolla 1.0 t/hm² and T8, N0P0K0 (control). Recommended dose of P and K [26.2 kg/hm² P as single super phosphate (SSP) and 33 kg/hm² K as muriate of potash (MOP)] were applied at the time of transplanting in all the treatments except the treatment having absolute control (N0P0K0).

Azolla microphylla at 1.0 t/hm² 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/hm² as top dressing at 2 d after transplanting and for proper growth of these bio-fertilizers standing water (3–5 cm) was maintained in rice crop. 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 iron, 82–85 mg/kg zinc, 165–174 mg/kg manganese and 14–17 mg/kg copper 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 m² and 16 m², 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 seedlings 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 observation on plant height, grain yield and quality attributes was 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. Grain quality parameters like grain length, grain width, 1000-grain weight, grain moisture content, germination rate, seedling length, seedling dry weight and vigor indices were 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 grains 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 straws of rice samples were determined by the modified Kjeldahl method. N uptake was calculated by multiplying grain and straw yields with corresponding values of N concentration and expressed in kg/hm².

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 its organic carbon content (Prasad et al, 2006).

Water use and productivity

Data on water use were recorded from only two methods of rice cultivation. Each irrigation depth was measured by Parshall Flume and using an ordinary scale meter, which had mm and cm mark. In each plot, the depth of water was measured at 10 selected spots after each irrigation and on the basis of these observation; 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/(hm²-mm)] = Grain yield (kg/h hm²) / Total water consumed (mm);
Water saving (%) = (Water use in paddy control – water use in aerobic treatment) / Water use in paddy control × 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 the control (Table 1). Plant height was significantly higher in CT as compared to rice 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 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 dose as well as INM as compared to the control. Similar trend was observed in the number of effective tillers per hill. Days to 50% maturity were 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 Pusa 44 was significantly higher as compared to PB1 and the test weight was significantly increased due to application of recommended dose 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 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 integrated nutrient management as well as application of inorganic fertilizer over control. The grain yield of 4.44 to 4.23 t/hm² was recorded with recommended dose of chemical fertilizers which was statistically at par with INM treatments. However, grain yield was higher with INM as compared to the recommended dose of chemical fertilizers. The similar trend was recorded with straw yield. Harvest index of Pusa 44 was significantly higher as compared to 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 yield was significantly higher in CT.
Both the rice varieties showed very high germination rates (93.9% to 96.6%) during both the years of experimentation and the difference in their germination rate was not significant (Table 2). Germination rate was very high under both methods of rice cultivation and it ranged between 95.4% to 96.2%. Germination rate was not significantly influenced due to variation in crop nutrition. Shoot and seedling lengths of Pusa 44 were significantly higher as compared to PB1. INM and the recommended dose 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 dose of chemical fertilizers as compared to the control treatment. The grain quality as evident by quality parameters was superior in SRI as compared to CT.

Concentration and uptake of nitrogen

Concentrations of N in grains and straws of rice were significantly increased due to application of INM and the recommended dose of chemical fertilizers compared to the control treatment (Table 3). However, the concentrations among both the methods of cultivation and rice varieties were statistically at par. Similar trend was recorded in the concentrations of protein in grains and N in straws. Significantly higher uptake of N in grains and N in straws was found due to the application of N in the recommended dose of chemical fertilizers and INM. The concentration of protein in grains was increased in SRI as compared to the control was 45% in SRI as compared to the control treatment. The grain quality parameters were superior in SRI as compared to CT.

Soil organic carbon content

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

Water use and productivity

Conventional transplanted rice needed higher number of irrigations (16 and 14) than SRI (7 and 6) in both years (Table 4). So, there was a saving of 9 and 8 irrigations in SRI as compared to CT. Besides saving in number of irrigations, there was saving in crop nutrition. Both the rice varieties showed very high germination rates (93.9% to 96.6%) during both the years of experimentation and the difference in their germination rate was not significant (Table 2). Germination rate was very high under both methods of rice cultivation and it ranged between 95.4% to 96.2%. Germination rate was not significantly influenced due to variation in crop nutrition. Shoot and seedling lengths of Pusa 44 were significantly higher as compared to PB1. INM and the recommended dose 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 dose of chemical fertilizers as compared to the control treatment. The grain quality parameters were superior in SRI as compared to CT.
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Table 2. Influence of rice varieties, nutrient management and methods of cultivation on seed quality parameters.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Germination rate (%)</th>
<th>Shoot length (cm)</th>
<th>Seedling length (cm)</th>
<th>Seedling dry weight (mg)</th>
<th>Vigor index I</th>
<th>Vigor index II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cultivation method</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CT</td>
<td>95.4</td>
<td>96.0</td>
<td>5.1</td>
<td>5.2</td>
<td>14.5</td>
<td>13.5</td>
</tr>
<tr>
<td>SRI</td>
<td>96.2</td>
<td>95.5</td>
<td>5.8</td>
<td>6.3</td>
<td>14.4</td>
<td>14.6</td>
</tr>
<tr>
<td>LSD (%)</td>
<td>NS</td>
<td>0.6</td>
<td>0.8</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Variety</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pusa Basmati 1</td>
<td>96.6</td>
<td>94.3</td>
<td>4.2</td>
<td>4.7</td>
<td>13.9</td>
<td>12.4</td>
</tr>
<tr>
<td>Pusa 44</td>
<td>95.9</td>
<td>93.9</td>
<td>5.9</td>
<td>5.6</td>
<td>14.5</td>
<td>14.7</td>
</tr>
<tr>
<td>LSD (%)</td>
<td>NS</td>
<td>0.9</td>
<td>0.6</td>
<td>0.3</td>
<td>0.7</td>
<td>4.3</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Treatment</th>
<th>N concentration in grain (%)</th>
<th>N concentration in straw (%)</th>
<th>Protein content in grain (%)</th>
<th>N uptake in grain (kg/hm²)</th>
<th>N uptake in straw (kg/hm²)</th>
<th>Soil organic carbon content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cultivation method</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CT</td>
<td>1.34</td>
<td>1.35</td>
<td>0.56</td>
<td>0.57</td>
<td>8.0</td>
<td>8.0</td>
</tr>
<tr>
<td>SRI</td>
<td>1.42</td>
<td>1.40</td>
<td>0.58</td>
<td>0.59</td>
<td>8.4</td>
<td>8.3</td>
</tr>
<tr>
<td>LSD (%)</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Variety</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pusa Basmati 1</td>
<td>1.35</td>
<td>1.37</td>
<td>0.60</td>
<td>0.58</td>
<td>8.0</td>
<td>8.2</td>
</tr>
<tr>
<td>Pusa 44</td>
<td>1.31</td>
<td>1.29</td>
<td>0.58</td>
<td>0.57</td>
<td>7.8</td>
<td>7.7</td>
</tr>
<tr>
<td>LSD (%)</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

DISCUSSION

Integrated application of nutrients through biofertilizers and / or organic manure in combination with chemical fertilizer (urea) produced taller plant of rice compared to control. Plant height was significantly higher in CT compared to rice grown through SRI. Pusa Basmati 1 (PB1) variety produced higher plants than Pusa 44. 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

water in each irrigation also 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 (1568.8 and 1594.4 mm) than SRI (978.8 and 1044.4 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/(hm²·mm)) as compared to conventional rice which produced 4.86 and 4.48 kg/(hm²·mm) grain for the same amount of water. There was a saving of 37.6% and 34.5% water under SRI over conventional rice was recorded during both the years due to the adoption of alternate drying and wetting irrigation (AWDI).
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 plants. 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 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 encourages 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 at that leaf age. 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 Hosikawa, 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 transplanted 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 decreased with ripening, the rate of decrease is different among planting densities, and chlorophyll content was higher with wider spacing (30 by 30) compared to narrow spacing (20 by 20) (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 had a higher photosynthetic rate in their leaves than did those with closer spacing regardless of water management during the ripening stage of the rice plants (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 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, panicle length, filled grain / panicle and spikelet fertility. On the contrary, PB1 had less number of grains per panicle and lower number of total and effective tillers per hill. Grain and straw yield of rice were significantly influenced by integrated nutrient management as well as application of inorganic fertilizer over control. However, these yields were higher with INM as compared to the recommended dose of chemical fertilizers. The sustainable yield advantages by integrated nutrient management have been emphasized by many workers (Gunri et al, 2004; Singh and Mandal, 1997; Dixit and Gupta, 2000). 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

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

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Irrigation water use (mm)</th>
<th>Irrigation water saving (%)</th>
<th>Irrigation water productivity [kg/(hm²·mm)]</th>
<th>Total water use (mm)</th>
<th>Water saving (%)</th>
<th>Water productivity [kg/(hm²·mm)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT</td>
<td>800 (16)</td>
<td>-</td>
<td>6.16</td>
<td>1568.8</td>
<td>-</td>
<td>5.14</td>
</tr>
<tr>
<td></td>
<td>700 (14)</td>
<td>-</td>
<td>6.93</td>
<td>1594.4</td>
<td>-</td>
<td>5.04</td>
</tr>
<tr>
<td>SRI</td>
<td>210 (7)</td>
<td>180 (6)</td>
<td>73.8</td>
<td>978.8</td>
<td>37.61</td>
<td>4.36</td>
</tr>
<tr>
<td></td>
<td></td>
<td>74.3</td>
<td></td>
<td>1044.4</td>
<td>34.50</td>
<td>4.48</td>
</tr>
<tr>
<td>LSD (5%)</td>
<td>128</td>
<td>67</td>
<td>5.47</td>
<td>154.4</td>
<td>0.41</td>
<td>0.29</td>
</tr>
</tbody>
</table>

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

Values in parenthesis indicate number of irrigations. *Rainfall of 2009 and 2010 was 768.8 and 894.4 mm during cropping season, respectively.
SRI and CT were statistically at par but straw yield was significantly higher in CT. Lu et al (2004) 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 rice yield under SRI management than with conventional practices been reported and compilation of results from 11 surveys in 8 countries, including 16 000 SRI farmers, has shown, on average, a 47% yield increase, 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 cultural practices was 3.9 t/hm$^2$. Harvest index (HI) was found significantly higher in SRI as compared to CT. Stoop (2005) and Hossain et al (2003) also found higher HI in SRI as compared to conventional method. The HI of rice plants under SRI (0.44–0.51) was higher than under traditional flooding (0.38–0.45) (Zhao et al, 2009; Thakur et al, 2010b).

Significantly higher root dry weight per hill and per unit area with 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 plant) was observed during the early ripening stage of the rice plants. In addition, the amount of xylem exudates and the exudation rate per hill were significantly higher in SRI than recommended management practices (Thakur et al, 2010a, b).

Seed germination was quite high (> 95%) in both the rice varieties under both methods. However, germination rate was not significantly influenced due to variation in crop nutrition. INM and the recommended dose of fertilizers enhanced the seedling length significantly over the control. 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 dose of chemical fertilizers as compared to the control treatment. 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 soil (Singh and Mandal, 1997; Gunri et al, 2004) and this might have influenced the grain quality positively. The grain 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 grain quality.

Application of the recommended dose of chemical fertilizers and INM significantly increased the concentrations of N in grains and straws of rice compared to the control treatment. Significantly higher uptake of N in grains and straws was found due to the INM and the recommended dose of fertilizers. Organic matter is considered a reservoir of nutrients in soil and it is also a good indicator of available N into the soil. Similar findings were reported by Chaphale et al (2000) and Singh et al (2002). Due to the inoculation of bio-fertilizers like BGA and Azolla, the amount of fixed atmospheric N$_2$ and organic matter content into soil 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 straws 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). Nitrogen 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
recommended dose of fertilizers significantly enhanced the soil organic carbon content (SOCC) over control but rice varieties and methods of cultivation did not show any significant influence on the SOCC. The increase in SOCC due to application of Azolla, BGA, FYM and integrated nutrient management 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 crops of rice were grown on a long-term basis.

Higher numbers of irrigation were required in conventional transplanted rice than SRI and there was a saving of 9 and 8 irrigations in SRI as compared to CT. Besides, there was saving in water in each irrigation also 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 (1568.8 and 1594.4 mm) than SRI (978.8 and 1044.4 mm), 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 of the rice plants (Mishra and Salokhe, 2010).

Similar findings were reported by Thiragarajan et al (2002). Anbumozhi et al (1998) reported increased water productivity (1.26 kg/m³) in AWDI plot at 9 cm ponding depth compared to continuous flooding (0.96 kg/m³). 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/m³ after the application of AWDI, 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/(hm²·mm)) as compared to conventional rice which produced 4.86 and 4.48 kg/(hm²·mm) grain for the same amount of water. There was a saving of 37.6% and 34.5% water under SRI over conventional rice was recorded during both the years due to the adoption of alternate drying and wetting method. 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. 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.

**CONCLUSION**

It was concluded that the grain yield and its 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 grain quality was also more superior than those obtained in sole chemical fertilizer application and control treatment. 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 grain quality was superior with 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% water over conventional rice cultivation without much reduction in yield and thus found
promising method for rice cultivation.

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