SRI-A Method for Sustainable Intensification of Rice Production with Enhanced Water Productivity

Mahender Kumar R*, Raghuveer Rao P1, Somasekhar N1, Surekha K1, Padmavathi CH1, Srinivas Prasad M1, Ravindra Babu V1, Subba Rao LV1, Latha PC1, Sreedevi B1, Ravichandran S1, Ramprasad AS1, Muthuraman P1, GOPalakrishnan S1, Vinod Goud V1 and Viraktamath BC1
1Directorate of Rice Research (DRR), Hyderabad, India
2International Crop Research Institute for Semi-Arid Tropics (ICRISAT), India
3WWF–ICRISAT Patancheru, Rangareddy Hyderabad, India

Abstract

Climate change induced higher temperatures will increase crops' water requirements. Every 10°C increase in mean temperature, results in 7% decline in the yield of rice crop. Hence, there is a need to develop water saving technologies in rice which consumes more than 50% of the total irrigation water in agriculture. System of Rice Intensification (SRI) is one such water saving rice production technology. Experiments were conducted at different locations in India including research farm of Directorate of Rice Research (DRR), Hyderabad, during 2005-10 to assess the potential of SRI in comparison to normal transplanting/Standard Planting (NTP/SP) under flooded condition. SRI recorded higher grain yield (6 to 65% over NTP) at majority of locations. Long term studies clearly indicated that grain yield was significantly higher (12-23% and 4-35% over NTP in Kharif and Rabi seasons, respectively) in SRI (with organic+inorganic fertilizers) while the SRI (with 100% organic manures), recorded higher yield (4-34%) over NTP only in the Rabi seasons. Even though, SRI resulted in higher productivity, the available nutrient status in soil was marginally higher (10, 42 and 13% over NTP for N, P and K, respectively) at the end of four seasons. There was a reduction in the incidence of pests in SRI and the relative abundance of plant parasitic nematodes was low in SRI as compared to the NTP. About 31% and 37% saving in irrigation water was observed during Kharif and Rabi seasons, respectively in both methods of SRI cultivation over NTP. SRI performed well and consistently reduced requirement of inputs such as seed and water in different soil conditions. SRI method, using less water for rice production can help in overcoming water shortage in future and it can also make water available for growing other crops thus promoting crop diversification.

Keywords: System of Rice Intensification (SRI); Methods of rice cultivation; Water saving; Nutrient use efficiency

Introduction

Rice is the staple food for 65% population of India. The demand for rice is expected to rise due to increase in population increase (1.6% year-1) and reduction in area under rice cultivation in next 15-20 years. Hence, there is a need to increase the productivity of rice to feed the burgeoning population. Water scarcity appears to be one of the major constraints affecting rice production across the globe. More than 80 percent of the fresh water resources in Asia are used for agriculture and about a half of it is used for rice production [1]. Available estimates indicate that fresh water availability in India will be reduced to one-third by 2025. Therefore, future rice production depends on how we improve the water use efficiency of the rice crop. Reducing amount of water in irrigated rice production has become a matter of global concern and of self-sufficiency of food grains in many countries including India; it has been attained at the cost of soil health [4]. Therefore, emphasis should be laid on reducing the use of chemical inputs and to improve input use efficiency. The information on long term effects of organic nutrient application in different methods of rice production (SRI and Normal Transplanting) with regard to water productivity and sustainable rice production under different soil and climatic conditions under India is very meager. Hence, present investigations were carried out to assess SRI-as sustainable intensification of rice production system for enhancing the water productivity.

*Corresponding author: Mahender Kumar R, Directorate of Rice Research, Hyderabad, India, E-mail: kumarm213@gmail.com

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Materials and Methods

Experimental site characteristics

DRR under its All India Co-ordinated Rice Improvement Program (AICRIP) organized multi-location (25 locations) trials (MLT) during 2004-2007 to evaluate SRI method vs. normal transplanting to understand the scientific basis and the merits of the system and to fine tune for wider adaptability and to identify limitations, if any. The treatments included two methods of crop establishment viz., Normal transplanting (NTP) and System of rice intensification (SRI).

Three genotypes viz., variety Krishnahamsa, rice hybrid KRH-2 and a local check variety of the respective location were used. The selected genotypes are widely adopted and promising with higher yield potential with wider adaptability. The details of the locations and soil information are furnished in table 1. Studies were conducted under identical nutrient management practices across the treatments in different soil condition in split plot design replicated three times at each location (Directorate of Rice Research -D.R.R Progress reports, 2005-2008) (Table 1).

Further, experiments were also conducted at the experimental farm of the Directorate of Rice Research, International Crop Research Institute for Semi Arid tropics (ICRISAT) campus (17-53°N latitude, 78.27°E longitude, 545 m altitude, with a mean maximum temperature of 32°C, mean minimum temperature of 20°C and mean annual precipitation of 750 mm), Hyderabad, India from 2008 to 2010 covering four season-two wet (WS) and two dry seasons (DS) with wider adoptability. The details of the locations and soil information were furnished in table 1. Studies were conducted under identical nutrient management practices across the treatments in different soil condition in split plot design replicated three times at each location (Directorate of Rice Research -D.R.R Progress reports, 2005-2008) (Table 1).

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In SRI and Normal Transplanting methods, the inputs applied were same (50% organic+50% inorganic) while in SRI-organic, total nutrients were supplied through organic sources (FYM, Vermicompost and green manure, Gliricidia). Rice varieties with bold grain quality (Sampada) were tested during wet and dry seasons. The local recommended dose of inorganic fertilizers were given at the rate of 100-60-40 kg N, P₂O₅, K₂O/ha during WS and 120-60-40-10 kg N, P₂O₅, K₂O and Zn/ha during DS through urea, single super phosphate, muriate of potash and Zinc sulphate, respectively. Insect pest incidence was recorded on ten randomly marked hills in each plot as and when the incidence was observed in both the seasons 2009 and 2010. For nematode analyses, soil samples were collected from rhizosphere (0-15 cm depth) form three spots from each plot at the time of harvest. Soil collected from three spots in each plot was pooled to make a composite sample. Nematomes were extracted using modified Cobb's sieving and decanting technique from 100 g soil sub-samples taken from each composite sample (Hooper, 1986). Total number of plant-parasitic and free-living microbial feeding nematodes in each sample was counted by observing nematode suspension under stereo zoom microscope. Nematode population densities were expressed as nematodes/100 g of soil. All the plants in an area of 5 m×5 m for each replicate (25 m²) were harvested (excluding border rows) for determination of yield per unit area and grain yield was adjusted to 14% seed moisture content. Harvest Index was calculated by dividing dry grain yield by the total dry weight of above ground parts. Soil Chemical properties were evaluated by the wet digestion method of Walkley and Black [5], rapid titration method) for organic carbon (OC%); modified Kjeldahl method [6] for total N (kg ha⁻¹), and colorimetric method [7] for available P (kg ha⁻¹). All the data were statistically analyzed using analysis of variance (ANOVA) procedure of SAS (SAS, 2000) and the significance between the means of the treatments differentiated based on least significant difference (LSD) at 5% probability level. Details of management practices followed for SRI and NTP are given in table 2.

### Table 1: Details of the Locations.

| Zone          | Location  | Soil type          | pH  | Varieties (local) | Available NPK (kg/ha) |
|---------------|-----------|--------------------|-----|-------------------|-----------------------|
|               |           |                    |     |                   |                       |
|               |           |                    |     |                   |                       |
| Hilly areas   |           |                    |     |                   |                       |
| 1             | Almora    | Silty clay loam    | 5.5 | VL Dhan-61        | 310                   |
| 2             | Malan     | Silty clay loam    | 5.70| HPR-2143          | 403                   |
| 3             | Kapurthala| Clay Loam          | 8.5 | PR-115            | -                     |
| 4             | Chattha   | Loam               | 7.14| PC-19             | 174                   |
| 5             | Panipat   | Silty loam         | 8.02| Pant Dhan-4       | -                     |
| Eastern       |           |                    |     |                   |                       |
| 6             | Jagdalpur | Sandy loam         | 6.3 | Swarna            | 198                   |
| 7             | Raipur    | Loam               | 7.20| Mahamaya          | 205                   |
| 8             | Varanasi  | Sandy loam         | 7.30| ProAgro-6201      | 184.60                |
| 9             | Ranchi    | Silty loam         | 6.10| IR-64             | 230                   |
| 10            | Patna     | Sandy loam         | 7.20| Rajendra Sweta    | 278.00                |
| 11            | Umiam     | Sandy loam         | -   | RCPL-1-87-8       | -                     |
| 12            | Titabar   | Clay loam          | 5.30| Ranjh              | 212                   |
| 13            | Pusa      | Silty clay loam    | 8.20| Prabhat            | -                     |
| 14            | Karingang | Clay loam          | 5.5 | Ranjith            | 250                   |
| 15            | Arundhatin| Clay loam          | 5.60| -                  | 0.13                  |
| 16            | Chiplima  | Silty loam         | 6.40| Lalat             | 245                   |
| Western       |           |                    |     |                   |                       |
| 17            | Nawagam   | Sandy loam         | 7.33| GR-11             | -                     |
| 18            | Karjat    | Clay loam          | 6.5 | Sahyadri-1        | 212                   |
| Southern      |           |                    |     |                   |                       |
| 19            | ARI, R Nagar| Clay loam       | 7.8 | M-7               | 310                   |
| 20            | Coinbatore| Clay loam          | 7.30| CO-47             | 225                   |
| 21            | Aduthurai | Clay loam          | 7.09| ADT-47            | 260.00                |
| 22            | Siriguppa | Clay               | 7.7 | IET-16937         | 337                   |
| 23            | Karakal   | Clay loam          | 7.5 | ADT³-45           | 188                   |
| 24            | Maruteru  | Clay Loam          | -   | MTU-100           | -                     |
| 25            | Madya     | Silty loam         | 7.10| BR-2655           | 281                   |

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S.No. | Practices | SRI Method | Normal transplanting (NTP)
---|---|---|---
1 | Nursery | Uniformly distributed 5 kg ha⁻¹ organic manured raised bed (100 m²/ha) and irrigated with rose can 3-4 times a day. | 30 kg/ha in an area of 1000 m² and grown in flooded situation
2 | Seeding age at transplanting | 10-12 day old seedling | 30-35 day old seedling
3 | Plant spacing and density | One seedling per hill was transplanted in a square planting at a spacing of 25 cm×25 cm and carefully after uprooting | One seedling per hill were transplant at a spacing of 20×15 cm
4 | Weed management | Four weedings by cono-weeder were performed at 10,20,30 and 40 DAT to incorporate weeds and aerate the soil | Hand and manual weeding twice at 20 and 35 DAT
5 | Water management | Seedlings were transplanted 1-2 cm deep in to a puddled saturated field without any ponding water. During the vegetative growth phase, plots were kept saturated (not flooded) and after panicle initiation stage, 2-3 cm of standing water was maintained on the field and drained 15 days before harvest | Seedlings are transplanted 3-5 cm deep into a puddle field with 5-6 cm pounded water, and same level was maintained during the vegetative stage. After P I stage 2-3 cm of standings water was kept on the field and drained 15 days before harvest
6 | Nutrient management | For both sets of methods, organic manure was applied at the rate of 5 t/ha along with chemical fertilizers (urea single super phosphate and muriate potash at the recommended dose of N P K of the location (Table 1). The entire amount P was applied at the time of final land preparation, while N at 3 splits (50% basal, 25% at vegetative stage and 25% at panicle initiation) and K at 2 splits (75% at basal and 25% panicle initiation ) | Three seedlings per hill were transplanted at a spacing 20×15 cm

Table 2: Crop management practice for comparative evaluation of SRI and Normal Transplanting (NTP). In all locations (Stable yield performance in 13 Locations).

**Results and Discussion**

**Response of SRI method on grain yield across the locations**

The results of multi location trials (MLTs) clearly indicated that the performance of SRI varied from location to location indicating that response of SRI is location specific. SRI recorded consistently higher grain yield than NTP at half of the locations (10-13). The mean grain yield increase in SRI method was in the range of 6 to 65% as compared to NTP (Table 3). Out of 98 instances 73 times SRI recorded higher grain yield (kg/ha) over Normal transplanting with an average increase grain yield of 19.6%. The increase in grain yield under SRI could attribute to profuse tillingering (19.1%). Panicles m² gave significant relationship with grain yield and contributed for higher yield in SRI over NTP practice but no significant with panicle weight (Figure 1). Further, SRI method improved soil aeration achieved through the soil disturbance by cono weeder operation, in addition to effective weed suppression [8-11], Thiyagarajan et al. and Bouman et al. [12,13] are also reported similar factors contributing for higher yield in SRI method. The performance of hybrid was superior over high yielding varieties due to better tillering ability of the hybrids at most of the locations. The results of the long term comparative studies of SRI vs. NTP clearly indicated superiority of SRI (Table 4). Grain Yield ranged from 3.92 t/ha to 5.41 t/ha in SRI-organic, 5.34 to 6.73 t/ha in SRI as compared to 4.97 to 5.17 t/ha in NTP. The NTP recorded 7 and 23% lower yield than

| Locations | 2004 | 2005 | 2006 | 2007 | Mean |
|---|---|---|---|---|---|
| Aduthurai | 55.6 | 11.6 | 18.7 | 92.9 | 45.0 |
| Rajendranagar | 20.1 | 9.6 | 34.0 | 20.1 | 20.9 |
| Arundhatinagar | 41.6 | 67.0 | 93.4 | 58.9 | 65.2 |
| Chatha | - | 5.9 | 5.0 | 22.6 | 11.2 |
| Combatore | 3.1 | 46.2 | 15.2 | - | 21.5 |
| Jagdalpur | 12.3 | 7.8 | 1.8 | 2.5 | 8.1 |
| Karjat | 4.0 | 9.4 | 6.4 | 5.3 | 8.3 |
| Paninagar | 0.3 | - | 6.8 | 11.4 | 6.2 |
| Patna | 55.5 | 23.9 | 10.6 | 19.6 | 27.4 |
| Ranchi | 11.5 | 15.9 | 16.1 | 15.1 | 14.7 |
| Siruguppa | 6.6 | 24.7 | 36.4 | 24.6 | 23.1 |
| Tiltar | 16.4 | 8.4 | 5.5 | 7.7 | 9.5 |
| Umir | - | 13.7 | 12.8 | 15.9 | 14.1 |
| Mean | 13.7 | 18.7 | 12.4 | 12.76 | 14.32 |

SRI performance (% yield increase) over Normal transplanting (NTP) in different locations (Stable yield performance in 13 Locations).

SRI under similar nutrient management during wet season. During dry season, SRI-organic also recorded on an average 4.4% higher grain yield over NTP which was significantly inferior during earlier seasons (i.e., 2 wet seasons). The grain yield decrease was to the extent of 21% in SRI-organic over NTP in 1st season. In all the seasons SRI recorded significantly higher harvest Index values than NTP. Since the experimental field was under transition stage, organic fertilizers did not result in increased yields and chemical fertilizers and INM were found superior initially. However, repeated application of organics over the years may build up sufficient soil fertility by improving soil biological activity. The recession in the crop yields during initial phase of transition from conventional to organic agriculture and recovery in yields after 2-3 years was reported by Sharma and Singh [14]. With regard to straw yields, there were significantly higher values in SRI and NTP over SRI-organic in both the seasons (WS & DS). In general, expectedly, the grain yields were high in the dry season due to bright sunshine and favorable weather and crop was free from pest and disease attack. Seshu and Cady [15] reported that solar radiation during the dry season (17-18 MJ) was about 30% more than during the wet season (12-15 MJ) and this radiation during post flowering stage of a rice crop correlated positively with economic yield. A number of previously published reports on SRI have showed enhancement of rice yield [3,16-19]. This study found that SRI management practices increasing grain yield by 5-24% while utilizing fewer seeds, less nursery area and less water. The total dry weight of above ground parts at harvest was greater in SRI under similar nutrient management during wet season. During dry season, SRI-organic also recorded on an average 4.4% higher grain yield over NTP which was significantly inferior during earlier seasons (i.e., 2 wet seasons). The grain yield decrease was to the extent of 21% in SRI-organic over NTP in 1st season. In all the seasons SRI recorded significantly higher harvest Index values than NTP. Since the experimental field was under transition stage, organic fertilizers did not result in increased yields and chemical fertilizers and INM were found superior initially. However, repeated application of organics over the years may build up sufficient soil fertility by improving soil biological activity. The recession in the crop yields during initial phase of transition from conventional to organic agriculture and recovery in yields after 2-3 years was reported by Sharma and Singh [14]. With regard to straw yields, there were significantly higher values in SRI and NTP over SRI-organic in both the seasons (WS & DS). In general, expectedly, the grain yields were high in the dry season due to bright sunshine and favorable weather and crop was free from pest and disease attack. Seshu and Cady [15] reported that solar radiation during the dry season (17-18 MJ) was about 30% more than during the wet season (12-15 MJ) and this radiation during post flowering stage of a rice crop correlated positively with economic yield. A number of previously published reports on SRI have showed enhancement of rice yield [3,16-19]. This study found that SRI management practices increasing grain yield by 5-24% while utilizing fewer seeds, less nursery area and less water. The total dry weight of above ground parts at harvest was greater in SRI than NTP. The divergence in grain yield between SRI and NTP was due to differences in harvest Index rather than dry matter production. The plants grown in SRI had more open architecture, with tiller spread out more widely, covering more ground area and more erect leaves that avoided mutual shading of leaves. These plants also had higher leaf area index due to significant increase in leaf size and erect leaves in rice can increase both biomass production and grain yield.

| Table 4: Comparison of grain yield t/ha, straw yield and HI (%) as influenced by SRI and NTP. |
|---|---|---|---|---|
| Treatment | 08, 09 | 08, 09 | Mean 08, 09 | Mean 08, 09 |
| SRI-Organic | 3.92 | 5.41 | 4.67 | 4.33 |
| SRI (Org+inorg) | 5.34 | 6.73 | 6.04 | 5.06 |
| NTP | 4.97 | 5.17 | 5.07 | 4.88 |
| LSD (0.05) | 0.514 | 0.554 | 0.528 | 0.748 |
| Treatment | 08, 09 | 08, 09 | Mean 08, 09 | Mean 08, 09 |
| Kharif | 53.42 | 54.65 | 52.65 | 51.08 |
| Rabi | 47.52 | 57.08 | 51.1 |
| Kharif | 48.22 | 51.44 | 47.83 |
| Rabi | 2.79 | 1.56 |

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Saving in water

Irrigation water inputs for different methods of rice cultivation were recorded using digital water meters during the crop seasons indicated that the water saving in SRI ranged from 17-47% (Figure 2 and Table 5). Both the SRI-organic and SRI-organic+inorganic received significantly lower irrigation water compared to NTP in all the four seasons. SRI saved nearly 25% irrigation water without any penalty on yield compared to conventional transplanting [20]. Using intermittent irrigation, Thiyagarajan et al. [16] reported water saving of 50% in SRI over the traditional flooding without any adverse effect on grain yield. Thus, it can be concluded that in the SRI method, irrigation use efficiency was higher over the conventional method of rice cultivation [17].

Table 5: Comparison of available nutrient status as influenced by SRI and NTP.

| Treatment          | Kharif | Kharif | Available K (ppm) | Available P (ppm) | Available N (ppm) | OC (%) |
|--------------------|--------|--------|-------------------|-------------------|-------------------|--------|
|                    | Mean   | Mean   |                   |                   |                   |        |
| SRI-Organic        | 782    | 820    | 264               | 331               | 66                | 64     |
| SRI (Org+inorg)    | 782    | 875    | 60                | 92                | 92                | 96     |
| NTP                | 739    | 835    | 54                | 75                | 75                | 74     |
| LSD (0.05)         | 172.3  | 113.9  | 11.2              | 8.2               |                   |        |

Table 6: Comparison of water inputs and productivity as influenced by SRI organic, SRI organic+inorganic and NTP.

| Season              | Treatment           | Water Parameters | Water Parameters | % water saved over NTP |
|---------------------|---------------------|-------------------|-------------------|------------------------|
| Wet season 08 (Kharif) | SRI-Organic         | 5885.2            | 0.576             | 1736                   | 44.90 |
|                     | SRI (Org+inorg)     | 7167.9            | 0.731             | 1368                   | 32.89 |
|                     | NTP                 | 10680.1           | 0.439             | 2277                   |       |
| L.S.D (0.05%)       |                     | 734               |                   |                        |       |
| Dry season 08-09 (Kharif) | SRI-Organic      | 11466.2           | 0.323             | 3099                   | 29.22 |
|                     | SRI (Org+inorg)     | 13365.9           | 0.395             | 2531                   | 17.50 |
|                     | NTP                 | 16200.9           | 0.265             | 3776                   |       |
| L.S.D (0.05%)       |                     | 1031              |                   |                        |       |
| Dry season 08-09 (Rabi) | SRI-Organic      | 7703.6            | 0.707             | 1414                   | 47.10 |
|                     | SRI (Org+inorg)     | 8268              | 0.658             | 1520                   | 43.22 |
|                     | NTP                 | 14562.2           | 0.360             | 2779                   |       |
| L.S.D (0.05%)       |                     | 1326              |                   |                        |       |
| DRY season 09-10 (Rabi) | SRI-Organic      | 10254.8           | 0.792             | 1263                   | 32.39 |
|                     | SRI (Org+inorg)     | 11125.3           | 0.734             | 1362                   | 26.65 |
|                     | NTP                 | 15168.1           | 0.399             | 2507                   |       |
| L.S.D (0.05%)       |                     | 1328              |                   |                        |       |

Table 6: Comparison of water inputs and productivity as influenced by SRI organic, SRI organic+inorganic and NTP.

Soil nutrient status

Changes in soil fertility parameters (mean of two seasons) at the end of each year (WS 08-09 and D8 09-10) were monitored and presented...
in table 6. After two years, except the available N, all the soil properties were influenced significantly by the methods of crop establishment. SRI either organic or organic-inorganic recorded significantly higher values of available N (828-831 kg/ha) phosphorus (61-65 kg/ha) and potassium (93-93.5 kg/ha). Compared to initial soil values, there was an increase in SOC, available N, P and K by 35, 10, 42, 13 and 26% with organics, respectively, at the end of two years. Comparable increases in available N, P and K through addition of organic materials was reported by Pathak et al. [21] and Singh et al. [22]. Superior soil fertility status on organic farms compared to soils fertilized with chemical fertilizers was reported by Sharma and Singh [14]. They reported that higher carbon and nitrogen mineralization rates and soluble carbon content in organically managed soils indicate that sufficiently higher amounts of available nutrients are made available to the crop.

Pests dynamics in SRI

The pest incidence data indicated that yellow stem borer damage was high at all stages of crop growth period and its damage (dead hearts) was low under SRI (7.0%) as compared to NTP (11.4%). However, at reproductive stage, the damage (white ear heads) of yellow stem borer was high in SRI (28.3%) than NTP (21.2%). The data collected from farmers through survey indicated that in general, SRI had low pest incidence resulting in lower or no-pesticide application and thus gave higher benefit cost ratio (1.77 and 1.76) than NTP [23]. Similar results of low pest incidence in rice grown under SRI due to vigorous and healthy growth of plant coupled with wider spacing has been reported by Padmavathi et al. and Gasparillo [24,25].

Influence of SRI on soil nematodes

Transition from normal transplanting system to SRI significantly alters the composition of soil biota with a gradual shift towards the species that prefer upland or aerobic environment [1,26]. Investigations on the impact of SRI practices on soil nematodes (which include both harmful plant parasitic nematodes that inflict serious yield losses and beneficial microbial feeding nematodes that promote plant growth by enhancing organic matter decomposition and nutrient cycling) revealed that the abundance of Plant Parasitic Nematodes (PPN) and microbial feeding nematodes (MFN) were significantly higher under SRI as compared to the NTP system. However, the relative abundance of PPN was observed to be low (0.58) in SRI as compared to that of NTP (0.64) system. In contrast to this, the relative abundance of MFN was significantly higher (0.42) in SRI as compared to the NTP (0.36). The PPN community in these experimental plots was dominated by relatively less pathogenic species like rice root nematode (Hirschmanniella spp.) and other ectoparasitic nematodes [27,28]. This may be the reason for higher yields in SRI despite increase in the abundance of plant parasitic nematodes. However, it is possible that the effects of SRI management can be negative in areas where there are inherent populations of more damaging nematode species like root-knot nematode (Meloidogyne graminicola). Significantly lower rice yield under SRI as compared to that in NTP as a consequence of rapid buildup of root-knot nematode Meloidogyne graminicola was reported in other studies [29]. Farmers are to be cautioned to monitor carefully for parasitic nematodes when adopting SRI.

Conclusion

Understanding how to produce more rice with higher factor productivity and in ways that are environmentally friendly and socially more beneficial is the main focus of research in recent years. SRI system which facilitates production of more rice with less quantity of inputs such as water, seed and chemical fertilizers is one of the promising approaches in this direction. Our results have clearly demonstrated that the increase in productivity with SRI based on concomitant increase in factor productivity is possible under certain situations. SRI, however, is a methodology that continues to raise more questions than we have sufficient answers for it. Therefore, there is a need for collaborative research studies to help examine systematically the opportunities that SRI method is opening up for its wider adoptability to benefit the farming community in India where large percentage of farmers are mainly small or marginal farmers and depends primarily on rice cultivation for their livelihood.

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