

## Stand establishment techniques of rice in conjunction with nutrient sources for soil health and productivity of rice (*Oryza sativa*)–wheat (*Triticum aestivum*) cropping system

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### ABSTRACT

A field experiment was conducted during 2010–12 at Pantnagar, Uttarakhand, to study the effect of varying nutrient sources and methods of rice (*Oryza sativa* L.) cultivation on the growth, yield attributes, productivity, economics of rice and soil fertility and its carry-over effect on wheat [*Triticum aestivum* (L.) emend. Fiori & Paol.]. The treatment comprised 3 rice-establishment methods, viz. conventional transplanting (CT), system of rice intensification (SRI) and direct-seeded aerobic rice (DSR) in main-plots, and 4 nutrient sources, viz.  $N_{25(\text{FYM})} + N_{95(\text{urea})}$ ,  $N_{50(\text{FYM})} + N_{70(\text{urea})}$ ,  $N_{75(\text{FYM})} + N_{45(\text{urea})}$  and  $N_{120(\text{urea})}$ , in sub-plots, with 4 replications. Significantly higher number of panicles/m<sup>2</sup>, leaf-area index (LAI), chlorophyll content of leaf, root dry weight and panicle weight of rice were obtained with system of rice intensification (SRI) compared to conventional transplanting and aerobic methods of cultivation. This method also recorded significantly higher grain yield (5.49 t/ha, pooled over 2 years), being 11% higher than conventional transplanting. The lowest grain yield (4.63 t/ha, pooled over 2 years) was recorded under direct-seeded aerobic rice, being 7% lower than conventional transplanting. System of rice intensification, among 3 rice establishment methods was more advantageous in terms of net return (23%) and grain yield (11%) than conventional transplanting. The total productivity (pooled over 2 years) was also higher (9.44t/ha,) under system of rice intensification (SRI) treatment. Among the nutrient sources,  $N_{75(\text{FYM})} + N_{45(\text{urea})}$  produced higher number of panicles/m<sup>2</sup>, leaf-area index (LAI), chlorophyll content of leaf, root dry weight, root volume, panicle weight and pooled (over 2 years) grain yield of rice (5.17 t/ha) and wheat (3.77 t/ha). The higher net monetary returns (₹ 41,450/ha average of 2 years) as well as benefit: cost ratio (1.59; average of 2 years) of the system was also observed under this treatment.  $N_{75(\text{FYM})} + N_{45(\text{urea})}$  kg/ha was found best in improving the yield and yield attributes of wheat after rice.

**Key words :** Aerobic rice, Conventional rice, Cropping systems, Rice-grain equivalent yield, SRI, Soil fertility, System productivity

Increasing water scarcity, now forcing rice farmers towards less-water demanding technologies even sacrificing some yields of crop. Aerobic rice cultivation, where fields remain unsaturated throughout the season like an upland crop offers an opportunity to produce rice with less water. The conventional transplanting method of rice cultivation is the most widely adopted method of rice production, which requires high continuous water inputs and labour, usually at a critical time for labour availability, which often results in shortage and increasing labour costs, that not only increases the cost of production but high water requirements also threatens the sustainability of the irrigated

rice system and food security in Asia (Tuong and Bouman, 2003).

The system of rice intensification (SRI) is a new methodology for increasing the productivity of irrigated rice by changing the management of plants, soil, water and nutrients resulting in both healthy soil and plants, supported by greater root growth and the soil microbial abundance and diversity. If SRI were to be applied with the water now being used for rice irrigation, it would be able to increase irrigated area by at least 50%, leading to 50% increase in rice production (Thakkar, 2005)

Rice cultivation under non-flooded conditions (aerobic) is an alternative to the conventional rice cultivation system in regions, where rainfall and freshwater resources are limited. Aerobic rice cultivation is becoming popular, as it reduces the amount of irrigation water for rice while real-

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izing high yields and increasing water productivity. Input water savings of 35–57% have been reported for dry-seeded rice sown into non-puddled soil with the soil kept near saturation or field capacity compared with continuously flooded (5 cm) transplanted rice (Singh *et al.*, 2003).

Among the plant nutrients, nitrogen deficiency is one of the major limiting factors for cereals. Hence fertilizer nitrogen application is an essential input for crop productivity preferentially rice. In an estimation it was found that 24% increase in Asian rice was attributed to use of fertilizers, mainly nitrogen. It has been observed that the rice crop needs a higher amount of N (greater than 120 kg N/ha) to achieve a good yield. However, it is subjected to huge losses, as its efficiency in rice is less than 40% of the applied N. These losses could be minimized greatly by substituting chemical fertilizer with organic manure in an integrated manner. To realize the facts, an investigation was undertaken to study the effect of rice-establishment methods and integrated nitrogen sources on growth, yield of rice and its residual effect on wheat productivity and soil fertility under rice–wheat system.

#### MATERIALS AND METHODS

The field experiment was carried out at Pantnagar, Uttarakhand during 2010–11 and 2011–12 (29°N, 79.29°E, 243.94 m above mean sea-level). In a narrow east-west belt (8–25 km wide) under the foothills of Shivalik range of Himalayas known as *tarai*. The experimental soil is of alluvial in origin, relatively young and is classed as Aquic Hapludoll. The chemical analysis of top 15 cm soil showed that it was rich in organic matter and medium in phosphorus and potassium, and neutral to slightly alkaline in reaction. The experimental field has been under rice–wheat rotation since 1966. An exhaust crop of wheat has been grown during the winter (*rabi*) season before experimental crop of rice every year on fixed site for 2 years.

The experiment was laid out in a split-plot design, replicated 4 times in plot of 8 m<sup>2</sup>. There were 3 main plot treatments, comprising conventional transplanting (CT), system of rice intensification (SRI) and direct-seeded aerobic rice (DSR), and 4 nutrient resources, i.e. 25 kg N/ha through farmyard manure (FYM) + 95 kg N/ha through urea, 50 kg N/ha through FYM + 70 kg N/ha through urea, 75 kg N/ha through FYM + 45 kg N/ha through urea and 120 kg N/ha through urea in 8 m<sup>2</sup> plots during both the years.

Rice variety ‘Pant Dhan 18’ at the rate of 5 kg/ha for SRI, 35 kg/ha for conventional transplanting and 50 kg/ha for aerobic rice was used. The rice seedlings were raised on a raised bed size of 8 m long and 1.25 m broad and 15 cm height with wet-bed method. Wheat ‘UP 2565’ was

sown as succeeding crop during the *rabi* season and uniform dose of 120-60-40 kg N- P-K/ha was applied to wheat to observe the residual effect of integrated nitrogen management and system of rice establishment.

The chemical analysis of FYM showed 0.50% N, 0.13% P<sub>2</sub>O<sub>5</sub> and 0.36% K<sub>2</sub>O in 2010, whereas 0.50% N, 0.14% P<sub>2</sub>O<sub>5</sub> and 0.40% K<sub>2</sub>O in 2011. Nitrogen was supplied through urea and FYM as per treatments. Phosphorus and potassium were supplied through single superphosphate (SSP) and muriate of potash (MOP) respectively. The FYM was applied on dry-weight basis of N content before transplanting @ 5 t/ha in N<sub>25</sub> (FYM) + N<sub>95</sub> (urea), 10 t/ha in N<sub>50</sub> (FYM) + N<sub>70</sub> (urea) and 15 t FYM/ha in N<sub>75</sub> (FYM) + N<sub>45</sub> (urea). It was thoroughly incorporated into the top 15 cm soil with the help of spade manually. The crop was uniformly fertilized with 120:60:40 N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O kg/ha and 25 kg ZnSO<sub>4</sub>/ha in N<sub>120</sub> (urea). Fertilizer 60 kg N (from urea and FYM) and entire amount of phosphorus, potassium and zinc sulphate was applied uniformly as basal dose before puddling and incorporated thoroughly in the soil with the help of a spade. The remaining 60 kg N was top-dressed at active tillering and the second at panicle-initiation stage. Water 2–3 cm for conventional transplanting was maintained during the initial stage up to seedlings establishment. Thereafter, plots were kept continuously flooded and irrigated whenever required in order to maintain a ponded layer of 5–6 cm depth during the vegetative stage and attempts were made to maintain this level up to milk stage. In SRI plots, soils were kept saturated but with no standing water during the vegetative stage. Stagnated rain water from these plots was drained out. After panicle initiation, 2–3 cm water was maintained in the bed and plots were drained 15 days before harvest. In aerobic rice, the soil moisture was maintained near about saturation at sowing to milk stage. Two sprays of zinc sulphate @ 5 kg/ha dissolved in 1,000 litres water/ha were applied 25 and 40 days after transplanting/sowing to control *khaira* disease in rice. For controlling stem-borer and other insects, cartap hydrochloride 4 G (@ 25 kg/ha) was applied.

To check the weed growth in SRI plots, conoweeder was run 10, 20 and 30 days after transplanting between rows of rice crop. The weeds growing very close to the rice plants were pulled out by hand. And in conventionally transplanted rice plots (closer planting), weeds were controlled by applying butachlor @ 1.5 kg a.i./ha at 3 days after transplanting followed by 1 hand-weeding in the third week after transplanting. In aerobic rice, pendimethalin @ 1 kg ai/ha was applied 2 days after sowing followed by 2 hand-weedings at 20 and 30 days after sowing. Five random plants were sampled from each plot for growth and yield attributes. Chlorophyll content of leaf

was recorded at 90 days after transplanting by selecting 30 shoots randomly from each plot and SPAD (Minolta, Japan) value was recorded from the middle of the top-most leaf of each selected shoot. The area of leaves of 5 plants was measured with the help of leaf area meter (Model 3100, USA) and leaf area index (LAI) was calculated. Data pertaining to root volume and root weight was recorded 90 days after transplanting by selecting 2 hills of average vigour from second row of plot boundary. For this, 2 hills were dugout separately from a depth of 20 cm along with soil mass with 20 cm soil length for 20 cm × 20 cm spacing, 25 cm × 25 cm spacing and 10 cm for conventional transplanting (20 cm × 10 cm spacing). The root portion of plants along with the soil mass was put in a fine-meshed plastic/nylon bag and was immersed in a running water, so that soil mass gets sufficiently loosened and all the roots were recovered and then cut off from the shoots. The fresh and cleaned roots of each plant were put separately in a graduated measuring cylinder partially filled with clean water and the rise in water level in the cylinder due to immersion of roots was noted as root volume. The root volume of 2 hills was averaged out to get root volume/hill. Thereafter, these roots were separately dried in an oven at  $70 \pm 2^\circ\text{C}$  until constant weight for obtaining root dry weight.

Data on grain yield were recorded after each season of crop harvesting and system productivity in terms of rice-grain-equivalent yield (RGEY) was evaluated as:  $\text{RGEY (t/ha)} = \text{rice yield} + \{(\text{yield of rabi crop} \times \text{price of rabi crop}) / \text{price of rice}\}$ . Net return was calculated on the basis of prevailing market price of the inputs and produce. Soil samples up to depth of 30 cm were collected at the end of cropping cycle and analysed for organic carbon and available NPK content by following standard laboratory procedures. Data of years were subjected to pooled analysis.

## RESULTS AND DISCUSSION

### *Growth attributes of rice*

Growth parameters of rice, viz. LAI, chlorophyll content, root volume and root weight increased significantly under SRI (Table 1). Growth of rice plants improved with increasing levels of fertility owing to continuous supply of nutrients. The LAI due to  $\text{N}_{75}$  (FYM) +  $\text{N}_{45}$  (urea) was significantly more than the remaining treatments. Also  $\text{N}_{50}$  (FYM) +  $\text{N}_{70}$  (urea) caused significantly more LAI compared to  $\text{N}_{25}$  (FYM) +  $\text{N}_{95}$  (urea) and  $\text{N}_{120}$  (urea). The increase in LAI might be owing to production of higher number of functional leaves, which increased total photosynthetic surface with the increase in leaf area and besides increased availability of nitrogen for longer period in  $\text{N}_{75}$  (FYM) +  $\text{N}_{45}$  (urea). SPAD 502 chlorophyll meter readings at 90 DAT are related to chlorophyll content of crops.

Chlorophyll content was significantly higher under SRI followed by conventional transplanting method. This might be, because of the fact that hills with single seedlings maintained a higher rate of photosynthesis, more Rubisco content and greater leaf nitrogen content than plants in hills with 3 seedlings (Velliangiri *et al.*, 2011). The treatment  $\text{N}_{75}$  (FYM) +  $\text{N}_{45}$  (urea) being at par with  $\text{N}_{25}$  (FYM) +  $\text{N}_{95}$  (urea) and  $\text{N}_{50}$  (FYM) +  $\text{N}_{70}$  (urea) caused significantly more chlorophyll content compared to  $\text{N}_{120}$  (urea).

Root volume and root weight were significantly higher in SRI method of cultivation than conventional transplanting and aerobic methods. Mechanical weeding with conoweeder increased soil aeration by dissolving oxygen in water, thus increased root growth. Higher root volume and root weight in SRI were also reported by Thakur *et al.* (2010). The seedlings were planted at narrow spacing (20 cm × 10 cm) because of which plants competed with one another for nutrients, water, solar radiations,  $\text{CO}_2$  and space and other resources, probably resulted in poor root growth in conventional transplanting. Higher root weight and volume also found in aerobic rice than conventional transplanting due to proper supply of oxygen to the roots. Kato and Okami (2010) also found that the 2 morphological components of the rice system, i.e. adventitious root emergence and lateral root proliferation, were down regulated under aerobic culture conditions, resulting in a significant decrease in total root length in this method. Among sources of nutrients,  $\text{N}_{75}$  (FYM) +  $\text{N}_{45}$  (urea) resulted in the significantly higher root volume and root dry weight/hill than  $\text{N}_{120}$  (urea) but at par with the rest of treatment.

### *Yield attributes of rice*

The conventional transplanting resulted in significantly higher number of panicles/ $\text{m}^2$  than SRI and aerobic. The SRI significantly enhanced the spikelets/panicle, grain weight/panicle, 1,000-grain weight, grain and straw yield in comparison to conventional transplanting and aerobic methods (Table 2). The treatment consisting of  $\text{N}_{50}$  (FYM) +  $\text{N}_{70}$  (urea) kg/ha and  $\text{N}_{75}$  (FYM) +  $\text{N}_{45}$  (urea) kg/ha being at par with  $\text{N}_{25}$  (FYM) +  $\text{N}_{95}$  (urea) recorded similar panicles/ $\text{m}^2$ , but these values were significantly higher than treatment  $\text{N}_{120}$  (urea). Varying proportion of FYM in conjunction with nitrogen through urea did not show significant effect on spikelets/panicle and grain weight/panicle. Among the INM treatments,  $\text{N}_{75}$  (FYM) +  $\text{N}_{45}$  (urea) resulted in the highest 1,000-grain weight which was statistically significant over  $\text{N}_{120}$  but at par with  $\text{N}_{50}$  (FYM) +  $\text{N}_{70}$  (urea) and  $\text{N}_{25}$  (FYM) +  $\text{N}_{95}$  (urea). This improvement in panicles/ $\text{m}^2$ , spikelets/panicle and panicle weight with combined application of FYM and fertilizer was observed

owing to better root growth and tillering of rice.

#### Grain and straw yields of rice

Grain and straw yields were found significantly higher under SRI followed by conventional transplanting and the least under aerobic method (Table 2). Among the different rice-production methods, the SRI caused 11.3% increase in grain yield compared to conventional transplanting and 19.3% increase owing aerobic method. The improvement in grain yield under SRI practice was mainly due to improved morphology and physiological features of rice plant below and above the ground surface (Velliangiri *et al.*, 2011). Straw yield under SRI was found to be 4.8 and

9.3% higher than conventional and aerobic methods, respectively.

Among the nutrient sources, the highest grain yield was noticed with N<sub>75</sub> (FYM) + N<sub>45</sub> (urea). Fertilizer N<sub>75</sub> (FYM) + N<sub>45</sub> (urea), being at par with N<sub>50</sub> (FYM) + N<sub>70</sub> (urea), showed significant increase in grain yield compared with the remaining treatments. Significant increase of grain yield in N<sub>75</sub>(FYM) + N<sub>45</sub>(urea) may be owing to the contribution of yield components such as grains/panicle, grain weight/panicle and 1,000-grain weight. It might be owing to regulated supply of N to rice crop through slow-mineralization process of FYM and by way of providing good physical condition for plant growth.

**Table 1.** Leaf-area index (LAI), chlorophyll content, root volume and root weight at 90 days after transplanting of rice as influenced by rice establishment method and nutrient combination (Pooled data over 2 years)

Treatment	Leaf-area index (90 DAT)	Chlorophyll content (90 DAT)	Root volume (cm <sup>3</sup> )	Root weight (g/hill)
<i>Establishment methods</i>				
CT	4.53	39.2	16.4	4.48
SRI	4.98	41.1	31.8	11.30
Aerobic	4.32	36.0	19.0	5.19
SEm±	0.05	0.27	0.44	0.23
CD (P=0.05)	0.17	0.94	1.54	0.95
<i>Integrated N management</i>				
N <sub>25</sub> (FYM) + N <sub>95</sub> (urea)	4.54	38.7	22.6	6.71
N <sub>50</sub> (FYM) + N <sub>70</sub> (urea)	4.66	39.0	22.8	7.14
N <sub>75</sub> (FYM) + N <sub>45</sub> (urea)	4.88	39.6	24.0	7.69
N <sub>120</sub> (Urea)	4.11	37.8	20.3	6.39
SEm±	0.11	0.31	0.57	0.26
CD (P=0.05)	0.33	0.91	1.67	0.63

CT, Conventional transplanting; SRI, system of rice intensification; DAT, days after transplanting

**Table 2.** Panicles/m<sup>2</sup>, filled spikelets/panicle, 1,000-grain weight and grain and straw yields of rice as influenced by crop establishment methods and source of nutrients (Pooled data over 2 years)

Treatment	Panicles/m <sup>2</sup>	Filled spikelets/panicle	Grain weight/panicle (g)	1,000-grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)
<i>Establishment methods</i>						
CT	262	83	2.35	28.2	4.94	5.59
SRI	214	110	3.08	28.7	5.49	5.86
Aerobic	249	82	2.33	28.2	4.60	5.36
SEm±	0.4	1.86	0.05	0.07	0.03	0.04
CD (P=0.05)	12.0	6.42	0.17	0.25	0.12	0.14
<i>Integrated N management</i>						
N <sub>25</sub> (FYM) + N <sub>95</sub> (urea)	240	92	2.56	28.3	4.93	5.52
N <sub>50</sub> (FYM) + N <sub>70</sub> (urea)	245	93	2.59	28.4	5.08	5.67
N <sub>75</sub> (FYM) + N <sub>45</sub> (urea)	249	92	2.66	28.6	5.17	5.83
N <sub>120</sub> (urea)	234	91	2.54	28.1	4.85	5.39
SEm±	0.4	1.14	0.05	0.07	0.05	0.05
CD (P=0.05)	11.1	NS	NS	0.21	0.13	0.15

CT, Conventional transplanting; SRI, system of rice intensification; DAT, days after transplanting

**Nutrient uptake by rice**

Significantly higher uptake of total nitrogen, phosphorus and potassium by the rice crop was noticed in with SRI method of cultivation as compared to the aerobic and conventional transplanting methods (Table 3). Alternate wetting and drying might have improved the soil aeration and thus root activity to improve the uptake of nutrients under this method of SRI. Higher uptake in SRI having younger seedlings could be attributed to increased root volume and root weight which might have enabled more absorption area. Belder *et al.*, (2005) also reported relatively low up-

**Table 3.** Effect of crop establishment methods and source of nutrients on total nutrient uptakes (grain + straw) by rice (Pooled data over 2 years)

Treatment	Total nutrient uptake (kg/ha) by rice		
	N	P	K
<i>Establishment methods</i>			
CT	94.9	24.3	110.5
SRI	103.5	29.1	132.1
Aerobic	88.3	22.1	101.1
SEm±	1.01	0.40	0.45
CD (P=0.05)	3.48	1.39	1.57
<i>Integrated N management</i>			
N <sub>25</sub> (FYM) + N <sub>95</sub> (urea)	93.2	24.1	111.3
N <sub>50</sub> (FYM) + N <sub>70</sub> (urea)	96.3	25.5	116.6
N <sub>75</sub> (FYM) + N <sub>45</sub> (urea)	101.8	28.0	123.1
N <sub>120</sub> (urea)	91.0	23.0	107.3
SEm±	0.90	0.52	2.24
CD (P=0.05)	2.62	1.51	6.50

CT, Conventional transplanting; SRI, system of rice intensification; DAT, days after transplanting

take of nitrogen under aerobic conditions compared to flooded conditions, which was reflected by the relatively low fertilizer-N recovery under aerobic conditions.

The treatment N<sub>75</sub> (FYM) + N<sub>45</sub> (urea) recorded significantly higher N, P and K uptakes than rest of the treatments. Increased uptake of nutrients was observed with the application of N<sub>75</sub> (FYM) + N<sub>45</sub> (urea) might have due to supply of timely required nutrients and balanced nutrition. Another possible reason could be owing to more proliferation of roots in N<sub>75</sub> (FYM) + N<sub>45</sub> (urea) as compared to N<sub>120</sub> (urea), which could have tapped more volume of soils and thus total uptake of other nutrients might have also increased.

**Yield attributes and yield of wheat**

Spikes/m<sup>2</sup>, test weight and straw yield of wheat were not significantly influenced by different rice-establishment methods (Table 4); however, grain weight/spike was significantly higher in SRI than over conventional transplanting and direct-seeded aerobic treatment. Overall, the maximum spikes/m<sup>2</sup>, test weight and straw yield of wheat were obtained under system of rice intensification while, the lowest with conventional transplanting method. System of rice intensification significantly increased the grain yield of wheat in comparison to conventional transplanting but at par with aerobic rice.

The treatment comprising N<sub>75</sub> (FYM) + N<sub>45</sub> (urea) kg/ha was found best in improving the yield and yield attributes of wheat after rice (Table 4), i.e. significantly higher number of spikes/m<sup>2</sup>, grain weight/spike and 1,000-grain weight was recorded in N<sub>75</sub> (FYM) + N<sub>45</sub> (urea) as compared to N<sub>120</sub> (urea) treatment but being at par with N<sub>25</sub>

**Table 4.** Yield and yield attributes of wheat as influenced by carry-over effect of rice-crop-establishment methods and sources of nutrients applied to rice under rice-wheat system (pooled data over 2 years).

Treatment	Spikes/m <sup>2</sup>	Grain weight/spike (g)	1,000-grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)
<i>Establishment methods</i>					
CT	388	1.51	45.3	3.48	5.22
SRI	407	1.77	46.4	3.78	5.74
Aerobic	399	1.54	46.1	3.57	5.73
SEm±	5.72	0.04	0.36	0.06	0.16
CD (P=0.05)	NS	0.13	NS	0.22	NS
<i>Integrated N management</i>					
N <sub>25</sub> (FYM) + N <sub>95</sub> (urea)	399	1.57	45.7	3.53	5.43
N <sub>50</sub> (FYM) + N <sub>70</sub> (urea)	404	1.63	46.4	3.68	5.54
N <sub>75</sub> (FYM) + N <sub>45</sub> (urea)	419	1.77	46.8	3.77	6.06
N <sub>120</sub> (urea)	370	1.46	44.8	3.46	5.21
SEm±	5.25	0.03	0.37	0.04	0.13
CD (P=0.05)	15.2	0.10	1.06	0.12	0.38

CT, Conventional transplanting; SRI, system of rice intensification; DAT, days after transplanting

(FYM) + N<sub>95</sub> (urea) and N<sub>50</sub> (FYM) + N<sub>70</sub> (urea) treatments. Significant differences were not observed in straw yield of wheat due to variable proportion of FYM integrated with N (urea). Wheat grain yield obtained under N<sub>75</sub> (FYM) + N<sub>45</sub> (urea), was at par with N<sub>50</sub> (FYM) + N<sub>70</sub> (urea), but significantly higher than that obtained with N<sub>25</sub> (FYM) + N<sub>95</sub> (urea) and N<sub>120</sub> (urea).

### System productivity

System productivity in terms of rice-grain-equivalent yield was significantly influenced by rice-establishment methods and integrated nitrogen-management treatments during both the years (Table 5). Significantly higher system productivity was observed under system of rice intensification establishment method, followed by conventional transplanting and aerobic rice treatments. System productivity under system of rice intensification increased to 7.6 and 12.9 % (in 2010 and 2011) as compared to conventional transplanting method, while, it increased up to 9.2 and 16.8 % (in 2010 and 2011) compared to direct-seeded aerobic rice. Among the integrated nitrogen-management treatments, system productivity was found significantly higher in N<sub>75</sub> (FYM) + N<sub>45</sub> (urea) followed by N<sub>50</sub> (FYM) + N<sub>70</sub> (urea), while least was observed with N<sub>120</sub> (urea) during both the years. The increase in system productivity under N<sub>75</sub> (FYM) + N<sub>45</sub> (urea) over N<sub>120</sub> (urea) was of the order of 6.6 and 8.8% during 2010 and 2011 respectively.

### Economics

Significantly higher net income was obtained under system of rice intensification (SRI) than conventional transplanting and aerobic method of cultivation. The minimum net returns were recorded with conventional transplanting method, which was significantly lower in 2010 but at par in 2011. Higher income in case of SRI was owing to higher paddy and straw yield and low cost of cultivation particularly in raising of seedling and seed cost and less number of irrigations.

Benefit: cost ratio under aerobic rice method was the highest in 2010 and was significantly higher than SRI and conventional transplanting. Minimum was recorded in conventional transplanting. However, in 2011 significantly higher benefit: cost ratio was recorded under SRI than conventional transplanting, but at par with aerobic cultivation method. No significant differences were found due to INM treatments during both the years.

It has been observed that SRI with 25 cm × 25 cm spacing enhanced net return and benefit: cost ratio compared to conventional transplanting under same date of nursery sowing (Shekhar *et al.*, 2009). In aerobic rice cultivation higher benefit: cost ratio was recorded in 2011 as compared to conventional and SRI methods, this might be owing to less cost of cultivation as it requires less labour, number of irrigation and land preparation. Similar findings were also reported by Tuong and Bouman (2003).

**Table 5.** System productivity (rice-grain-equivalent yield) and profitability of rice-wheat system as influenced by direct and carry-over effect of rice crop-establishment methods and source of nutrients applied to rice

Treatment	2010-11				2011-12			
	System productivity (t/ha)	System profitability Cost of cultivation (×10 <sup>3</sup> ₹/ha)	Net monetary returns (×10 <sup>3</sup> ₹/ha)	Net benefit: cost ratio	System productivity (t/ha)	System Profitability Cost of cultivation (×10 <sup>3</sup> ₹/ha)	Net monetary returns (×10 <sup>3</sup> ₹/ha)	Benefit: cost ratio
<i>Establishment methods</i>								
CT	8.46	30.3	33.2	1.08	8.48	27.7	39.4	1.42
SRI	9.10	27.7	41.0	1.48	9.57	25.3	48.1	1.90
Aerobic	8.33	22.2	38.8	1.75	8.19	21.3	40.4	1.89
SEm±	0.07	-	0.615	0.02	0.08	-	0.725	0.03
CD (P=0.05)	0.25	-	2.13	0.08	0.28	-	2.51	0.11
<i>Integrated N management</i>								
N <sub>25</sub> (FYM) + N <sub>95</sub> (urea)	8.46	26.3	37.3	1.45	8.59	24.3	41.7	1.73
N <sub>50</sub> (FYM) + N <sub>70</sub> (urea)	8.78	27.0	37.9	1.43	8.89	25.1	43.1	1.73
N <sub>75</sub> (FYM) + N <sub>45</sub> (urea)	8.91	27.6	38.7	1.42	9.12	25.5	44.2	1.74
N <sub>120</sub> (urea)	8.36	25.9	36.7	1.43	8.38	24.0	41.7	1.76
SEm±	0.09	-	0.742	0.03	0.07	-	0.815	0.03
CD (P=0.05)	0.25	-	NS	NS	0.21	-	NS	NS

CT, Conventional transplanting; SRI, system of rice intensification; DAT, days after transplanting

**Table 6.** Soil fertility at the end of 2 years cropping cycle of rice–wheat system as influenced by rice crop-establishment methods and source of nutrients applied in rice

Treatment	Organic carbon (%)	Available N(kg/ha)	Available P(kg/ha)	Available K(kg/ha)
<i>Establishment methods</i>				
CT	1.02	225.9	19.29	237.2
SRI	1.03	240.0	20.9	242.2
Aerobic	1.01	225.0	18.3	234.4
SEm±	0.14	3.3	0.36	3.0
CD (P=0.05)	NS	11.3	1.24	10.3
<i>Integrated N management</i>				
N <sub>25</sub> (FYM) + N <sub>95</sub> (urea)	1.03	232.7	19.1	236.8
N <sub>50</sub> (FYM) + N <sub>70</sub> (urea)	1.05	238.3	20.1	241.2
N <sub>75</sub> (FYM) + N <sub>45</sub> (urea)	1.06	245.7	20.4	244.3
N <sub>120</sub> (urea)	0.98	206.9	17.8	229.4
SEm±	0.21	3.3	0.34	2.7
CD (P=0.05)	0.06	9.5	1.0	8.0
Initial value	0.98	220	17.8	225.0

CT, Conventional transplanting; SRI, system of rice intensification; DAT, days after transplanting

### Soil health

Soil organic carbon content was 0.98% at the initiation of the experiment. At the end of 2 years of continuous crop cycle, more organic carbon content was under SRI and least in aerobic cultivation method. The SRI plots also recorded significantly higher available nitrogen, phosphorus and potassium than aerobic and conventional transplanting. Application of N<sub>75</sub>(FYM) + N<sub>45</sub>(urea), caused more organic carbon content, being comparable to rest of the treatments. Significant differences in the value of organic carbon were noticed due to N<sub>75</sub>(FYM) + N<sub>45</sub>(urea) compared to N<sub>120</sub>(urea), but all other treatments were at par with N<sub>75</sub>(FYM) + N<sub>45</sub>(urea). The highest amount of available N, P and K were recorded due to application of N<sub>75</sub>(FYM) + N<sub>45</sub>(urea) which was significantly superior to N<sub>120</sub>(urea) and N<sub>25</sub>(FYM) + N<sub>95</sub>(urea) but *at par* with N<sub>50</sub>(FYM) + N<sub>70</sub>(urea).

Thus system of rice intensification provided perceptible gains in productivity and income over conventional method. Integrated nutrient management comprising 75 kg N through FYM + 45 kg N through urea/ha under SRI seems to be the viable option to realize higher yields under rice–wheat system vis-à-vis avoids deterioration of soil health.

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